Sándor Vajna *Editor*

Integrated Design Engineering

Interdisciplinary and Holistic Product Development

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Preface

This book deals with Integrated Design Engineering (IDE), a human-centred, interdisciplinary and holistic model for product development. IDE includes the systematic use of integrated strategies,methods and tools in the development of products and services of any kind and of any discipline.It takes into account the entire product life cycle.

This book explains the basics, the different aspects and the practical application of IDE. Findings,strategies and procedures are based on extensive research and experiences from numerous industrial projects that have proven the efficiency of the IDE approaches.

This book is the first English edition. It is based on the second German edition of the same title.The first German edition appeared in 2014. It has been very well received so that the publisher suggested the second edition together with an English edition to include the current IDE research results and experiences from industrial projects, from teaching at universities, from the international IDE PhD school and the IDE workshops. The German chapters were translated using the DeepL Pro Software and were proof-read by Springer Nature.

I would be very pleased if the English edition would meet with as much interest as the German edition.

The variety of IDE topics made it necessary that numerous authors from international institutions contributed to this book. They were faced with the task of presenting a compendium of their respective contributions to IDE in a comprehensible way. The reader will find that all authors have perfectly succeeded. As editor, I read and edited only carefully to preserve the individual style of each author. I would like to thank the authors of the book! They all had to take on extra work due to my suggestions. For all discrepancies resulting from this, I am solely responsible.

This book has a modular structure. Each chapter can be treated individually. On the one hand, it is suitable for students interested in product development from all courses of study that are related to product development (such as engineering, computer science, industrial design, marketing,economics and entrepreneurship). On the other hand, product developers and managers from industry and academia will find a wealth of useful and easy-to-implement information and procedures for the development of such products. With its high and broad-based performance, IDE meets and can even exceed the customer expectations.

A guideline to how to undertake a concrete IDE development project will be published in the near future.

As editor, it is my pleasure to thank all those who have contributed to the success of this work.First and foremost, I would like to thank all the authors who, with their contributions, essentially designed and accounted for this present edition. I would like to express my sincere thanks to my family for their moral and practical support.

I would also like to thank Ms. L. Burato, Mr. M. Kottusch, Ms. E. Hestermann-Beyerle, Ms. B.Kollmar-Thoni, Mr. A. Doyle and their colleagues from Springer Nature as well as from SPS Chennai for their patience, constant motivation and smooth co-operation. To all of you involved:Vielen Dank! Merci beaucoup! Many thanks! Muchas graçias! Köszönöm szépen! Tack so mycket! Domo arigato! Bahut dhanyavaad!

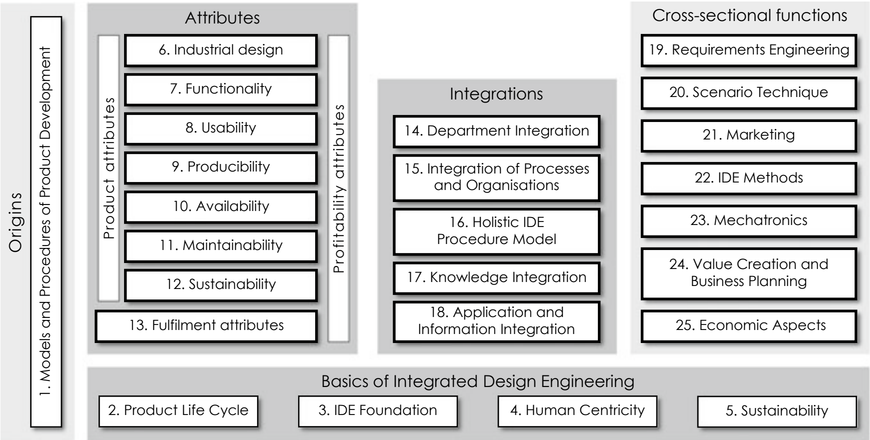
Weinheim, Germany Sándor Vajna
July 2020

Introduction

Integrated Design Engineering (IDE) is a human-centred, interdisciplinary and holistic approach to the description and development of any products from any disciplines. IDE includes all persons who are directly involved in the life cycle of the product. These can be buyers, users, developers, manufacturers, sellers or supporters, but also all persons who are affected by events, activities and related results in the different phases of the product life cycle without having any own interest in the product. IDE integrates these groups of people, products and their lifecycle phases, the associated processes and organizations, as well as the knowledge and information needed to do so. It thus enables interdisciplinary and holistic approaches to methods and procedures in product development.

Within IDE, products are created on the basis of direct and indirect, but always multi-criteria requirements. Here, a product is described in a neutral format both by its performance and its performance behaviour with diverse, but equivalent and equally important attributes. On the one hand, this offers considerably more, better and more comprehensive possibilities to describe and develop a product exactly according to various requirements, which could possibly be contradictory and dynamic. On the other hand, it does not prejudge already in the early phases the later way of realizing the product. The process model on which IDE is based offers eleven activities, which cover all possible development measures in any order. The dynamic navigation during development avoids an early restriction of the possibilities both by a rigid work organization and a special workflow. Instead, dynamic navigation enables every kind of flexibility within a development project, for example, a flexible response to changing customer requirements even at very late stages. Experiences have shown so far that products developed with IDE not only meet the customer's demands the most appropriate way, but also the social, ecological and economical requirements.

This book presents concepts, contents and interaction of thought models, methods and procedures used within IDE. The book consists of 25 chapters. These are structured in Origins, Fundamentals of Integrated Design Engineering, Integrations and Cross-Sectional Functions. Each chapter deals with a self-contained subject area.



Origins of IDE are, on the one hand, the Integrated Product Development approach (in Swedish: "Integrerard Produktutveckling", IPD) developed by Fredy Olsson in Lund (Sweden) in the 1980s and its further developments in Germany and Scandinavia up to the Magdeburg Model of IPD, and, on the other hand, traditional and current models and procedures of product development from the German and the European area.

Basics of IDE gives first a general view on a product and the associated life cycle. The main properties of IDE are human centricity, sustainability in all activities and the description of the product by means of its performance offer (performance and behaviour when providing this performance) via eleven equivalent but not similar attributes, without thereby prejudging any possibilities of realization in any discipline.

Integrations cover different forms of integration within IDE. This concerns the individual departments of a company (with a focus on Design for X and X for Design), the organizational and process integration for structural organization and process organizations as well as teamwork and dynamic navigation, the holistic IDE procedure model, knowledge integration and computer-aided applications necessary for all activities within IDE.

Cross-sectional functions deal with topics that can be used at any point within IDE. Thus, requirements engineering, scenario technique and marketing all allow the consideration of market needs combined with the design of the use of products in their markets. Mechatronics as a comprehensive product and process concept can support and enrich all phases of the product life cycle. Methods support the execution of activities within IDE. The last two chapters deal with the possibilities for the successful entry of a product idea into the market as well as the economic efficiency of IDE.

An extensive glossary, the short biographies of the authors and a keyword index complete the book.

Contents

Chapter 1
Models and Procedures of Product Development

Sándor Vajna, C. Burchardt, P. Le Masson, A. Hatchuel, B. Weil, T. Bercsey, and F. Pilz

Sándor Vajna

Integrated Product Development (IPD) is one of the best-known integration approaches to support product development [GeBa-2002], which is not limited to specific industries. It arose from the necessity to integrate all areas involved in the generation of a product (starting with marketing, followed by production to sales) into product development by means of suitable measures, to overcome forms of organization based on the division of labour and to concentrate not only on solving technical problems but also on the associated processes [Olss-1985, Ehrl-1995, Burc-2001]. IPD focuses on the following objectives [Naum-2005]:

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- Shortening the time from capturing the needs and requirements of customers and the market to production release, market launch, use and return of the product, respectively, conception, market launch, usage and withdrawal of a service,
- The best possible implementation and fulfilment of these needs and requirements,
- Reduction of development, creation, usage and return costs of the product and
- Improvement of product and process quality.

IPD thus initially covers product development. This consists of product planning, sales and marketing, industrial design, (advance) development, (Engineering) design, calculation and simulation, production preparation with a -**-sign and testing [VWZH-2018]. In addition, it covers the entire life cycle of a product (product life cycle, see Chap. 2). IPD is linked to the other divisions by a mutual flow of information. This makes it possible to develop accompanying objects in close coordination with the actual product at the same time, for example operating materials and packaging [Bram-2004].

In terms of planning and foresight (*predictive engineering*[1]), the information flow from IPD contains, in addition to the complete product documentation at the time of release for production, all specifications calculated, simulated and evaluated during IPD for the various guidelines and activities in the company for production, sales and distribution, use and maintenance/servicing as well as for the return and reuse of the product or its components at the end of their life. To make this possible, the flow of information into IPD is required in the form of feedback and preliminary information from those areas of the product life cycle that follow the actual development (*reverse engineering*[2]). This results in a cycle of predictive engineering, reverse engineering and subsequent front loading [Geid-2000] of activities from downstream to product development. With these approaches and activities, IPD is the most important source of innovation in the company and is thus causally and decisively responsible for the success of the company.

Due to its central role, IPD influences the major part of the total costs of product realization, since during product development about three-fourth of the total costs and about two-thirds of the manufacturing costs of a product[3] are determined by conceptual and strategic decisions, while the costs incurred (mainly personnel and IT costs) amount to only one-seventh of the total costs [Wien-1970], Fig. 1.1.

With IPD, all subsequent product properties and the behaviour of the product under operating conditions can be simulated during product development so that

[1]In *predictive engineering*, the properties, behaviour and associated processes of a product and its components are simulated in advance, both individually and in conjunction, by corresponding systems (predominantly FEM systems) and evaluated with current information (at least from those areas downstream of the IPD, usually from the subsequent product life) [Wart-2000].

[2]*Reverse engineering* analyses an existing product in order to identify the components used in it and their interrelations in order to create product documentation from it, especially if access to the original product documentation is no longer possible [OtWo-2001].

[3]This statement supports the *Pareto Principle* formulated by Vilfredo PARETO at the beginning of the twentieth century according to which about 80% of the results can be achieved in 20% of the total time of a project, but the remaining 20% of the results require 80% of the total time (see also Sect. 15.4.3 in Chapter 15).

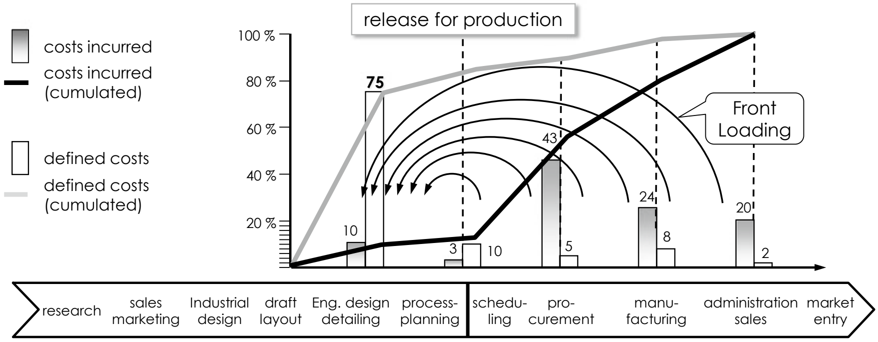

Fig. 1.1 Early cost determination in product development [Wien-1970] with the addition of front loading

as many influences as possible from the life cycle of the product can be taken into account at the earliest possible point in time and corresponding decisions can be made and implemented in good time. Therefore, the focus in IPD is on the interdisciplinary cooperation of all participants, the timely provision of knowledge and information in the required quantity and quality, a flattening of hierarchies and the delegation of competences. The aim is to ensure trouble-free production and use of the product after release for production [Burc-2001].

In this chapter, we will first describe those procedural models that emerged in the second half of the twentieth century, mainly in the German-speaking world, and which created the basis for a methodical and systematic approach to Engineering design. Then, both origin and further development of selected models of IPD are described, before the Magdeburg model of IPD [Burc-2001], from which Integrated Design Engineering (IDE) emerged, is dealt with in the third part. In the last part, the C-K design theory, the Autogenetic Design Theory and the Development of Simple Products are presented. These works do not originate from the tradition of (mechanical) engineering procedures and methods, but use methods and procedures from other disciplines (C-K design theory: Information processing, model theory and cognitive science; Autogenetic Design Theory: Biological evolution and Chaos Theory; Development of Simple Products: System Theory and multi-criteria optimization). They are thus able to develop arbitrary tangible and intangible products from different disciplines as well as to enable completely different and not necessarily sequential processes and procedures to develop in a turbulent environment.

1.1 Procedure Models for Product Development and Engineering Design

Methodical design can be traced back to REDTENBACHER (1809–1863), who was a professor of Mechanics and Mechanical Engineering at the Karlsruhe Polytechnic from 1841 until his death. He founded scientific mechanical engineering by moving it

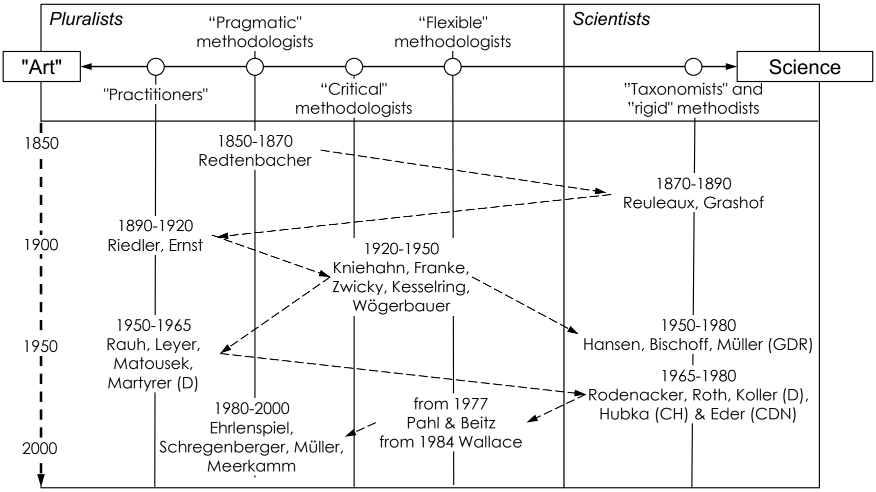

Fig. 1.2 Schematized phase model of methodological ideas between art and science between 1850 and 2000 (after [Ehrl-1995, Heym-2005])

from a rather empirical basis to a strictly mathematical basis. The further development of methodological design up to the year 2000 is roughly shown in Fig. 1.2 (after [Ehrl-1995] and [Heym-2005]). Interesting is the subdivision of the representatives into the categories *artists*, *practitioners*, *methodologists* and *scientists*. Behind this lies the question of whether designing is rather an art, i.e. an intuitive procedure, or a strictly rational, almost mathematical procedure?

The first procedural models for design were developed on the basis of knowledge and experience from various technical fields. Prior to this, and over the centuries, the process from recognition of a market need or a customer order to the beginning of the production of the product had been shaped almost exclusively by intuition and empiricism, and in some cases even regarded as an artistic process. It was not until the middle of the twentieth century that systematic research began on the development and design process (for example [Wöge-1943, BiHa-1953, Kess-1954]). This work has intensified since the 1960s (for example [Müll-1970, Rode-1970, Hubk-1973, Hans-1974, Kolle-1976, Hubk-1976, PaBe-1977, Roth-1982, Müll-1990, HuEd-1992, Wall-1995][4]). The relevant research work, which since then has developed a methodical, comprehensible and therefore more rational approach to design under the term *Methodical Design,* has not yet been completed.

[4]Ken WALLACE (1944-2018) translated with L. Blessing and F. Bauert the most significant textbook of German design, the 'Konstruktionslehre' by G. Pahl and W. Beitz, into English ('Engineering design—a Systematic Approach') and edited it. Without his congenial treatment and adaptation of the contents of the book to the Anglo-Saxon forms and ways of designing, the 'Konstruktionslehre' would not have acquired this importance in English-speaking countries that it has today.

In the course of finding a solution, models and methods of different levels of abstraction and with different information contents must be generated and combined. Such models and procedures are required both for individual work steps and in qualitatively different phases of the development process. In the research results, the methodical creation, evaluation and continuous improvement of solution variants are used as problem-solving strategies, so that the corresponding procedural models are regarded as an evolutionary solution-finding process in development [VBCA-2005].

However, by focusing on the design process, cross-company considerations, such as the inclusion of all areas from the product life cycle or the management of development processes, have only recently become a topic of discussion.

In the following the general procedure model of designing according to HUBKA (because in this model a product is continuously defined and treated as a technical system) and the current versions of the VDI guidelines 2221 and 2222 are described as a synthesis of the extensive German research work in the field of design methodology. The Taxonomy for Mechanical Design according to ULLMANN offers a powerful tool for classification and structuring process models.

1.1.1 General Procedure Model of Designing According to Hubka

According to HUBKA[5], the main task of the design process as an information processing process is the transformation of requirements (also: the problem situation) into the description of the desired technical system. This system must have certain properties and effects in order to meet the requirements. For this, it is necessary to develop a synthesis of the different requirements and the environment in which the system is to be used and to manifest it in the system [Hubk-1976].

The general procedure model of designing [Hubk-1980] describes an ideal workflow with a representation of the individual sequences of the work phases, which HUBKA called *stages*. In this procedure model, technical and logical connections are shown, whereby idealized starting conditions are assumed, for example, with regard to the working conditions of the groups of people involved.

In the conception of the general procedure model, different laws from the fields of technical processes and systems, findings from psychology, heuristics and ergonomics as well as the basics of model structuring are incorporated into the formulation of the steps in designing. All steps in designing are described by the following basic operations:

- Determine the task,
- Search for a solution and
- Decision and solution-finding.

[5] Vladimir HUBKA (1924–2006), pioneer of modern design sciences, founder of the International Conference on Engineering design series (ICED) in 1981, which has been held since then every two years at various locations around the world.

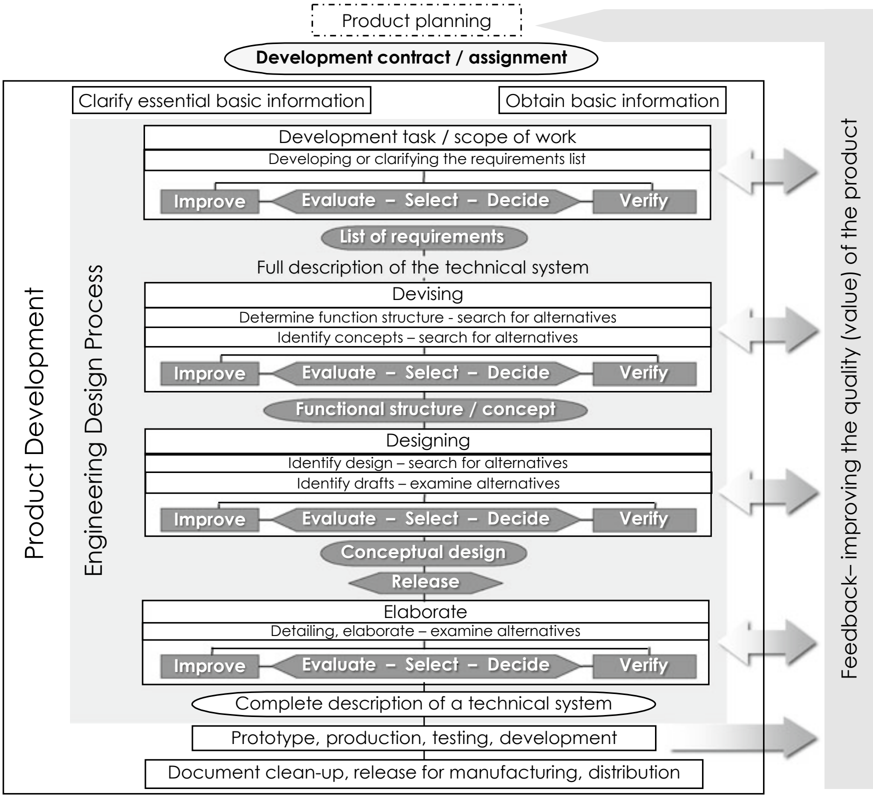

Fig. 1.3 General procedure model for designing after HUBKA [Hubk-1980]

These steps are supported by the results of the respective operations, provision of information, verification and presentation. They can be applied in an iterative form for each stage of the process, Fig. 1.3. The stages that are passed through sequentially are subdivided into task formulation, conception, design and elaboration. Each stage has defined the results of the activities it contains, which serve as input for the next stage.

Within each stage, there is the same sequence of activities that serve to improve the outcome of that stage. These activities are improving the current solution (so that several alternatives emerge), evaluating these alternatives to select the most promising one, and verifying the selected alternative (with a possible jump back if previously unknown problems were discovered during verification).

The main features of HUBKA's process model are as follows:

- A product is regarded as a technical system that is embedded in its environment and must exist there according to the requirements.
- Product development is superior to design because it covers several areas of the product's life cycle.

- Activities can be basically divided into the sequential stages of developing tasks, conceptualizing, designing and elaborating.
- In each group of activities there is the same pattern of activity from (1) Evaluate, (2) Select, (3) Decide. Selected products must then be verified and, if necessary, improved.
- Feedback and repetitions in the process are necessary to improve product and process quality.

This procedure model is designed to be generally valid. The following influences must, therefore, be taken into account when applying this procedure model to a specific application:

- The technical system to be developed and its variety of components including their degrees of complexity, the necessity of variants, etc.
- Boundary conditions for the realization of the idealized design process. These conditions consist of both the knowledge and design experience of the employees, given working conditions, available work equipment, etc.
- The affected organizational areas of the company with their structures, their respective deadlines and capacities, the technical possibilities of production, assembly, sales, etc.
- The social environment, for example, standards, regulations, environmental protection.

During processing, the designer needs support not only in the form of suitable tools but also in the form of prepared knowledge, which must be offered to him as context-sensitive as possible. Chapter 17 deals in more detail with the aspects of knowledge integration.

1.1.2 VDI Guidelines 2221 and 2222

The guidelines VDI 2221 (Methods for Developing and Designing Technical Systems and Products) [VDI-2221/93] and VDI 2222 Part 1 (Methodological Development of Solution Principles) [VDI-2222/97], which aim to describe the design process, were developed in the 1990s as a synthesis of German-speaking design research after the Second World War. From their origin, the two guidelines describe the methodical design of mechanical products in the capital goods industry, preferably from large-scale mechanical engineering and special mechanical engineering. The guidelines contain descriptions of the procedures, presentation and application of individual methods as well as their work results. Both guidelines quickly became international standards after their publication, also through their provision in English and other languages.

The system technical problem-solving methods are summarized in groups in the form of a method catalogue. Their application is assigned to the individual work stages of the general procedural plan. For the application of VDI Guideline 2221 in

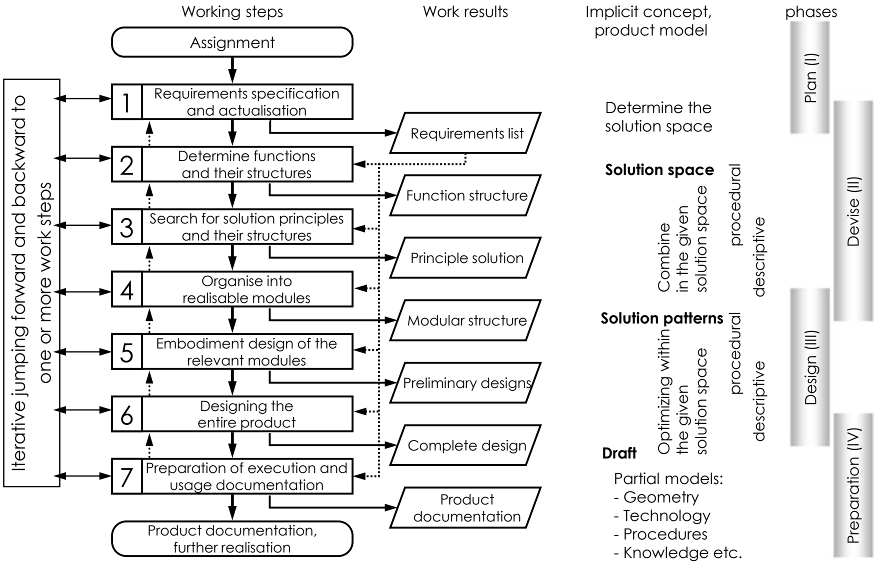

Fig. 1.4 General procedure for design [VDI-2221/93] with an addition from [VBCA-2005]

a company, a function-oriented organizational form is required. Both involvement and integration of computer support are also required and shown exemplary Fig. 1.4.

Figure 1.4 describes under the heading 'Implicit concept, product model' the design according to biological evolution as a process to determine the solution space for possible solutions, to combine elements within this space and to create equivalent but not similar solution patterns from which the desired solution is selected and the required partial models are created (Autogenetic Design Theory, [VBCA-2005]).

In addition to the general procedure plan according to VDI 2221, the guideline VDI 2222 provides detailed documents for task specification, function recognition and function linking as well as for finding basic solutions. The individual methods are subdivided into the following:

- Clarification of the task.
- Division of the overall function into sub-functions[6]
- Search for suitable solution principles (e.g. using design catalogues according to Roth [Roth-1982]).
- Combination and definition of the solution concept (e.g. according to the Morphological Box method after Zwicky [Zwic-1982]).

VDI Guidelines 2221 and 2222 contain a design procedure plan with individual methods for the respective work steps. The two directives focused on mechanical products and referred only to design and development phases, even though VDI Guideline 2221 demonstrated the fundamental transferability to other disciplines

[6]According to the Latin principle of 'divide et impera' (divide and rule).

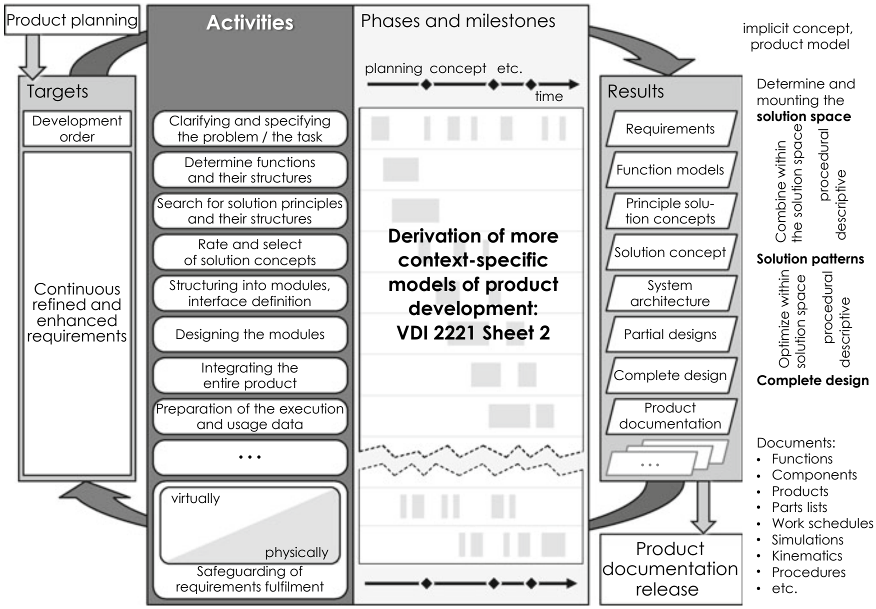

Fig. 1.5 Current version of the VDI guideline 2221 of 2019 [VDI-2221/2019]

using examples. Therefore, the VDI guideline 2206 (Development Methodology for Mechatronic Systems) [VDI-2206] extended the approaches of the aforementioned guidelines to mechatronic products. The V-shaped structure of VDI 2206 is based on the V-model from software development [IABG-2013]. Organizational aspects, such as teamwork, are, however, only rarely explained in the guidelines mentioned above, and possible forms of computer support are only shown as examples.

VDI 2221 was fundamentally revised and released in 2019 [VDI-2221/2019]. It forms a framework concept for all phases of the design process that also extends beyond the core area of mechanical product design, because it can include software development, for example. As before in the edition of 1993, the new edition of the guideline contains the methodological principles for designing technical systems and products. It proposes a general and cross-industry plan of action that would allow a systematic approach to technical problems at different stages of development, from the abstract to the concrete (Fig. 1.5).

- Incoming is the development order as a result of product planning. The output is the description of the solution ('product documentation').
- In its structure, the model follows the so-called ZHO approach (in German: Zielsystem—Handlungssystem—Objektsystem, in English: Target system—action system—object system) that goes back to ROPOHL [Ropo-1975] and that has essentially been extended by ALBERS for product development [AlEL-2012].
- In the target system (left), it should be noted that the requirements for the product to be developed are not static, but a change in the course of development—be

it due to changed external specifications (e.g. by the customer) or be it due to identified errors and weaknesses, the elimination or mitigation of which become new requirements.

- The action system (centre) shows in the vertical plane the different fields of activity (almost identical, incidentally, in all the descriptions of the design methodology mentioned above): Clarification and specification of the problem/task, functional and principle considerations, evaluation and selection, decomposition into modules, their design and assembly into a functional overall product up to the detailed elaboration of the execution information plus, if necessary, further documents.
- In the horizontal, the recurring phases of a concrete development project are indicated: All activities are planned, concepts are created and results are worked out. However, depending on the type and scope of development, the activities mentioned must be carried out more or less intensively. The derivation of a specific process model for a given development task in a particular company depends on a number of context factors. These are the subjects of the (new) Sheet 2 of the VDI Guideline 2221 [VDI-2221/2019].
- The object system is represented by the work results in the individual fields of activity: Requirements, functional and principle models, part drafts, overall drafts, etc.
- In contrast to the earlier editions of VDI Guideline 2221, the continuous validation of the relevant product properties is explicitly included in the model (lower part of the action system in the centre). Virtual (CAx-) or physical methods (experiments) can be used for this purpose. The safeguarding closes the circle by checking whether the current work results meet the requirements or where there are still gaps.

1.1.3 Taxonomy for Mechanical Design According to Ullman

In addition to his design method [Ullm-1992a], which is clearly oriented on the work of PAHL and BEITZ [PaBe-1977] and the VDI guidelines 2221 and 2222 [VDI-2221/93, VDI-2222/97], ULLMAN in the *Taxonomy for Mechanical Design* describes, categorizes, classifies and compares procedures, features and properties of process models as well as corresponding tools and organizational forms [Ullm-1992b]. The taxonomy is divided into three parts: Factors (environment, task and process), characteristics of these factors and the concrete manifestations of the process model examined, Fig. 1.6.

ULLMAN basically divides Engineering design into the environment in which it takes place, the task to be solved, represented by the (respective) initial and the (desired) final state, as well as the actual activities within the framework of the design processes with the description of the steps leading from the initial state to the final state, their effects on Engineering design and the strategies and tools of error detection and error elimination.

factor	Characteristics		Concrete manifestation
Environment of Engineering design	Participants		1.
	Characteristics of the participants		2.
	Resources of the participants		3.
Development task	Initial state	Refinement level	4.
		Visualization	5.
	Final state	Refinement level	6.
		Visualization	7.
	Satisfaction criteria		8.
Process	Work schedule		9.
	Work to be carried out		10
	Impact		11.
	Bug fixing		12.

Fig. 1.6 Taxonomy for Mechanical Design von ULLMAN [Ullm-1992b]

The description of the environment includes the parties involved in solving the design task, their characteristics, their responsibilities and the resources available to them. The resources of the design process include, for example

- Methods for the individual designer in the form of individual approaches and procedures to improve the design process, such as Failure Mode and Effect Analysis (FMEA).
- Methods for a group of Engineering designers in the form of methodical support of group activities in designing, for example, idea-collection in the group by brainstorming and gallery method [Hell-1978].
- Automation of designing through CAx systems with modules that independently (without human interaction) develop a solution, such as parametric or the use of expert systems.
- CAx systems for single users.
- Computer-aided tools for user groups that also enable simultaneous and consistent access to a product model by several designers, for example, product data management (PDM) systems or collaboration platforms that can synchronize product model data in an interdisciplinary and cross-company manner.

The task describes the interplay between a (further) level of refinement or detail and the representation of the respective result in order to move from the initial state(s) to the (desired) final state. In this process different phases of detailing are passed through, Fig. 1.7. Results can be described in textual (report, documentation), verbal (presentation), graphical (as sketch or drawing, numerical (computer-internal product model, process instructions, etc.) and physical form (model, prototype) or in mixed forms of them.

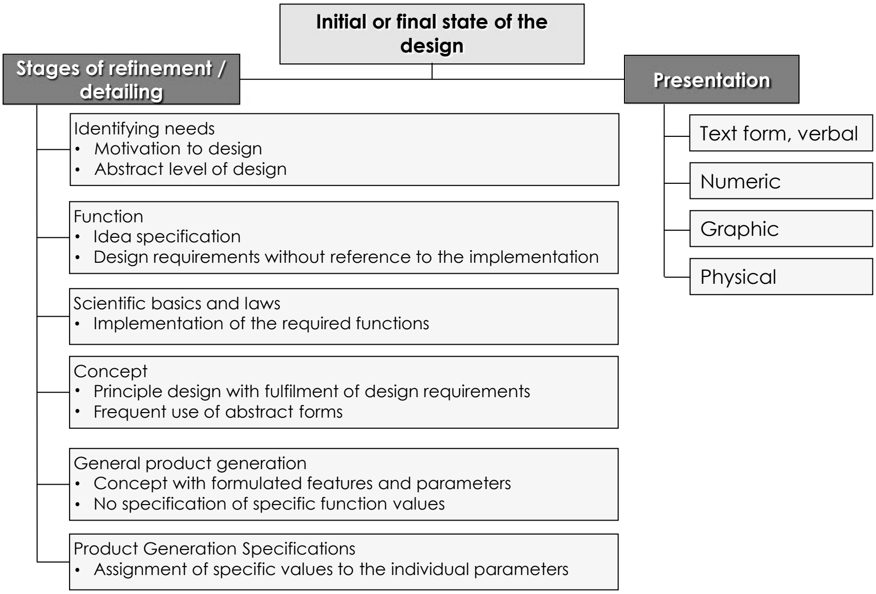

Fig. 1.7 Stages of refinement/detailing for solution processing [Ullm-1992b]

Contents of the factor 'processes' are as follows:

- Flow charts with procedures and control strategies to describe the design process,
- Implementation of the individual processing steps using the flow charts,
- Flexible variation of the flow charts and the processing steps by detailing and improving, decomposing, combining and modifying as well as
- Sequential and iterative error detection and correction.

As mentioned above, this taxonomy can be used to classify and compare existing process models at different levels of detail. Figure 1.8 shows the classification of

Factor	Characteristics		General procedure model (Hubka)	VDI 2221 - Function determination
Construction environment	Participants		1. Individuals or groups	1. Individuals or groups
	Characteristics of the parties		2. Women and men with different knowledge backgrounds	2. Women and men with different knowledge backgrounds
	Participant resources		3. Creation systems, management systems	3. (not specified)
Development task	Initial state	Refinement level	4. Need (direct or indirect)	4. Function
		Visualization	5. Text form, verbal, numerical	5. Text form, graphic (sketches)
	Final state	Refinement level	6. Realization of artefact	6. Function
		Visualization	7. Text form, graphical, numerical, physical	7. Text form, graphic (sketches)
	Satisfaction criteria		8. Acceptable fulfilment of the need	8. Satisfactory performance
Process	Work schedule		9. Stages and self-similar activities	9. Search
	Work to be carried out		10. Different, depending on the stage	10. Search
	Impact		11. Decomposition, different types of connection levels	11. Decomposition, different types of connection levels
	Bug fixing		12. Feedback, iteration	12. Iteration

Fig. 1.8 Classification of HUBKA's general procedure model and the function finding in VDI Guideline 2221 with the taxonomy according to ULLMAN

both HUBKA's general procedure model at the highest level of consideration and the step of function finding within VDI Guideline 2221.

With the Taxonomy for Mechanical Design, ULLMAN created a common denominator from the process models of the 1990s. However, he left unchanged the paradigms inherent in this focus on functional fulfilment and the largely sequential processing. The taxonomy can therefore still be used today (due to its few criteria) for an initial comparison of design methods and process models.

1.1.4 Summary

The procedural models described here exemplarily are oriented towards the processing of tasks in the development and design phases. They divide the individual problem-solving process into sequential phases with prescriptive and linear guidelines for action. They thus have a prescriptive-normative character, i.e. they provide the constructor with certain procedures within the framework of a repeatable and standardizable process. The early phases play a special role in the design, since 75% of the later product costs are determined here (Fig. 1.1). It is decisive that all requirements of the later product life should already be considered here.

Before the next phase can be edited, the current phase must be completed. The individual phases each produce an abstraction or concretization stage of the product described as a technical system (and represent this in a product model). During the passage through the respective phase, the solution space is continuously constricted (funnel model). The result of this approach is therefore a single solution. The specification of sequential work steps and prescriptive action guidelines should on the one hand enable a transparent procedure and on the other hand, support the designer in achieving the required solution quality.

The focus of these process models is on the design of mass products of the capital goods industry in mechanical engineering, not necessarily on individually adapted products, where the procedures are essentially controlled by the required properties and behaviour of the product. The procedures are not easily transferable to products from non-mechanical disciplines. However, they serve as a basis for process models, for example for mechatronics or for software (Sect. 1.1.2).

If certain actions and guidelines can be captured in algorithms, these can be used as a basis for automatic design of at least partial solutions on CAx systems. Thereby, these algorithms should cover all possible alternatives to a solution. If this is not possible throughout, possibilities for the designer to intervene in order to control the algorithm must be provided (see also Chap. 18, Application and Information Integration).

However, these procedure models have some weak points [GaNa-2004]:

- They are predominantly static and do not take into account any changes in requirements and environmental conditions that occur over time (for example, the complete list of requirements must be available, otherwise the process can't start), are too deterministic, not always empirically sound and heuristically weak.

- Findings from cognitive ergonomic about individual patterns of thinking and action are not or only insufficiently taken into account.
- For solution support, primarily discursive methods are available, e.g. list of requirements, functional structure, search for active principles, morphological box for variation and evaluation of partial solutions, subsequent selection and combination to complete solutions. Discursive methods and problem-solving strategies, however, leave neither enough room for (spontaneous) creativity and innovation nor do they support a dialectical approach of the sequence 'Thesis—Antithesis—Synthesis'.
- Decomposition procedures are too 'sub-complex' for most design problems when solving a task according to the principle of sharing and domination since in decomposition the possible mutual influences of the components are not or not completely taken into account (because 'the whole is more than the sum of its parts').
- Organizational, economic and management aspects are rarely included.

For a holistic, interdisciplinary and integrating generation of products, which on the one hand considers all phases of the product life and on the other hand is stable enough to exist in a turbulent environment, the focus on Engineering design must be abandoned in favour of an integrative consideration of the complete product development (from marketing/sales up to the planning of the manufacturing processes). Such approaches can be found, for example, in the C-K design theory (Sect. 1.6) and the Autogenetic Design Theory (Sect. 1.7), which show ways in which holistic methods for the development of (almost) arbitrary products can develop, provided that no consideration is given to existing thought patterns.

The transition to IPD and later to IDE leads to new perspectives, planning methods and procedures as well as to systemic and networked thinking across the disciplines involved, to adaptive planning methods and to empirical research. The resulting product is automatically described with all possible properties and facets, not only from the point of view of fulfilling functions. The Engineering designer becomes a product developer with more freedom and motivation for his own creativity with the flexible application of methods and strategies.

1.2 Formation and Further Development of Integrated Product Development

The term 'Integrated Product Development' (IPD) and the concepts underlying IPD were first coined by OLSSON[7] at Lund University in Sweden in the late 1960s. The main features of IPD were presented to the public in several papers at the first *International Conference on Engineering Design* (ICED) in Rome in 1981

[7]Fredy OLSSON (1935–1993) taught at the University of Lund (Sweden). His dissertation 'Systematisk Konstruktion' from 1976 already contained the name, type and contents of IPD [Olss-1976].

[Olss-1981, AnOl-1981]. The English term *Integrated Product Development* (IPD) was first presented in 1982 at the *Design Policy* conference [HPAO-1984]. OLSSON was involved in all these publications.

The first publication dedicated only to the IPD model was published in 1985 under the Swedish title *Integrerard Produktutveckling* [Olss-1985]. OLSSON described this as a development method that includes parallel work and is based on so-called 'integrated teams' from different areas of a company[8]. The members of these teams were to come from those areas of the company whose cooperation was necessary for the development and production of products. Even if the parallel work of interdisciplinary teams is no longer a special feature today, these ideas were still quite unusual in 1985.

While IPD according to OLSSON was industrially applied mainly in Sweden through the massive support of Sveriges Mekanförbundet (the Swedish Mechanical and Electrical Industries Association), in 1987 the book *Integrated Product Development* by ANDREASEN, who received his doctorate from OLSSON in 1980, and HEIN (DTU Lyngby), in which IPD was presented as an idealized model of product development, drew the attention of a broad international public. OLSSON's work in Lund was continued by BJÄRNEMO. EHRLENSPIEL (TU Munich) developed IPD further in the German-speaking area and introduced it very successfully as a development method in training and application. Since 1994 his book *Integrierte Produktentwicklung* (Integrated Product Development) has been published (now in its 6th edition, since the 5th edition together with MEERKAMM (University of Erlangen-Nuremberg), [EhMe-2017]).

The work of ANDREASEN and HEIN influenced EEKELS (TU Delft), MEERKAMM [Meer-1994] and BERCSEY (TWU Budapest) [BeHo-1999] as well as BURCHARDT [Burc-2001] and VAJNA (both Otto-von-Guericke-University Magdeburg) [VaBu-1998]. *Integrated Design Engineering* (IDE) was developed from the resulting Magdeburg model of IPD. In Sweden, OTTOSSON (then University of Halmstad) was the first to implement the teaching model of Integrated Product Development shortly after its publication at Halmstad University. A few years later NORELL founded her chair for IPD at KTH Stockholm [Nore-1999], which is now continued by RITZÉN. In Malta, BORG is conducting research in this field. Parallel to the activities in Europe, IPD developed in the USA, for example through OCHS, Lehigh University, Bethlehem PA [WaOB-1998] and CAGAN, Carnegie Mellon University, Pittsburgh PA [CaVo-2013] (whereby both are using IPD predominantly for the development of new products and less in the research environment), Fig. 1.9.

Today, IPD is researched and taught at numerous institutions. Based on OLSSON's IPD model, definitions and contents of IPD have diversified since then. However, no convergence or consolidation of definitions and content has been observed so far, and there is currently no common understanding or definition of IPD.

[8] The term 'integrated team' originates from the military environment. Napoléon Bonaparte was the first to use the term 'integrated army corps' for teams of infantrymen and cavalrymen [Smed-1994].

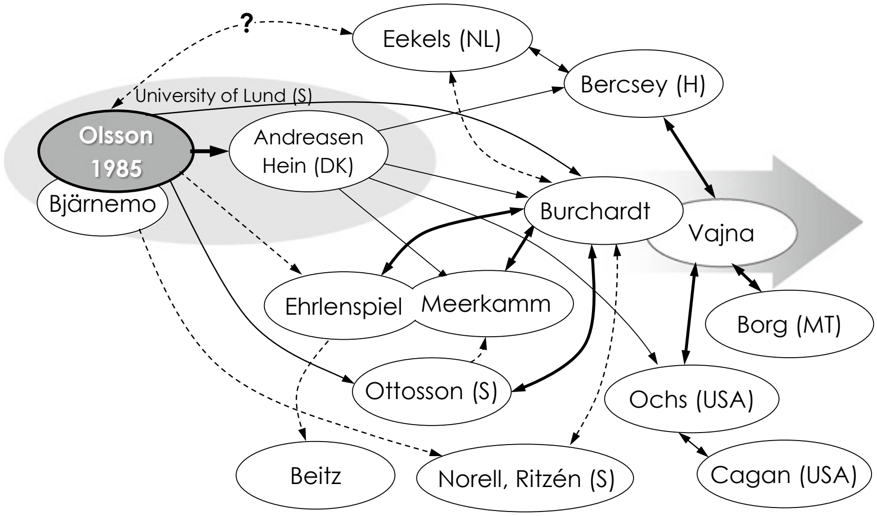

Fig. 1.9 Origin and further development of IPD (according to [Meer-1994, Burc-2001, Otto-2004]; solid line: cooperation, dotted line: mainly exchange of information)

The topics covered range from IPD as an independent development philosophy with different levels of integration[9], the inclusion of industrial design and the focus on mechanical engineering with complementary industrial project work, to the approach that IPD is merely another term for Simultaneous Engineering (SE) and/or Concurrent Engineering (CE)[10] (e.g. [FoSt-2003]) or Collaborative Product Commerce (CPC), whereby SE and CE only describe organizational aspects of IPD and CPC focuses on cooperation between partners. In many cases, IPD is limited to the development of new products. However, new developments represent only a small percentage of the development work, since this is dominated by the adaptation of existing products.

In the following, the models of Olsson, Andreasen and Hein, Ehrlenspiel, Meerkamm and Ottosson are presented before the Magdeburg model of IPD is discussed, as all these models document the evolution of IPD.

[9]The integration of activities and/or fields is supported by all European sources, but also for example by the Product Development and Management Association (PDMA): 'A philosophy that systematically employs an integrated team effort from multiple functional disciplines to develop effectively and efficiently new products that satisfy customer needs.' [PDMA-2011].

[10]In SE, different (and originally sequential) activities in product development (such as development, Engineering design and process planning) are overlapped in time and executed in parallel, with an intensive exchange of information occurring in each overlap area. With CE, a voluminous task is divided among several persons who work on it in parallel. Therefore, the definition of physical and logical design spaces with clear interfaces between each other is a prerequisite for CE. The most important criterion for parallelization for SE and CE is the question of when the results of the previously started work step are so stable that the statistical probability of a change and the associated change costs are lower than the costs caused by working too late [VWZH-2018].

1.2.1 *Integrerad Produktutveckling According to Olsson*

In his IPD concept, of which the foundation was laid by OLSSON [Olss-1976] and which was first broadly published at ICED Rome in 1981, OLSSON spans the spectrum from the requirements situation to the product accepted by the customer on the basis of the product's properties. This IPD, therefore, does not end with the delivery of the product, but only when the customer has given positive feedback.

OLSSON initially worked with four system levels: initialization (either an innovation = new design or an improvement = adaptation design, whereby an improvement can also be achieved by partial new design, by dimensional changes = variant design, or mixtures thereof[11]), (concept-driven) development, (detailed) product design and concrete problem-solving. People working at these levels use processes and appropriate methods as well as tools that are embedded in an existing environment (e.g. companies, but also legislation and culture). The human being, who is seen here with his character, his abilities and his psychological disposition, makes use of the required resources within the given goals [Olss-1981].

OLSSON structured IPD into four parallel strands of activity, namely Marketing, Distribution and Sales, Development and Design, Production and Project Management and Economics, Fig. 1.10. This was a paradigm shift at a time when the focus was on the design of products that took place in sequential phases, where a phase could only begin when the previous one had been completed. OLSSON was one of the first to take up the approach of Simultaneous Engineering.

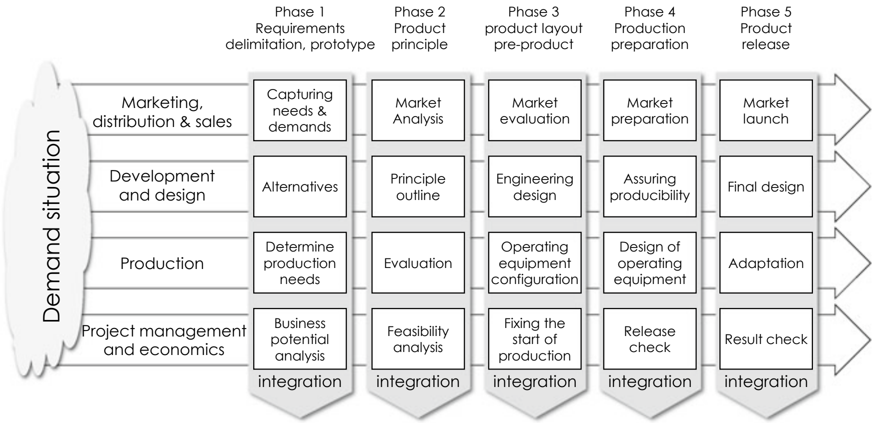

Fig. 1.10 Integrerard Produktutveckling—the IPD Model from OLSSON [Olss-1985]

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[11]In general, it is hardly possible to specify the exact proportions of new design, adaptation design and variant design in practice, especially since the boundaries are fluid. Estimates are in the range of 20–30% variant design, 15–25% new design, thus approx. 45–65% matching adaptation design.

At the same time, the activities in these four parallel strands can each be divided into five equal phases [Olss-1976]:

- In the first phase, the problem to be solved is narrowed down to such an extent that a prototype solution is available at the end of this phase.
- In the second phase, possible solution principles are established and evaluated.
- In the third phase, these lead to the so-called preliminary product, which already contains essential elements of the solution.
- In the fourth phase, all steps necessary for the realization of the preliminary product are carried out.
- In the fifth phase, the results of the previous work are released for the next phases or for the market.

Another innovation from Olsson was that product development was triggered by a demand situation, regardless of whether that demand was generated by the market or by a (discretionary) customer (and yet it doesn't matter whether it is a mass product for the consumer goods sector or a single product for the capital goods sector), by a particular strategy or by an (e.g. political) environment. This IPD does not 'wait' until a potential customer formulates his wishes to the product development of a company. In the 'Marketing, distribution and sales' activity strand, IPD requires that the market be actively worked on (the 'capturing needs and demands' and the 'market analysis' phases), that the possibilities for placing a product in the market be critically scrutinized (the 'market evaluation' phase), that the market be accordingly and appropriately prepared for the new product (the 'market preparation' phase) and, finally, that the new product is successfully positioned in the market (the 'market launch' phase), taking into account the best launch time and the shortest launch duration.

Looking at the activity strand 'Development and design' separately, it does not fundamentally differ from the procedure as postulated in the VDI Guideline 2221 of 1993 [VDI-2221/93]—apart from the fact, that assuring the producibility (and thus the release for production) does not represent the last activity in this strand (in VDI Guideline 2221 this is the seventh step 'elaboration of the execution and usage data') but is used as the last form of influencing the resulting product before the final design of the product can take place in the last activity of this strand. This ensures that only products that can be manufactured in the company arrive in production.

Parallel to the other strands of activity, the 'Production' strand prepares for smooth and rapid production by means of suitable organizational and technical measures. The first activity, 'Determine production needs', is of a planning nature and is therefore actually part of production planning and control (PPS), not product development. Here, however, it correlates with the activity 'capturing needs and demands' in the first line. In addition to assuring the manufacturability of the product (up to and including product adaptation shortly before the start of production), the other activities serve to provide the necessary operating resources. At the time when Olsson set up his model, these activities were also not part of the design activities, but (only) of the areas after the design area.

Also new in 1981 was the approach of introducing one strand of activity ‘Project management and economics’ into product development on an equal footing with the other strands. The activities contained therein not only support the feasibility of the activities in the other three strands but also take into account the respective environment in which the company operates. In addition, activities in the other strands are continuously checked for their cost-effectiveness in order to be able to intervene in product development at the earliest possible time in the event of disruptions. This is to ensure that the parallel work is concluded with a positive result (which is also checked in the last activity).

The cross-connections between the parallel activity strands act as integrations ensuring that a permanently active comparison of the individual activities takes place.

OLSSON designed his IPD model for the development of new products but pointed out that the model does not have to be completely run through for every task, but that it is possible to start processing later if the relevant information is already available, as is the case with the adaptation and modification of products [Olss-1981], which are among the most frequent activities in product development with a share of more than 65% [VWZH-2018].

In summary, the innovations that OLSSON introduced with IPD were the following:

- Inclusion of the customer satisfaction to be achieved by the product.
- Parallel processing of equivalent tasks (in terms of time and tasks in the sense of Simultaneous Engineering), thus shifting activities to earlier processing (front loading), for example shifting production in parallel to the development and design area.
- Define phases with comparable task patterns in all activity strands.
- Inclusion of project management and the on-going review of the economics of all activities in product development.

Compared to traditional predominantly sequential procedures, IPD results in improved solutions, as the desired product properties, the use of technical production equipment and economic aspects are taken into account. As mentioned above, this IPD model was used for student education at Halmstad University in early 1990, where OTTOSSON was the responsible head of the courses. On the basis of experiences from the courses, the accompanying project work and the resulting start-ups, he made some adjustments to the OLSSON model. He divided the activity strand ‘Marketing, distribution and sales’ into the two strands ‘Marketing’ and ‘Distribution and sales’, because marketing is more active in the early phases of product development, while distribution and sales distribute the products to the market in the later phases. A further difference is a temporally changing frequency distribution of the now five parallel activity strands. OTTOSSON divided the work into a technical and a commercial part and added an activity pattern for dependent decisions to this presentation in order to point out the cooperation between the individual activities (see also Sect. 1.4).

1.2.2 Integrated Product Development According to Andreasen and Hein

The IPD according to ANDREASEN and HEIN, first described 1987 in [AnHe-1987], is based directly on the work of OLSSON. It describes the product development process as an integrated and iterative process in which a large number of variants and alternatives to product configuration are created as the level of detail of the product increases, whereby the best solution is found and further processed by means of selection criteria. The key objective of this IPD is to optimize business success. The sequence of the individual steps is predefined, and the individual development phases are processed sequentially on each activity strand. Product development activities are examined with regard to their interrelationships, interplay and chronological sequence, and suitable integration approaches are identified. These approaches include

- the realization of common objectives at operational, strategic and conceptual corporate levels,
- a holistic view as well as an interaction of the areas marketing, product and production (if necessary also further areas) not only within the own enterprise but also beyond enterprise borders, e.g. with development cooperation as well as
- the coordinated and simultaneous cooperation of different product development activities and projects with regard to coordination and control.

This IPD includes the following task fields:

- Marketing, product and production tasks, which (based on the model of OLSSON) are carried out in three parallel activity strands [HPAO-1984],
- Short-term tasks, project-oriented tasks and tasks related to long-term strategic planning, as well as
- individual development activities.

This IPD promotes a holistic approach with simultaneous optimization of the product and its production processes, taking into account the conditions in the market, Fig. 1.11.

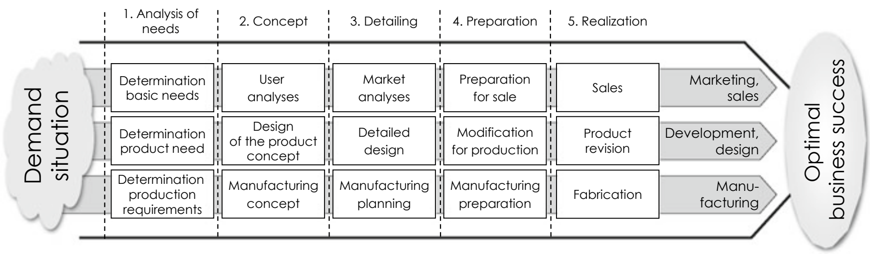

Fig. 1.11 IPD model according to ANDREASEN and HEIN [AnHe-1987]

The trigger for product development is a demand situation in the market, which is assumed here to be stable. A possible need situation can also result from a project idea of the company, if a future market is seen for it or if the market must first be created for it[12]. The IPD process is then divided into five phases that are similar to the procedure in VDI Guideline 2221 of 1993 [VDI-2221/93].

- Needs analysis: For marketing, this means recording how many products the market will absorb, for business management how this product and the expected quantities will fit into the company's product portfolio, for development and design what characteristics the product must-have, and for manufacturing what capacities must be created in order to bring the product to the market at the desired time.
- Conception: Conducting investigations on possible preferences and behaviour of the user, which leads to the definition and formulation of the product properties as well as the means of production [AnFa-1995].
- Detailing: Design and construction of the product with inclusion of knowledge from the divisions involved in the detailing.
- Preparation: Examination and, if necessary, adaptation of the product with regard to its manufacturability and preparation for market entry.
- Realization: Production and sale of the developed product. On the basis of the feedback from production and the market, a first revision of the product can already take place now (this activity corresponds to the activity 'Result check' in IPD model according to OLSSON).

When comparing IPD model by ANDREASEN and HEIN with IPD model by OLSSON (Fig. 1.17), one notices that the activity strand 'project management and economics' no longer appears here. In [AnHe-1987] the justification for this is that neither project management as a controlling and regulating activity of IPD nor economics as the (direct or indirect) result of the activities would directly contribute to the synthesis of the product created during IPD; rather, economics is implicitly contained in the activity strand 'marketing, sales', following the idea that a marketing activity would not be carried out in a properly running and financially soundly managed company without prospects of economic success. The fourth strand of activities is only necessary for companies in the start-up or expansion phase if it is not a question of expanding existing business areas, but of setting up completely new business units or business areas (such as the establishment of subsidiaries or diversification) [AnHe-1987].

Product development itself is regarded as a cyclic process, Fig. 1.12.

Any alternative to this cyclic process consists of proposals that need to be examined in terms of product design, production technology and means of production. The individual cycles of this process, therefore, represent a continuous examination

[12] For example, Apple used to launch products on the market before there was a direct need for them (thus created the respective need), starting with the digital music player iPod, the mobile phone iPhone, the tablet computer iPad and the Apple Watch. One of the reasons for the respective market success might be the fact that several previously separate application areas have been integrated into each of these devices, and the range of functions offered can be used via an intuitive user interface.

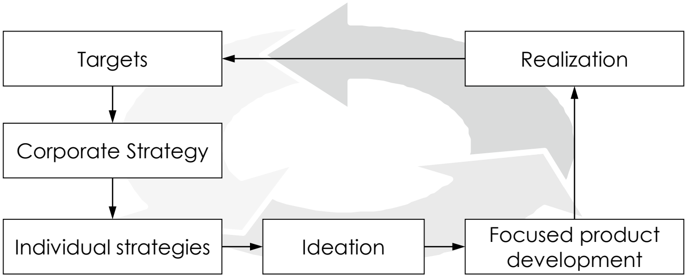

Fig. 1.12 Product development as a cyclic process [AnHe-1987]

and selection of proposals with continuous detailing and concretization of the solution and increasing definition of both parameters and data for the product, process and production system. The product is evaluated not only on the basis of design and product criteria but also on the basis of an overall view of the market, product and production aspects [AnKL-1985].

This IPD also includes:

- A structured approach for planning, for example, defining different work steps such as market analysis, product development and product evaluation, which have to be completed in a certain order,
- Forms of work and organization, e.g. consideration of employee requirements, forms of cooperation, project management, distribution of roles in product development,
- Use of various (predominantly manual) tools, such as DfX methods, competition analyses, systematic product search, product specification, planning tools and
- A management pattern, for example, cost and quality optimization, minimization of environmental impacts, changed the corporate culture.

IPD is to be implemented in project-oriented organizations with interdisciplinary teams.

The consideration of the employees within the company is essential for IPD since the employees should understand the overall context of development projects and should have the corresponding possibilities to influence it. These include in particular project management methods for controlling and coordinating projects. Project management includes various work activities, such as defining project strategies, product specifications, project planning and internal and external risk analyses.

The implementation of IPD in a company is not characterized by a rigid scheme. Rather, the implementation is to be carried out according to requirements and company specifications. According to ANDREASEN and HEIN, an analysis of the company must be carried out in order to determine a suitable degree of implementation. For example, the organizational structure (such as the functional structure), the decision-making structure (including the role of employees), the social system (taking humans into account), methods and tools (such as design methods) or the knowledge structure (such as the provision of information) are analyzed. In this scenario, the current status of the company is recorded, analyzed and individual measures for implementing IPD in the company are derived.

The IPD model by ANDREASEN and HEIN is an idealized concept with an emphasis on design and development activities. Essentially, it has the following characteristics:

- Simultaneity and integration of processes (well in the sense of Simultaneous Engineering),
- Inclusion of the influences of product development on the product life cycle on the one hand and the influences of the product life cycle on product development on the other hand, predominantly via DfX processes [Baue-2003],
- Emphasis on the need for a general preparation of any activity in the interaction of all involved parties in the sense of production preparation before the release of a product for production.

In [AnHe-1987] the implementation of IPD is shown with examples of methodical procedures for product specification, with the interaction of interdisciplinary teamwork, with increased consideration of customer and market needs as well as with process integration in the company. A project-oriented organizational form is to be used. However, changes in the requirements situation after order placement are not addressed. Even though numerous proven and tested procedures and tools are listed, the use of computer-aided aids is only mentioned in passing. IPD does not serve as an isolated strategy for successful product development, but as a nucleus for a renewing and increasingly integrating company.

1.2.3 Integrated Product Development According to Ehrlenspiel

The IPD according to EHRLENSPIEL [Ehrl-1995] and [EhMe-2017] arose in the 1990s. It includes as well iteration and recursion between and in the individual process steps in order to arrive at the best possible solution. With these, EHRLENSPIEL describes the self-similarity of activities at different levels of concretization and of detail. His widespread approach is an integrating methodology for overcoming the problems of today’s highly fragmented product creation (summing up product development and production).

IPD should promote close cooperation between all those involved in the development process and should broaden the horizon for defining product characteristics. The focus is on an integrating way of thinking, the flexible application of methods and the human being with his ability to cooperate and his rational and intuitive thought processes. IPD extends from incoming orders or the first product idea through development, production, delivery and use to the end of the product life cycle with the disposal. However, the focus is on the phases up to delivery. For their implementation, organizational methods for the overall optimization of the product and product creation are used to a high degree [Ehrl-1991, LBSV-1999]. EHRLENSPIEL describes IPD as an integrated product creation methodology (IP methodology) whose common basis was abstracted from the experiences of Engineering design methodology, psychological research, empirical investigations and systemic thinking. The IP methodology is used in product development, with particular emphasis on goal orientation and the cooperation of the people involved.

The following integration types bring elements and methods of IPD together:

- Personal integration: Employees should develop a holistic and integrative way of thinking and acting. In this respect, not only the immediate system boundaries should be taken into account in the processing of tasks, but an attempt should also be made to develop a holistic solution—involving all the areas involved. The primary focus is on synthesis. This requires employees to integrate their willingness to perform, their goals and their areas of knowledge.
- Informational Integration: As part of the product creation process, it is important that the information needed to make decisions is available to the right person at the right time, in the right place, in the right quantity and in the right quality[13]. This includes the integration of customers to implement a customer-oriented product design as well as the integration of tasks for the consideration of adjacent work areas in the company's own task processing. Another aspect of information technology integration is data integration for the realization of computer-integrated product development using computer-aided tools and integrated product models.
- Organizational integration: This covers the organizational form used with both organizational structure and process organization. An integration of the organizational structure can, for example, be created by flat hierarchies with the delegation of responsibility from top to the execution level. The integration of the process organization can, for example, be realized by parallelization (Simultaneous Engineering or Concurrent Engineering), the use of project organization forms or through local integration (different departments with the same areas of responsibility in common offices).

For a successful realization of integrated product creation, a common and cross-departmental target strategy with regard to time, costs and quality is required, which is characterized by holistic and integrative thinking and action. In this context, people are generally regarded as problem solvers and their abilities, motivation and willingness to perform are seen as important potential for product development.

In the next sections, a first look at the genesis of this IPD (exemplary for the other approaches presented here) and then at individual elements of its methodology is presented. These are the TOTE schema, the process cycle, the method kit, the process plan and the organization of cooperation.

[13]The strategies, activities and information systems necessary to ensure and optimize information flows are part of information logistics in analogy to logistics in materials management.

1.2.3.1 How Did the IPD According to EHRLENSPIEL Arise?

The integration of previously separate operational areas ([Olss-1976] and Fig. 1.17), initially proposed by OLSSON and necessary for product optimization, was followed a few years later by the IPD approach of ANDREASEN and HEIN [AnHe-1987] from the same thinking area. In the 1980s, these Scandinavian method approaches from the university sector were still unknown at the Technical University of Munich, rather the approach to realize a method for *cost-effective design* was pursued intensively together with industry. This resulted in the book 'Kostengünstig Konstruieren' (Cost-effective Design) [Ehrl-1985]. In this book the integrative teamwork within the IPD process cycle (Fig. 1.14) is described in Sect. 4.3c. This book was a precursor for the later IPD book in 1995 [Ehrl-1995]. Through years of research contact with many companies of the FVA (Forschungsvereinigung Antriebstechnik—Research Association for Drive Technology), cost-effective design has been further developed. The integration between design, work preparation and cost calculation is at the heart of this field of work.

The starting point for the above-mentioned work was originally Value Analysis and Engineering VA, [VDI-2800]), which was founded in the 1940s by MILES in the USA at General Electric [Mile-1972] and which had been increasingly introduced into German industry since the 1960s. For VA, it is essential, as OLSSON also demanded his IPD, that development tasks are carried out in integrated teams from different areas of a company (so-called value engineering teams), thereby driving forward the optimization and cost reduction of products. The VA work plan also showed the advantage of methodical work. It corresponds in principle to the IPD procedure cycle (see Sect. 1.2.3.3 and Fig. 1.14).

Further suggestions for IPD came from cooperation on VDI Guideline 2221 and joint cost research with PAHL (Darmstadt), the latter also leading to the book 'Cost-effective Design'. A research cooperation of twenty years with DÖRNER (Bamberg) provided important insights into the thinking processes involved in design [FrBB-1998]. The consideration of DfX[14] influences on IPD took place following the suggestion of MEERKAMM (Erlangen), which finally led to the joint authorship of the IPD book from the 5th edition [EhMe-2017].

1.2.3.2 TOTE Scheme

The scheme of Test-Operate-Test-Exit (TOTE scheme) is a general action strategy from psychology, cognitive sciences and cybernetics for solving problems of nested tasks by humans or machines. This schema was described in 1960 by MILLER, GALANTER and PRIBRAM [MiGP-1991], who assumed that cybernetic systems for solution-finding

[14]The acronym DfX stands for '**D**esign **f**or property **X**': e.g. design for production, assembly, use and recycling, see also Chap. 14).

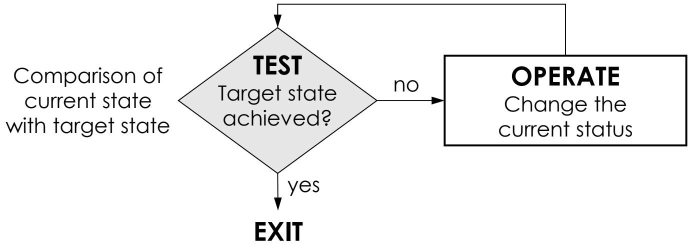

Fig. 1.13 TOTE scheme [MiGP-1991]

- have targets, for example, set-points for system parameters,
- have knowledge (in the form of data, information and rules) in appropriate repositories and
- use plans in the form of computer programs to achieve the objectives.

A control loop consisting of operation and evaluation (test) is run through until a solution adequate to the target is found (Fig. 1.13). Sub-problems that occur during this procedure require a subordinate control cycle. Only after the processing of the subordinate control cycle has been completed can the higher-level control cycle be processed further.

This cybernetic model of the control loop is also applied to humans [MiGP-1991]. For humans, the targets correspond to their own interests and external requirements (which, for example, result from a current task or a requirement specification). To solve the problem (operation) the human uses, in addition to plans and procedural patterns, his own experience and knowledge as well as the possibilities of accessing external information and knowledge portfolios. During the action, he checks in a feedback loop whether the target state has been reached. The activities in the cybernetic control loop can be represented in the TOTE scheme in four steps.

- Input test T: Analysis of the actual state of the problem solution and comparison with the target state. If the actual state cannot or can only partially be compared with the target state, the first operation phase must be run through in order to bring the actual state to the same reference basis as the target state. If the actual state then does not correspond to the target state, the next operation phase is run through. As soon as the actual state corresponds to the target state, the control loop is terminated directly via the fourth step (Exit).
- Operation phase O: On the basis of the test just performed, the actual state is changed (synthesis) in order to reach the target state. This can take place in the form of continuous further development of the solution or by setting up a new solution approach (hypothesis) for parts of the problem solution or for the overall solution.
- Results test T: Analysis of the actual state changed in the operation phase and comparison with the target state. If the target state has not yet been reached or has changed itself in the meantime due to changed requirements, the operation phase is repeated with a subsequent results test.

- Exit E: If the target state had been reached or if no further processing options are available (for example, due to lack of time or resources), the scheme is terminated.

During the process of solution-finding, the TOTE scheme procedure can be identified at any level of abstraction or concretization. The scheme thus forms a self-similar activity pattern for which it is worthwhile to provide extensive support possibilities (methods, procedures, techniques, systems) within IPD.

1.2.3.3 Procedure Cycle

The solution of an assignment or a problem contains a sequence of recursive steps, which are subdivided into sub-tasks and processed sequentially or in parallel. These are

- Clarify tasks, for example, analysis, formulation, structuring,
- Search for solutions, for example intuitive, creative, discursive approaches; create new solutions, search for existing solutions with different potentials for complete or partial reuse,
- Select solution, e.g. analysis, evaluation, decision.

These work steps are summarized in a procedure cycle [Ehrl-1995] Fig. 1.14.

The process cycle is a general pattern for solving various problems, whereby the individual work steps are processed according to the TOTE scheme (Fig. 1.20). Due to its abstractness, the process cycle occupies an intermediate position between a general methodology and its operational arrangement [Ehrl-1995]. It provides a control loop character to support the strategic planning of larger projects or complex

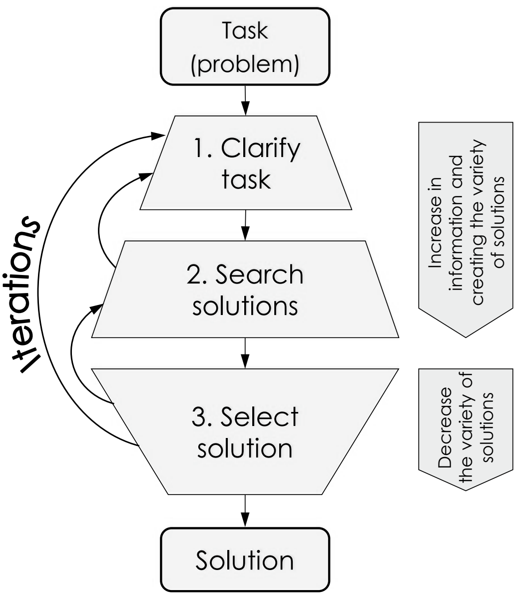

Fig. 1.14 Procedure cycle for problem-solving [Ehrl-1995]

products [Wach-1993]. The use of (adapted) procedure cycles serves the development of product, production and sales (which should take place as parallel and IT-coordinated as possible), similar to the IPD model according to ANDREASEN and HEIN [AnHe-1987] (Sect. 1.2.2).

When running through the procedure cycle, different iteration and recursion steps (derived from the system technology according to DAENZER [Daen-1992]) are applied between and in the individual process steps. In order to find a solution, the individual work steps in the process cycle are iteratively processed. Each step in one process cycle can be divided into smaller sub-process cycles that are similar in structure to the previous cycle. Partial problems that occur during work are also separated into subordinate cycles. In order to be able to leave a process cycle, the targeted goal must be achieved and all associated problems must be solved.

This division of the overall task into sub-tasks and the analogous structure of the processing of process cycles and sub-process cycles reflects, like the TOTE scheme, the self-similarity of the process cycle [Kiew-1991].

1.2.3.4 Method Toolkit

Within the framework of the procedure for task processing, various methods are used, which are summarized in a method toolkit as a systematically ordered collection of the various methods. This includes subject related methods to achieve a given objective as well as organizational methods that serve to design processes.

The multitude of methods makes it clear that there are often different alternatives to achieve a goal. The method toolkit contains exemplary methods for development and design, for example for solution search, design, assessment and decision-making [AmLi-1997, Frei-2001].

The use of methods can be handled very flexibly and offers various possibilities for task and problem processing. The long-term goal is the automatic and context-sensitive provision of suitable methods during the on-going problem-solving process[15] [Frei-2001].

1.2.3.5 Procedural Plan

The procedural plan is used to structure larger work tasks into individual sections as well as an organizational guide to show the divisions involved at which times in the project they will work in parallel with other divisions. Each step in the procedural plan is made up of procedural cycles (Sect. 1.2.3.3). Each step is followed by an analysis of the achievement of objectives and the appropriate use of resources,

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[15] In the knowledge-based process model of FREISLEBEN [Frei-2001], each method is assigned the corresponding procedures as well as manual and computer-aided tools, so that when a method is activated, all corresponding tools needed are automatically activated. The selection itself, if it cannot be performed context sensitively, can also be done with the Morphological Box of ZWICKY [Zwic-1982].

and if not achieved, by a return to the step in question. In connection with project management, there is direct and interdisciplinary coordination and regulation of all planning, control and decision-making processes in any task.

The graphical representation of an action plan is carried out using the familiar methods of project management, such as Gantt diagrams, milestones and activity lists.

1.2.3.6 Organization of Cooperation

In Ehrlenspiel's IPD methodology, the human being is both driver and problem solver of the implementation of integrated product creation. The organization of the cooperation leads to the overcoming of departmental 'intellectual walls' to the integration between the involved individuals and groups of persons in the form of an interdisciplinary, coordinated, mutually building or complementary cooperation with common objectives. The design of structural and procedural organization is particularly important for integration, and Ehrlenspiel characterizes it as 'From a routine based on labour division to a committed community', Fig. 1.15.

In conventional, i.e. usually functionally separated organizational structures, responsibilities and motivation for the implementation of a product type are only weakly pronounced, since this organizational form focuses only on a sub-function of the implementation. This is used for all product groups. Accordingly, there is little interest in the areas preceding or following one's own department, since the focus is on the fulfilment of one's own tasks (Fig. 1.15 left: 'Throwing results over the department walls'). This way of thinking leads to a local optimization of processes which, however, from a global perspective, lead to bottlenecks in order processing because they are not coordinated and local optimization gains are not passed on.

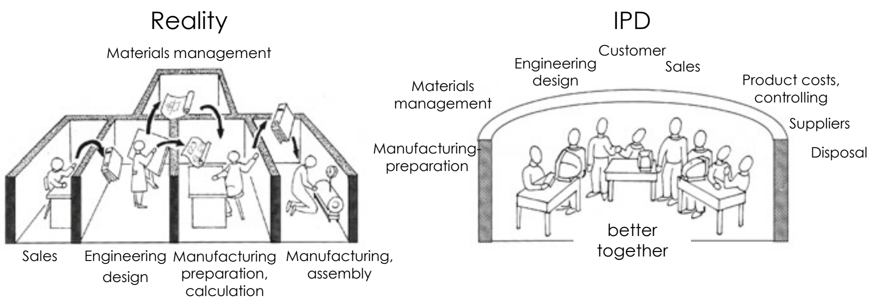


Fig. 1.15 Functionally separated and integrated organization (This presentation was hanging on the wall in many executive boards at the time.) [Ehrl-1995]

An efficient alternative is a product-related organization, for example, the divisional organization or the profit centre[16]. In the case of product-related organizations, the organizational units below corporate management are structured according to products and product groups, which work together in an organizational unit on all steps of product creation in context. This results in a stronger sense of togetherness compared to functional orientation.

As a mixed form between the functionally separated and the product-related organization, a matrix organization can be formed. Product managers or project managers are appointed who are responsible for coordinating products throughout the entire creation process or for controlling functional areas. To support organizational integration, responsibility is delegated to the point where the product is created and the associated decisions are made. The objective is for the groups to implement self-regulation of their area of work within specified management variables. This leads to a higher flexibility of the groups, a direct implementation of their creativity and an improvement of the informal flow of information.

The design of the process organization has an integrative effect on cooperation. EHRLENSPIEL considers the implementation of Simultaneous Engineering and Concurrent Engineering as essential in this context. Group work and teamwork as well as project management are important prerequisites to enable parallel and integrated workflows.

1.2.3.7 Merging into a Complete System

The elements of the IP methodology described in the previous sections are related to each other in the simplified way described in Fig. 1.16. This way is embedded in the product portfolio and profitability of the company's activities, competition, society and ecology. All these elements can be combined according to the type and complexity of the objects and processes to be processed. Due to its abstraction (which can be adapted at any time), the scheme of the IP methodology can be applied to the entire product development process for all company divisions and any product types and their entire life cycle.

This context enables the implementation of an integrated product development process and the overcoming of procedures based on the division of labour.

1.2.3.8 Strictly Rational and/or Intuitive Design?

From the 1960s onwards, design science, with great enthusiasm for systems engineering, rationally researched the earlier predominantly intuitive process of Engineering design, above all with methods of systems engineering [Ropo-1975], and thus made it teachable. This has led to the development of design methodology.

[16] A profit centre is usually a legally and organizationally independent organizational unit with full product and profit responsibility in the enterprise, usually in holding organizations.

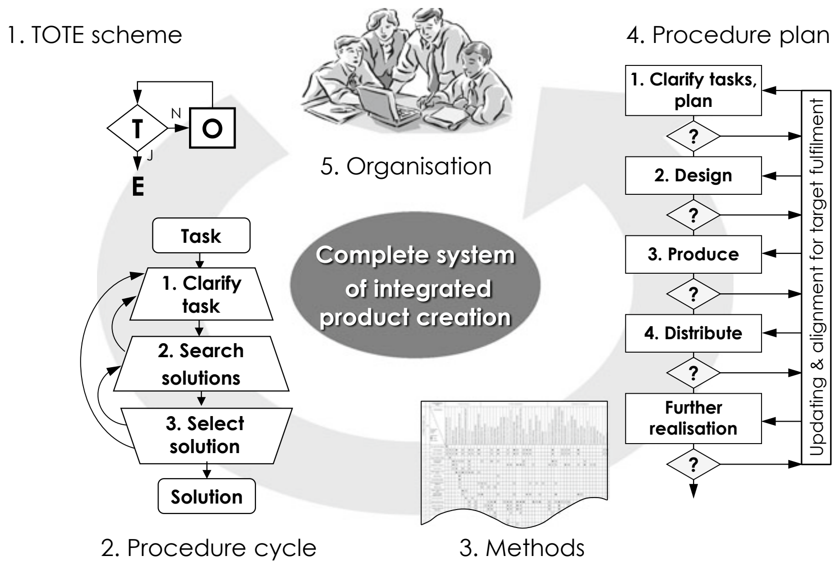


Fig. 1.16 Methodology of integrated product creation (free according to [EhMe-2017])

The vision and research drive for decades was that above all the rational application of methods can lead to high-quality products. It was overlooked, however, that the supposedly purely rational way of thinking of humans, when it comes to experience elements of positive and of error nature, always evaluates these experiences unconsciously and emotionally first of all in the limbic system of the brain and stores them dependent on the evaluation. Every action and decision supposedly purely conscious to man is unconsciously prepared from this pool [Gige-2008, Lehr-2009].

Furthermore, many years of research have shown that even intuitive, experience-led design leads to high-quality solutions, even in a short time, if the experience of the product developer is sufficiently covered for the task. Constructive decisions are made quickly and mostly effectively by heuristic rules (feeling of experience) or, according to GIGERENZER, by 'gut decisions'[17] [Gige-2008], Fig. 1.17.

Much of human action is controlled by the unconscious. *Normal operation* runs routinely in the unconscious. The unconscious has its own methods, which are so far only rudimentarily known[18]. This is why practitioners prefer the experiential, intuitive form of procedure in stage 1 of a two-stage operation. Only when the situation is no longer covered by the intuitively stored experience does a so-called critical situation arise (e.g. according to the definition of BADKE-SCHAUB and FRANKENBERGER

[17]Further details can be found in [EhMe-2017] and there in Sect. 3.6.

[18]To the well-known saying of DESCARTES 'I think, therefore I am', which is related to rational thinking, one would have to add according to today's knowledge: '*It* thinks, therefore I am' if one makes clear that all bodily functions of man are predominantly unconscious, and a large part of the sensory experiences of man, his rational thinking, is 'only a small icing on the cake of unconscious life'! Or, to put it another way: Man is lived more by the unconscious than is assumed.

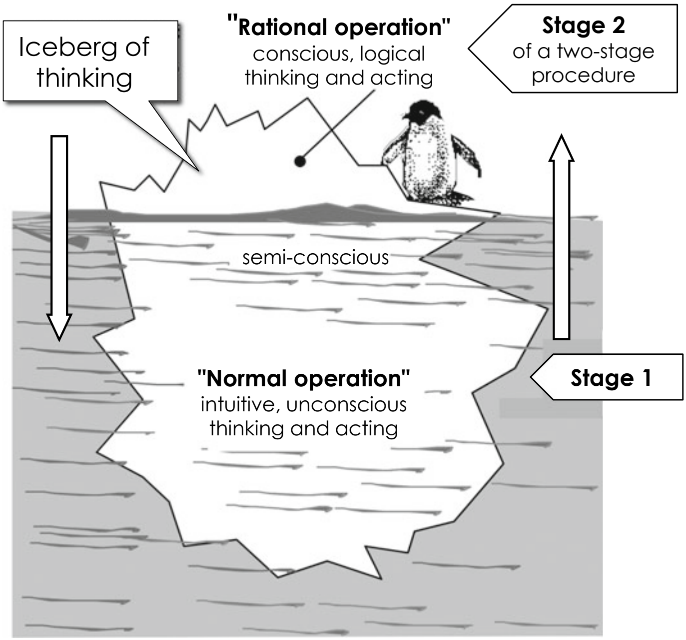


Fig. 1.17 Interaction of rational operation and normal operation in the human brain. The two arrows indicate how the conscious (explicit) and the unconscious (implicit) constantly change and exchange

[FrBB-1998]), which can then be overcome in stage 2 with rational actions (methods in *rational operation*). Such critical situations may occur more frequently with younger, inexperienced developers (possibly also with highly specialized ones having little general experience). You should then work more *efficiently from the* outset, Fig. 1.17.

Two rules can be derived from this:

1. Intuitive development and design in *normal operation* as often as possible with appropriate experience (see Fig. 1.24). However, a ‘minimal methodology’ according to Fig. 1.14 can also be helpful here: Intensive clarification of requirements or properties to be changed, search for several solutions, evaluation, selection and implementation of these.
2. Method-conscious, rational working in *rational operation* only when the situation requires it. Why so? Because rule 1 is much faster and leads to sufficiently good results. But: Large-scale projects in larger teams should be approached rationally and methodically from the outset (stage 2), and with project planning or the methods of systems engineering [Daenz-1992], because in such complex projects the intuitive human memory is clearly overwhelmed.

1.3 Integrated Product Development According to Meerkamm

According to MEERKAMM [Meer-1994], the philosophy of IPD is embedded in the tension field between time, costs and quality. This tension cannot be resolved by (more or less isolated) individual measures, but rather by holistic and integrated approaches such as IPD. It leads to a significant reduction in manufacturing costs (−35%), development times (−50 to −80%) and quality costs (−30%) and thus to a noticeable improvement in products and their accompanying processes (according to McKinsey, quoted from [Meer-1994]).

Of major importance here is the reduction of development times and thus the timely provision of a product for the market (time-to-market), as a product that is not brought to the market in time leads to noticeable losses in the possible product profit, Fig. 1.18. This figure also shows, however, that a significant increase in development expenditure, which may become necessary for the timely provision of the product on the market, has only a minor influence on the expected profit[19]. Conversely, it, therefore, makes sense to invest more resources in product development in order to be able to meet time and cost targets for the provision of a new product.

IPD according to MEERKAMM is an approach that consists of the people involved, an organization suitable for any problem-adapted procedures, methodology and supporting information technology, Fig. 1.19 (in this respect there is an analogy to the IPD according to EHRLENSPIEL, see Fig. 1.16).

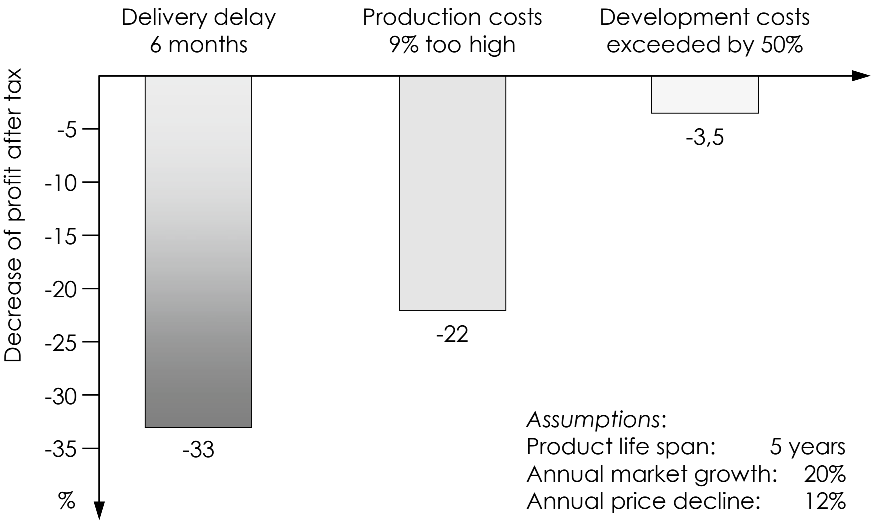


Fig. 1.18 Relationships between lost profit and possible causes of untimely product delivery (according to McKinsey, quoted from [Meer-1994])

[19]This agrees with the statement in Fig. 1.1 that product development influences 75% of the later total costs (and thus also the possible profits).

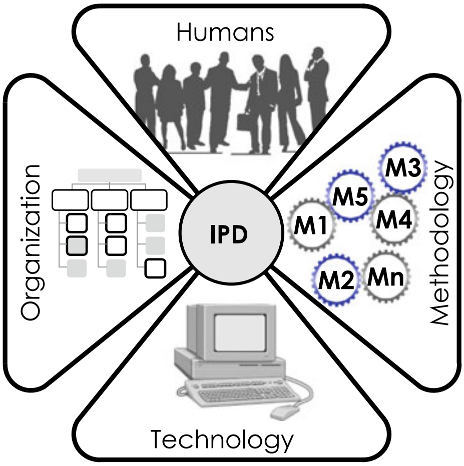


Fig. 1.19 Fundamentals of integrated product development [Meer-1994]

A prerequisite for the successful implementation of IPD is cooperation, not only with customers, partners and suppliers, but also at various levels and areas of the company [Meer-1994, MePa-2005], so that a complete formulation of the product specification can take place that takes all influences into account. For IPD this means that:

- Qualified employees with changed thinking and working behaviour work together in interdisciplinary teams. Thanks to their social competence and communication skills, these employees are geared towards a holistic approach in all activities and cooperation in partnership with all areas involved in the product lifecycle, whereby they don't lose sight of the entire product lifecycle, Fig. 1.20.

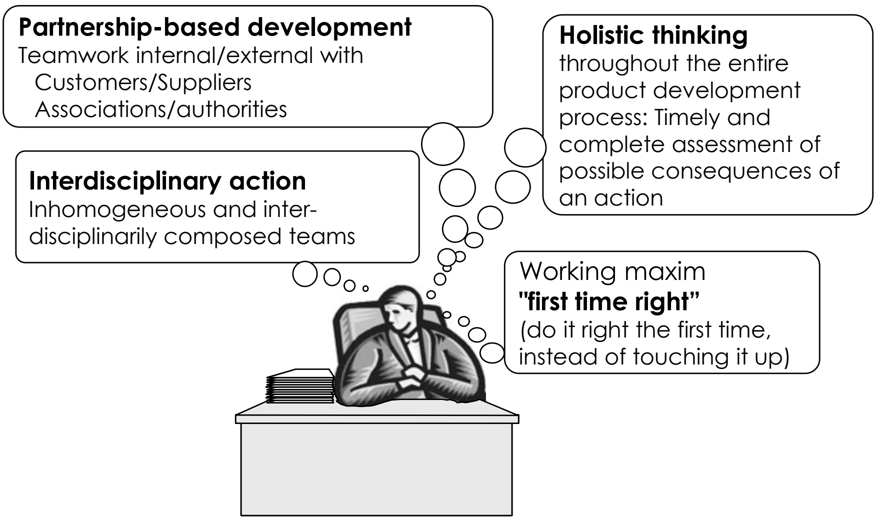


Fig. 1.20 Changes in thinking and working behaviour [Meer-1994]

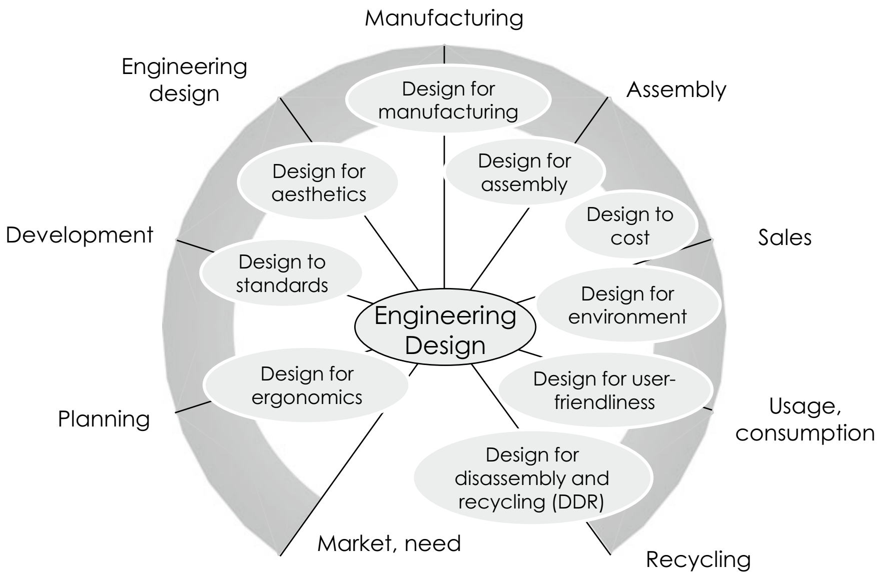


Fig. 1.21 Consideration of influences from the product life cycle in engineering design [Meer-1994]

- Methodical procedures are consistently implemented which, as also described in [EhMe-2017] and [Frei-2001], can cover the complete product life cycle as well as the associated processes, whereby first and foremost the influences from the areas following product development are taken into account over a multitude of “Design for-” dependencies (DfX), Fig. 1.21.
- Flexible organizational forms with flat hierarchies as well as the delegation of decisions and responsibilities to the levels of action are applied, which can be used for the partial parallelization of different activities, whereby this is supported by an appropriate spatial design (implementation of the integrated organization shown in Fig. 1.22 on the right side).
- Integrated information technology tools are applied as an intelligent compilation of task-related computer-aided tools to support all activities in the form of an *Engineering Workbench,* in order to be able to develop products holistically at this integrated workstation, whereby a feature-based product model is located at the centre of the workbench, in which features are the relevant carriers of all model information and with which all desired properties of the resulting product can be modelled, animated and simulated in conjunction, Fig. 1.22.

A decisive factor for the success of IPD is the synthesis of the four components in Fig. 1.22, all of which have the same importance. IPD cannot be successfully implemented if only one of these four components is absent or neglected [Meer-1994].

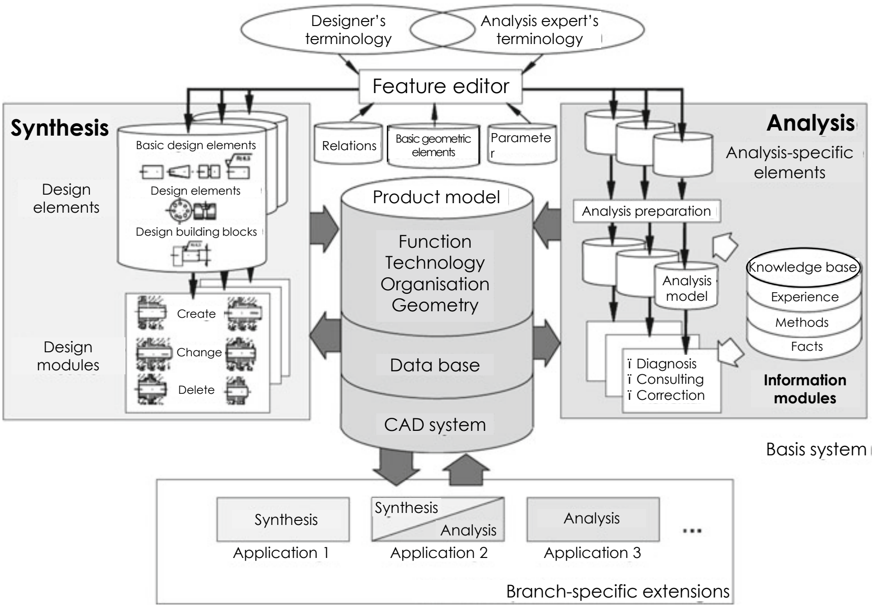


Fig. 1.22 The design system *mfk* as engineering workbench [KoHo-2001]

1.4 Dynamic Product Development According to Ottosson

The development of a wide variety of products (see also Chap. 2) can be carried out using traditional or dynamic approaches. Traditional approaches build on the description of (classical) mechanics according to NEWTON[20] in essential points, while the approach of Dynamic Product Development (DPD) uses findings from quantum theory.

DPD has been researched and developed by OTTOSSON since the mid-1990s [Otto-1996, Otto-2004], in which research has been conducted in the form of Inside Action Research [Bjoe-2004] and Participation Action Research [Otto-2003]. DPD applies dynamic principles that have been concentrated and consolidated into useful rules of thumb. Thus, they are applicable to arbitrary development tasks and objectives. Although it is difficult to conduct comparative studies, the application of dynamic development principles shows that they can reduce the time and cost of development while increasing product benefits and user satisfaction [Bjoe-2004].

[20] Sir Isaac Newton (1643–1727) conducted research in the fields of mathematics and physics. He is regarded as the founder of mechanics (including the laws of motion). With the laws of gravity, he described the phenomenon of gravity. Parallel to Leibnitz he developed the differential and integral calculus and founded acoustics discipline. In optics, he proved the composition of white light by the spectral colours and established the emission theory of light with the corpuscle model. Newton is considered one of the greatest scientists of all time.

DPD pursues the objective of significantly shortening the time to market of a new product, not only through dynamic principles but also through other forms of organization, which arise from the combination of linear or hierarchical structures and self-organization (the so-called *Planetary Organization*[21]).

The need for dynamic procedures is fostered by the fact that today product development takes place in an increasingly dynamic environment characterized by on-going external influences (e.g. changes in customer requirements or the legal environment) and internal influences (e.g. the outage of an employee or the use of new technology) that are difficult or impossible to plan. The frequency of chaotic situations in product development is also increasing due to technological developments, the globalization of markets and the further development of information and communication technologies so that it is becoming increasingly difficult to plan and to carry out product development in interaction with the other areas of a company.

A possible trigger for product development in DPD is, on the one hand, a concrete need that has to be fulfilled at short notice. To satisfy this need both the necessary knowledge and (partly) suitable initial solutions are available in the company so that usually an (easily to be scheduled) adaptation design is performed in which the degree of innovation is low. In the case of a lack (which is called ‘want’ in DPD) that cannot be clearly described, neither the existing knowledge nor the existing solutions within the company are sufficient to offer a short-term solution. Due to its longer time horizon, requirements and application areas can change. Possible solutions are created by a combination of adaptation and new design, which are characterized by incremental innovations. If a long-term, not necessarily concrete wish arises, the company usually has neither the knowledge nor the solutions available. In this case, starting a product development requires a vision of the product and its possible applications, and it can range from a radical to disruptive innovation in which completely different solutions and/or technologies replace the existing ones.

- In traditional procedures, at the time when the order is placed and the development can be started, all identifiable requirements are compiled into a requirements list and prioritized. This is the basis for the planning of the development project. Once this planning has been completed, both the project manager and team members are selected and the processing of the project begins. Both implementation and embodiment of the requirements are decided at the earliest possible stage because it is assumed that early decisions contribute to the stabilization of the development project.
- Instead, DPD categorizes and prioritizes the current requirements at the beginning of the development process and only processes the primary requirements as well as two or three secondary requirements, because it assumes that requirements vary, disappear and/or can be added during the development process. In order to

[21] In a Planetary Organization the manager/project leader (‘sun’) is in the centre, with sub-managers/sub-project leaders (‘planets’) around the sun, in direct contact with each other. Grouped around each planet are single associates or teams (‘moons’), also in direct contact with each other. In addition, experts and senior managers act as ‘comets’ by pollinating and influencing others in the organization (as planned or spontaneously) in a positive way [Otto-1998].

ensure that there is sufficient room for the consideration of such changes during the processing time, final decisions are taken on the requirements at the latest possible points in time. At the beginning of the development process, the project team leader is appointed, who himself is responsible for the appointment of his team members. As soon as the team is ready to work, the project begins.

DPD implies a dynamic, responsible and sustainable approach to the development of high-quality products. The dynamics of the approach results from decentralization, combined with rapid feedback on many ‘small’ decisions and determinations on the way to the development goal, which can’t be regarded to be stable, but can change itself due to changing requirements, changing resources, new technologies for implementation, legal environment, etc. DPD combines knowledge from various disciplines of the product life, i.e. marketing, development, production, sales, use, customer service and return of a new (or modified) product. This leads to a highly parallelized development, with the individual areas being processed in parallel in different proportions and being able to synchronize each other through mutually dependent decisions, Fig. 1.23.

With DPD, short lead times, high user satisfaction and a positive working environment can be achieved.

One of DPD’s main assumptions is that complex processes such as product development are difficult to predict and to simulate. In addition, one should value the development of people more than processes or tools. If process or tools drive development, a project team will be less pro-active, less responsive to changes and less likely to meet user and customer needs. Therefore, it is of little use to plan longer periods than one week precisely and in detail. Instead, a clear vision of the development goal, rough long-term planning, detailed short-term planning, and on-going

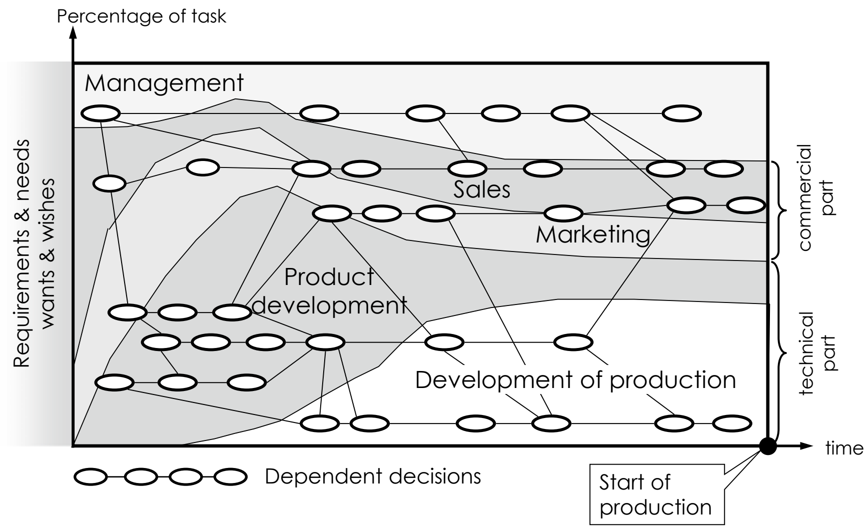


Fig. 1.23 Dynamic product development [Otto-1996]

testing[22] and simulation of the product and its functions (in their respective development states) during development (short feedback loops) are required to achieve the development goal. In putting sketches, working models and prototypes (e.g. user requirements, customer demands on price and quality, life cycle requirements, drawings, flow charts, product concepts) over comprehensive documentation developers always know what is needed to do the work without getting bogged down in minutiae. The documentation must be at a legal supportive level in case that the product is involved in accidences at a later stage. Experience-based rules of thumb that help product developers to continuously and opportunely adapt the necessary activities to current circumstances help in making the respective decisions.

In order to be able to react quickly to changing conditions in product development, the first step during implementation is to focus on essential requirements. If the evaluation of the (partial) solution developed on this basis is successful, further requirements can then be implemented and tested. This means that suitable solutions can be developed more quickly. This also leads to the fact that in DPD, in contrast to 'traditional' procedures, in which all requirements must first be present before development is started, development can already start as soon as the essential requirements are known and the customer either develops his requirements parallel to the solution finding by the contractor or changes his ideas during the development.

In industrial practice, one often finds the opinion that, in the case of a development contract, existing products are first further developed by adaptation[23]. However, this approach usually leads to detailed adjustments and not necessarily innovation. The essential content of an innovative development consists of thinking alternately and iteratively on the abstract level, the concrete level, the level of the complete product and on different levels of detail, and oscillating between these levels. To support innovative development, DPD includes the BAD—PAD—MAD cycle of procedures [Otto-2013].

- BAD (Brain-aided Design) describes such procedures and methods that take place on abstract levels and serve to round off possible solutions at an early stage. To do this, the problem must first be incubated and accepted in the active part of the brain. The main work is the translation of needs, deficiencies and wishes into suitable (possibly abstract) solution concepts.
- PAD (Pencil-aided Design) stands for the fast visualization of solution concepts by simple sketches, in order to accomplish the first examination on feasibility of the solution, and to get a continuously growing repository of solution ideas so that the creativity of the product developer is promoted for finding increasingly concrete solutions.
- MAD (Model-aided Design) stands for the creation of real and virtual models. At the beginning of product development, simple models made of soft materials, which can be easily modified by simple tools like knives, etc., are sufficient

[22]In [Schr-2000] it is stated that successful (and progressive) companies carry out significantly more tests per time unit than 'normal' companies.

[23]Hence the high proportion of adaptation design in industry (figures vary between 55 and 70% of all development assignments).

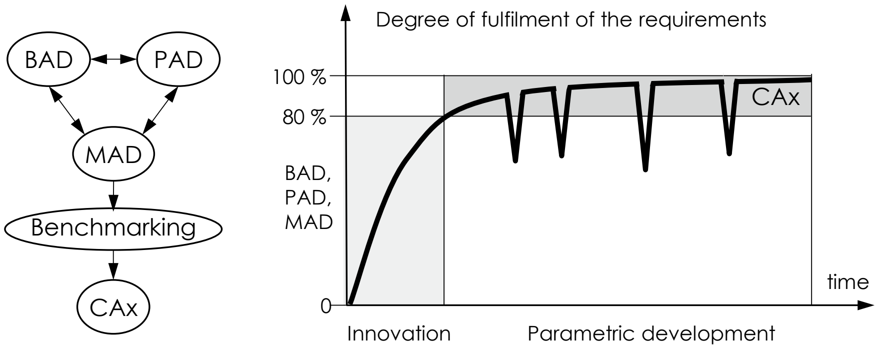


Fig. 1.24 Procedure cycle for innovative development. Left side: basic pattern. Right side: innovative and subsequent parametric development with increasing degree of fulfilment of the requirements [Otto-2013]

to quickly gain a first aesthetic and functional impression of the resulting solution through suitable tests. The more advanced and detailed (and usually more complex) a solution becomes, the more virtual models are used in suitable CAx and VR systems.

BAD, PAD and MAD do not run one after the other but are networked with each other in various ways via definitions and feedback. With this process cycle, solutions can be developed very quickly that already allow 80% fulfilment of the requirements (in analogy to the Pareto principle, see Footnote 4). Thus, the essential product properties are fixed (see also Fig. 1.1), so that the remaining 20% of the CAx system can be developed predominantly parametrically (whereby parameters can affect all properties of a product, i.e. dimensions, topologies, materials, manufacturing processes, etc.), Fig. 1.24.

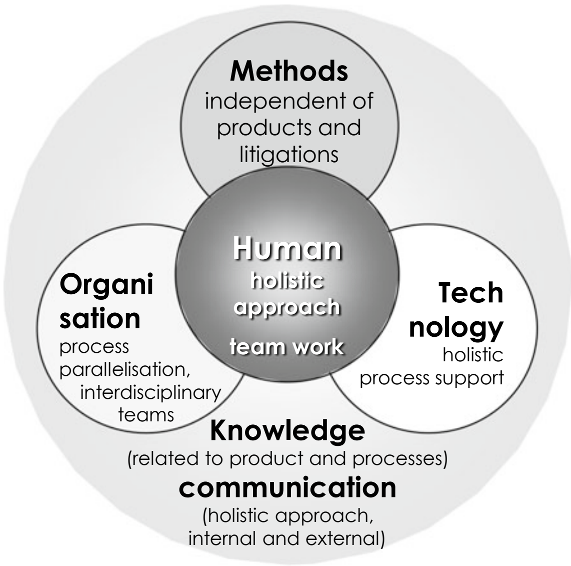
If changes in the requirements or problems occur during the parametric development (symbolized by the hanging points of the fulfilment curve in Fig. 1.31), it is possible to find and test suitable solutions with the procedure cycle of BAD, PAD and MAD and to continue with CAx modelling.

1.5 The Magdeburg Model of IPD

Carsten Burchardt and Sándor Vajna

Integrated Product Development according to Burchardt and Vajna [Burc-2001, VaBu-1998] arose in the middle of the 1990 years. It is, comparable to the IPD according to Meerkamm [Meer-1994], a human-centred development philosophy [Naum-2005] for the development of competitive products or services with high-quality, in reasonable time and with a reasonable price-performance ratio. It encompasses product development processes, consideration of the product life cycle, human

Fig. 1.25 Magdeburg model of Integrated Product Development [Burc-2001]



ways of thinking and working, teamwork, holistic organizational methods, the use of innovative technologies and extended forms of communication and information with minimized and sustainable use of production factors and resources.

The fundamental characteristic of this philosophy is the human at the centre of all activities, who uses suitable organizations and processes, methods and technologies in order to provide a customer with a product that meets his requirements in a reasonable time and at reasonable costs, Fig. 1.25.

This IPD is not limited to a specific product class, but can be used for any products from any industry. Products can be real objects, software or services (or combinations of these as mechatronic products, for example, Chap. 23) that are designed and developed according to market demand and customer needs[24].

IPD is not intended to achieve partial improvements in product development, such as improving product quality through process improvement measures. Rather, the integration of these aspects creates process transparency, which serves to find and to bundle potential within the company in order to generate synergy effects and strengthen core competencies. As a direct result, ineffective and resource-intensive processes can be identified and modified or unsatisfactory processes can be abandoned in favour of better ones. For companies, this results, for example, in changed forms of work organization, new sequences of process methods, new management structures, new procedures and tools to support engineering processes and an improvement in the economic organization of the company.

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[24] All results of the research on the Magdeburg Model of IPD are evaluated for relevance and relevance by industrial projects, the results of which flow continuously into the evolution of the Magdeburg Model and its successor Integrated Design Engineering (IDE).

IPD as development philosophy	*Traditional development methods*
Human centricity	Task centricity
Generalized approach	Specialization on product classes
Parallel and joint work	Mainly sequential work
Mainly interdisciplinary teamwork	Mainly individual work
Tasks usually as projects	Routine and project tasks
Anticipation of activities and decisions in product development	Implementation of activities and decisions on the site and at the time of their need
Functional fulfilment and product design are of equal value and equally important	Function fulfilment in the foreground ("form follows function")
High degree of work integration	High degree of division of labour (Taylorism)
Generalized and specialized knowledge	Rather specialized knowledge

Fig. 1.26 Differences between IPD and traditional development methods

In summary, the Magdeburg model of IPD differs from traditional development methods according to the points listed in Fig. 1.26.

The Magdeburg Model of IPD is an evolution of the models and approaches described in the previous sections, from which it has used and since developed the following elements:

- Parallel consideration and processing of market, product and manufacturing as well as the management of processes and their profitability from IPD according to OLSSON (Sect. 1.2.1) and IPD according to ANDREASEN and HEIN (Sect. 1.2.2),
- The introduction of the TOTE scheme and the use of process cycles and work plans, which can serve as process frameworks and templates, from IPD according to EHRLENSPIEL (Sect. 1.2.3),
- Interaction of people, organization, methods and technology as well as the aspects of Design for Property X (DfX) from IPD according to MEERKAMM (Sect. 1.3) and
- Consideration of the dynamics of development processes and their triggers from DPD of OTTOSSON (Sect. 1.4).

The main enhancements and innovations to the models described above are as follows

- A clear human centricity along the entire product life cycle,
- The equivalent cooperation of the development goals of function fulfilment and good design (product design) as well as
- A network as a dynamic organizational form with highly parallel activities.

These extensions and the other components of the Magdeburg model of IPD are described in the following sections.

1.5.1 Human Centring

In the Magdeburg model of IPD, the human being is at the centre because only he is capable of the following:

- generate and apply knowledge,
- structure problems and tasks,
- create organizational structures,
- find suitable and meaningful solutions for innovative products and services, and to
- apply the latest technologies.

Humans see themselves as part of nature and the environment and are therefore aware of their responsibility for the development of sustainable technologies and products. People are no longer, as in Taylorism, regarded as production factors (equivalent to machines, materials, funds and information), but as the company's most important resources [Gilb-1914, Bull-1996, Ferg-2000].

The integration of the parties involved results from the fact that in IPD employees from different departments (if necessary supplemented by employees of customers, partners and suppliers) with different skills and knowledge profiles communicate and, wherever possible and appropriate, work together in interdisciplinary and predominantly parallel working teams in partnership cooperation. This enables integrated planning and activities for all phases of the product development process and promotes employee cohesion. One consequence of this is a change in the corporate culture, which has a positive effect on motivation, innovative strength and creative potential of the employees.

Further characteristics of human centring are as follows:

- Consideration of human thought and action in the design of organizations and processes,
- Long-term thinking instead of short-term thinking,
- Attention to the skills and characteristics of employees, combined with the targeted development of their specialist, methodological and social skills through appropriate and timely qualification measures,
- Avoidance of unnecessary iteration circles and subsequent improvements by precise and complete task fulfilment (also when changes of the requirements appear),
- Implementation of the work philosophy of lifelong learning and
- Improving communication and information flow, for example, communication rules and automatisms.

Overall, human centring leads to a promotion of independent, goal-oriented work with a high degree of personal responsibility.

1.5.2 Equivalence of Function Fulfilment and Product Design

While in other models (and especially in the more classical Engineering design methods) the (most complete) function fulfilment is the development goal that has the highest priority, to which both product design and all other goals must be subordinated for the economic fulfilment of function (expressed in the sentence 'Form follows Function'), the two development goals function fulfilment and product design are treated as absolutely equivalent in the Magdeburg IPD model. Because of their opposing development processes, they influence each other in a variety of ways:

- In function identification, work starts with an abstract-theoretical entirety or a concept that is broken down into sub-tasks for which partial solutions are developed (in the case of extensive tasks, for example using Simultaneous Engineering or Concurrent Engineering), which are finally combined to form an overall solution as a geometric-material entity.
- In product design, the geometric-material and functional entirety, respectively, the design concept is created at the very beginning, which is initially refined in terms of aesthetics, appearance, ergonomics, etc. Only when this entirety has been determined and the product design is coherent can the sub-tasks and details be processed.

The conflicts arising from the opposing processing are resolved in IPD in good time before the start of production of the product by means of a variety of coordination and sufficient iterations during product development in the sense of a synthesis[25], Fig. 1.27.

1.5.3 Network Structure as Organization Form

Products are the result of processes that take place in suitable organizations. Processes and organizations are of a dynamic nature. Within IPD, humans design products and processes in a systemic way. Rigid organizational forms (e.g. hierarchical or matrix organizations) are less suitable for IPD, because

- requirements as well as initial, environmental, boundary and constraint conditions can change over time as a result of changed customer requirements and external

[25]The term 'synthesis' is not understood here primarily in the sense of design methodology as the transformation of requirements into solution characteristics, but in the sense of HEGEL'S dialectic with the argumentation triangle thesis—antithesis—synthesis (the triangle itself was introduced into dialectic by FICHTE). The thesis is an assertion to which an antithesis is made by negation, contradiction or opposition. Thesis and antithesis drive the cognitive process to a new level. This new level or the new formulation on this level results in the synthesis, in which the positions of thesis and antithesis are contained to a large extent equally, albeit in the changed form (according to [EWDS-1998]).

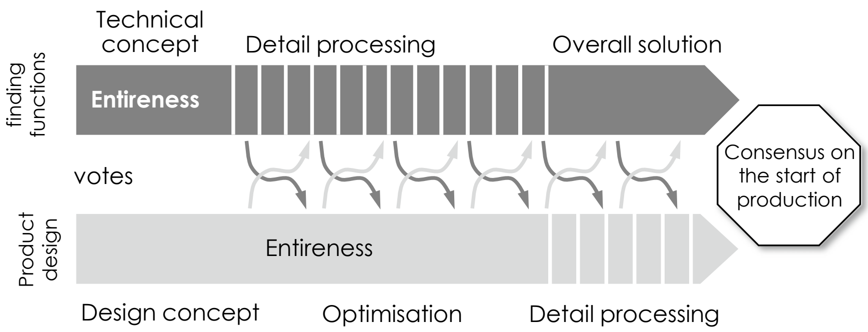

Fig. 1.27 Different procedures between function finding and product design

and internal disruptions (loss of resources, changes in the legal situation, etc.), leading to the so-called 'running targets' and

- the parallel processing of tasks and the joint processing of (not yet) stable or not yet converged (intermediate) results usually are not possible.

Instead, the organizational form must allow the integration of areas of product development with upstream and downstream areas (such as marketing, production control, costing and shipping) so that all aspects of the product lifecycle are taken into account. The work is to be carried out in inter- and multidisciplinary teams with dynamic task distribution and flattened hierarchy.

In IPD, a dynamic network serves to provide organizational support for this typical dynamic environment. The network is designed as a mesh net with nodes (cells) and edges (connections). Each cell is connected to all others in a latent form. These connections are dynamically activated and deactivated on demand (by the participants or by defined events).

The mesh network can support any combination, communication and cooperation forms between the individual cells and realize them in real-time. This enables any desired constellation of cells (serial, parallel, feedback, mixed forms) to be created, with which team-capable working structures can be set up and, if necessary, adapted. Individual process sequences can thus be implemented flexibly and easily. Subsequent process modifications, such as changes to forms of cooperation or changes to the process partners, can be carried out at any time during processing. All this enables close and interdisciplinary cooperation between all participants, a high degree of transparency of processes and decision-making paths and unhindered information and communication flows, Fig. 1.28.

In the IPD network:

- an individual employee or an employee group represents a cell. Each cell performs its tasks in a given autonomous workspace with appropriate resources (for example, methods provided by computer systems), organizing and controlling itself within the workspace. If necessary, the cell can be decomposed into a sub-network, for example, if the task becomes so complex or extensive that one cell alone can no longer perform this task and has to call in other cells for support.

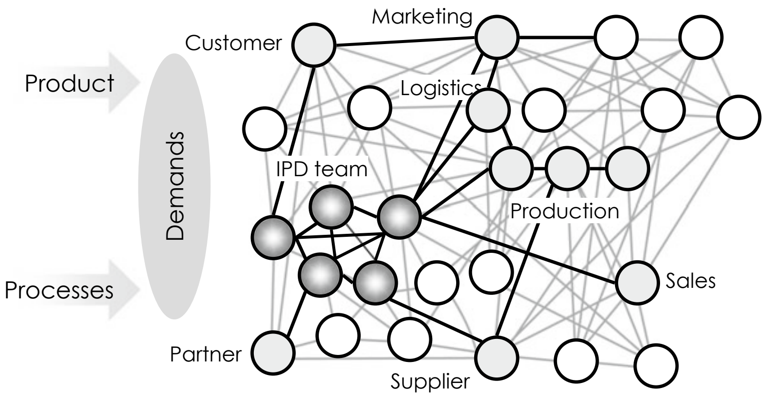

Fig. 1.28 Dynamic network of IPD. Grey circles, black lines: active cells and their connections. White circles, grey lines: further cells and possible connections

- the actions of the participants are based on the voluntary cooperation of the network partners on the basis of mutual trust, common concerns and objectives as well as the specification of management requirements.
- flat and project-oriented organizational forms emerge that enable cross-departmental, parallel work with high flexibility and fast response times.
- the holistic view on the product development process is supported as well as increased feedback of work results through feedback loops.

The IPD network does not have to be limited to your own company but can involve customers, partners and suppliers and adapt itself automatically to any form of order processing. It is obvious that in such a network the activities and processes are chaotic [Naum-2005].

1.5.4 Procedures, Methods and Technologies

In order to be able to provide procedures, methods and technologies in the context of the respective task during product development [Frei-2001], both systematization and standardization of the product development process under consideration of all aspects of the product life cycle as well as a description and formalization of procedures, methods and tools are necessary for advance.

In addition to the well-known methods for function identification, structuring and modelling, creativity and learning techniques, methods for solution identification, modelling, optimization, simulation and evaluation for design, function, handling and appearance of the product are used.

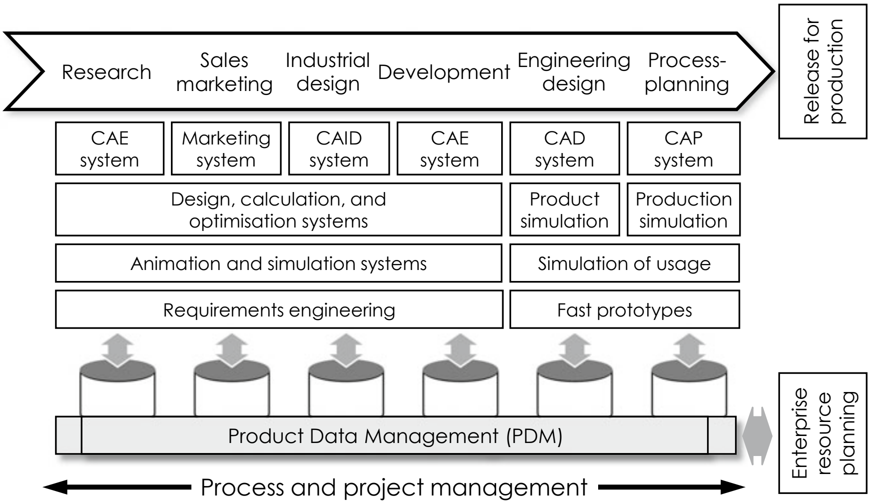

Fig. 1.29 Integration of technologies for the complete computer support of IPD [VWZH-2018]

The underlying IPD method toolkit contains [Frei-2001]:

- Links between tasks and appropriate processing methods,
- A more detailed description of each method and
- Selection criteria and instructions for the use of methods.
- Further information on how to learn the method and where further information is available.

Knowledge structures are developed and managed for storage, presentation, evaluation and selection of procedures, methods and aids. Integrated prediction methods enable a targeted selection of methods, procedures and technologies as well as the configuration of the IPD network from an economic point of view.

Similar to the *Engineering Workbench* in the IPD according to MEERKAMM (Sect. 1.3), the use of technology aims at the holistic and complete computer support of IPD and the realization of information and communication flows, Fig. 1.29.

This computer support is structured as a kit of building blocks in which standard CAx systems[26] are coupled together as building blocks via existing interfaces. Although holistic and comprehensive CAx product models are under development (for example under the term of *digital twin* [VWZH-2018]), data integration will be via PDM systems [Schl-2008] as long as these aren't available. The integration of the activities takes place with dynamic navigation systems according to [Frei-2001].

[26] 'CA' stands for *computer-aided* and 'x' is a placeholder for acronyms that specify certain fields of application (e.g. 'D' for *design*). *CAx* as a stand-alone term in the meaning *computer-aided Everything* describes the systematic use of computer-aided methods, procedures and tools [VWZH-2018].

1.6 C-K Design Theory

Pascal Le Masson, Armand Hatchuel and Benoit Weil

The C-K Design Theory (C for Concept, K for Knowledge)[27] was introduced by A. Hatchuel and B. Weil in 1996 [HaWe-2003, HaWe-2009] and is today the subject of numerous articles in the scientific literature. Recent research covers its implications, practical applications and its new developments. In this chapter the fundamental principles and the most recent formulations and have the C-K design theory are provided without necessarily giving the details of the formalisms applied in this theory.

1.6.1 Origins and Intuitive Motivation

The expectations of the C-K design theory are fivefold:

- From the point of view of contemporary innovation challenges: A theory that is able to address design issues that can't be addressed with traditional problem-solving and optimization methods, such as the design of new usages for emerging technologies, the design of products/services on very open briefs (e.g. smart mobility), the design under very strong constraints (e.g. 'zero energy', 'frugal innovation', etc.).
- From the point of view of designing professions: Providing a 'unified design theory', similarly useful for all kind of designing professions (e.g. industrial design, engineering design, architectural design, …)
- From the point of view of formalisms: A formal model that accounts for 'radical creativity', i.e. with strong generativity[28].
- From the point of view of methods: A theory that creates and supports methods for the process of so-called 'inventing' or 'discovering' (and actually designing) new functional requirements and the extension of design parameters.
- From the cognitive point of view: A theory and related methods for overcoming fixations[29].

To give an intuitive motivation of the C-K design theory, one can keep in mind that the theory focuses on the issue of how characterizing a design task and its initial point, usually called 'brief' or 'program' or 'specifications': Contrary to 'mapping based'

[27]For an introduction to the C-K design theory see [AHAB-2011], for a comprehensive synthesis and corresponding examples see [MaWH-2017].

[28]Generativity is the capacity of design theory to produce 'novel' solutions from a given knowledge background (see academic references in [MaWH-2017]).

[29]Fixation (in design and creativity cognition) describe the fact that, in a design task, designers tend to explore only a limited set of alternatives. As a prepossession, they are cognitively hindered to explore the whole set of imaginable alternatives (see academic references in [MaWH-2017])

design theories (such as programming, problem-solving, optimizing, all derived from Simonian theory of design[30]), that tend to clarify the initial task to design *inside* a given mapping, the C-K design theory seeks to preserve the ambiguity, equivocality, incompleteness or fuzziness of the initial brief, precisely because these features will enable to regenerate the mapping itself. The C-K design theory hence models the design of a *desirable but partially unknown 'object'*, which is undecidable while applying initially available knowledge. This intuitive motivation raises critical formal issues: How to rigorously reason on a partially unknown object? How to account for the evolutions of the knowledge that needs to be generated and/or has to be extended through the design process? These issues are addressed in the C-K design theory, as will be shown below.

1.6.2 Main Definitions and Properties

The underlying principle of the C-K design theory is to model design as an interaction between two spaces, the space of concepts (C) and the space of knowledge (K), with the following definitions and implications (see also Table 1.1):

- **Definition of K space**: The K space is composed of propositions characterized by the fact that they *all have a logical status* (true or false).
- **Definition of C space**: The propositions of the C space are characterized by the fact that they *are interpretable but undecidable with respect to the actual existing propositions in the K space.* Consequently, given the actually available knowledge, it is not possible to prove whether they are true or false. To solve this issue, the expansion of knowledge is needed (see Sect. 1.6.3). Note that this is relative to K (K-relative). With another reference to K, a proposition might become true (or false).
- **Structure of C**: Concepts are of the form 'C_n = *there exists a (non-empty) class of objects X for which a group of properties* $p_1, p_2, \ldots p_n$ *is true in K*'.
- **Structure of K**: The structure of K is a free parameter of the theory. This corresponds to the fact that design can use any type of knowledge, but also all types of logic, true or false; K can be modelled using simple graph structures, rigid taxonomies, flexible object structures or specific topologies or Hilbert spaces if there are stochastic propositions in K. The only constraint, from the point of view of the C-K design theory, is that propositions with a logical status (decidable) might be distinguishable from those that are not decidable.

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[30]The Simonian Theory of Design, formulated by H. A. SIMON in the 1960ies, is based on search algorithms in complex combinatorial problem spaces (c.f. e.g. [Simo-1997]).

1.6.3 Design Process: C-K Partitions and Operators

A design starts with a concept C_0, a proposition that is undecidable with the initial K space. The theory formalizes how this undecidable proposition becomes a decidable proposition. This is realized by two processes, *expansions* in K and *partitions* in C:

Expansions in K: It is possible to expand the K space (by learning, experimentation, remodelling, etc.). This expansion can continue until a decidable definition for the initial concept is obtained in K* (expanded K).

Partitions in C: It is possible to add attributes[31] (known in K space) to the concept to promote its decidability. This operation is known as *partition.* In the C-K design theory, the partitions of a concept C_0 are the classes obtained by adding properties (from K space) to the concept C_0. Formally, adding p_{n+1} (taken from K) to C_n gets: C_{n+1} = *there exists a (non-empty) class of objects X for which a group of properties* $p_1, p_2, \ldots p_n, p_{n+1}$ *is true in K.*

Implication 1: These expansions continue until they come up against a proposition derived from C_0 that becomes *decidable* in K* (i.e. expanded K, as it is when the decidability of the concept is studied, i.e. when the proof of existence is obtained). The concept then becomes a true proposition in K*. In C-K design theory, this is called a *conjunction.*

Implication 2: A partition presents a rather specific problem: What is the status of the new C_{n+1}? This status must be 'tested', i.e. its decidability with respect to the K space must be studied. This corresponds to making prototypes, mock-ups and experimentation plans. In turn, these operations can lead to expansions of the K space that are not necessarily related to the concept being tested (surprise, discovery, serendipity[32], etc.). The test has two possible results for C_{n+1}: Either C_{n+1} turns out to be undecidable with respect to K and the proposition, therefore, becomes a K space proposition, and the design ends in success; or C_{n+1} remains undecidable in terms of K and the proposition is in C space.

All operations described in the C-K design theory are obtained via four elementary operators representing the internal changes within the spaces (K → K and C → C) and the action of one space on the other (K → C and C → K):

1. The operator K in K covers the classical operations of inference, deduction, decision, optimization, etc.
2. The operator K to C, the disjunction operator, consists of creating a new undecidable proposition in C on the basis of decidable propositions in K.
3. The operator C to K, the conjunction operator, consists of creating decidable propositions in K on the basis of undecidable propositions in C.
4. The operator C in C generates undecidable propositions on the basis of other undecidable propositions, using only C propositions.

[31] Not to be confused with the 'attribute' term applied in Integrated Design Engineering (see Chap. 3 for its definition and description)

[32] The ability to make discoveries by chance and ingenuity that were not searched for.

Table 1.1 Glossary of main definitions and first results of the C-K design theory

1	A set of propositions having a logical status is known as **K space**
2	The addition of a proposition in K is known as an **expansion of K space** By definition, this proposition has a logical status
3	Given a K space, a proposition of the form {x, P(x)}, interpretable in the base K (P is in K) and undecidable in base K (P is in K), is known as a **concept** (the proposition {x, P(x)} is neither true nor false in K)
4	The addition of some supplementary property to the concept (which becomes {x, P(x), p_k(x)}) is known as a **partition** • Remark: C is K-relative • In a set-wise approach, a concept is a set from which no element can be extracted • Theorem: A concept space has a tree structure
5	Given a concept and its associated base K, an **operator** is an operation (using K or C) consisting of transforming a concept (partition) or of transforming the K space (expansion) Primary operators: K → K, C → C, K → C, C → K
6	K → C is the **disjunction** operator: Passing from decidable propositions to an undecidable proposition (using the known to work in the unknown)
7	C → K is the **conjunction** operator: Passing from an undecidable proposition to a decidable proposition (using the unknown to expand the known)
8	Given a space K and C ({x, P_1, P_2 … P_n(x)} on this space K, an **expansive partition** (conversely **restrictive**) is a partition of C making use of property P_{n+1} which, in K, is not considered to be a known property associated with X (nor with any of the P_i, i <=n) (conversely a property P_{n+1} such that P_{n+1} is associated with X in K or there exists an i, i <=n such that P_i and P_{n+1} are associated in K)

Table 1.1 provides both a synopsis and a glossary of main definitions and first results of the C-K design theory.

1.6.4 Main Implications

One of the immediate results from the C-K design theory is that, for a given C_0, the C space necessarily has a **tree structure**, as the tree structure is a consequence of the order relation created by successive partitions.

Second, the C-K design theory allows the distinction between **two types** of partitions: Restrictive partitions and expansive partitions. A concept is interpretable hence it relates to some knowledge in K. A restrictive partition is a partition that uses attributes coming from the knowledge associated with the concept or compatible with it. By contrast, an expansive partition is a partition that makes use of attributes that are not compatible with this knowledge. Expansive partitions

- lead to revision of the definition of objects,
- steer the exploration towards new knowledge that is no longer deduced from the available knowledge.

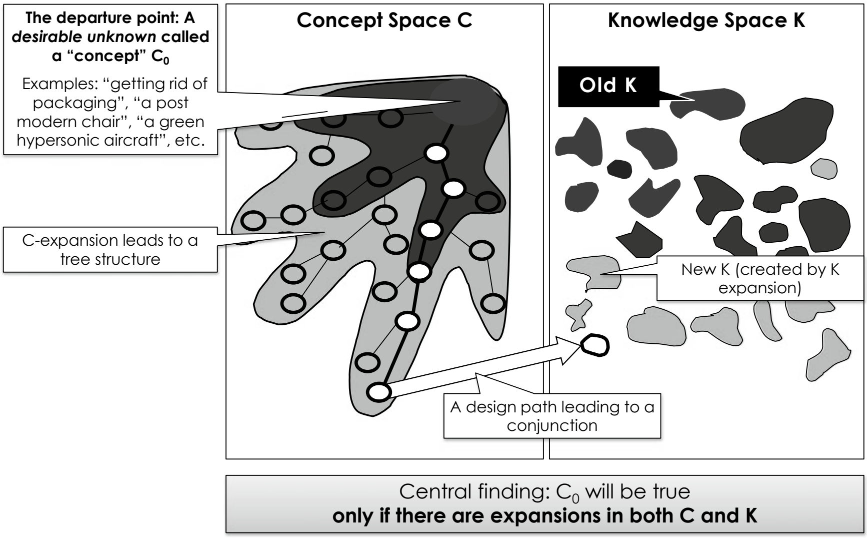

Fig. 1.30 Diagram summarizing the C-K design theory [MaWH-2017, p. 140]

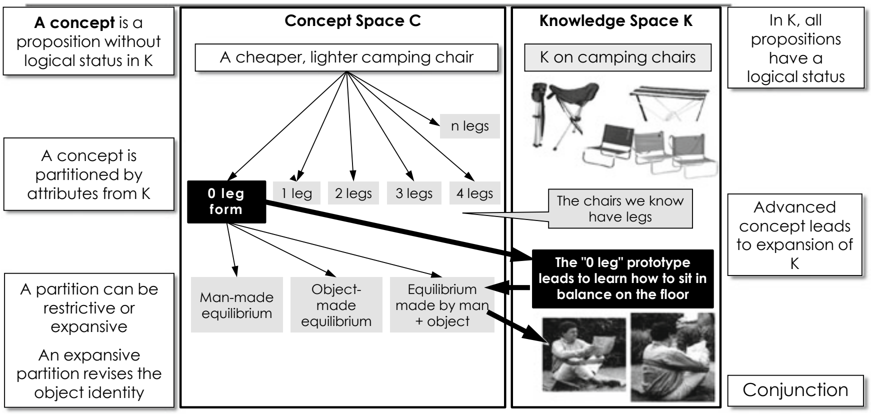

Fig. 1.31 A simple case to illustrate the main notions of the C-K design theory [MaWH-2017, p. 137]

The generative power of the C-K design theory relies on the combination of these two effects of expansive partitions, Fig. 1.30.

In the following, there is a very simple example to illustrate the different C-K notions, Fig. 1.31 (for further examples cf. [MaWH-2017]).

The task was to develop an innovative camping chair, which is cheaper and lighter than usual camping chairs. The initial knowledge covered knowledge of camping chairs. The initial concept C_0 was a cheaper and lighter camping chair. This proposition was interpretable with initial knowledge on camping chairs, their weight and their costs. At this time, the proposition is undecidable as it is impossible to show such a chair—and it is impossible to prove that such a chair is impossible.

To explore this partially unknown set C_0, C_0 is partitioned by using a proposition from K: 'Chairs we know have legs'. This proposition enables one to create the concepts 'a cheaper and lighter camping chair with *one* leg', 'a cheaper and lighter camping chair with *two* legs', etc. These concepts are subsets of the initial concept C_0. Note that the union of the subsets might not cover the whole C_0. Hence, to achieve a rigorous partition of C_0, one should add the concept 'a camping chair *without* legs'. This is formally a concept (neither true nor false) and this is also an expansive partition since the chair in this subset will have a property ('without leg') that is not a usual chair property.

This new concept 'a cheaper and lighter camping chair without legs' can be partitioned with propositions coming from K. And here the concept suggests looking in K for knowledge on chairs without legs. For instance, one can run experiments on a chair of which the legs were cut off. We learn then about 'sitting equilibrium'. This is a knowledge expansion, which is then used for partitioning 'a cheaper and lighter camping chair without legs'. Step by step the concept C_0 is partitioned and can give birth for instance to quite strange chairs. The sequence of partitions provides refinements to such an extent that the proposition in C becomes true: This is a conjunction. The true proposition is then in K.

1.6.5 Further Implications

While the presentation of the C-K design theory here is still succinct, the reader can be assured that using the elements given above, the theory meets the initial expectations expressed in Sect. 1.6.1:

- The theory is well adapted to address the types of innovation listed in Sect. 1.6.1.
- 'Professional expectations': The theory enables the relationship between the K-oriented professions (engineering) and the C-oriented professions (design) to be considered. It also reveals that there is K in design and C in engineering.
- Formal expectations: Taking note of the creative act: See the notion of expansive partition, heredity, conceived ontology, invariant ontology, etc.
- Methodological expectations: The theory allows the revision of object definitions, and hence the extension of the list of functional requirements and the design parameters.
- Cognitive expectations: The C-K design theory enables the effects of fixation to be overcome: A fixation will arise from the definition of certain objects; indeed, the theory allows these definitions to figure in K space, then to be rigorously and systematically re-discussed via expansive partitions in C.

Several techniques, methods and processes have been developed based on the C-K design theory to support innovative design processes and organizations.

Intense research work has led to deepen and reveal the theoretical foundations of the C-K design theory (C-K design theory and forcing, generative knowledge structures, C-K design theory and design logic, etc.).

1.7 Autogenetic Design Theory

Tibor Bercsey and Sándor Vajna

The Autogenetic Design Theory (ADT)[33] applies analogies between biological evolution and product development [BeVa-1994] by transferring the methods of biological evolution (and their advantageous characteristics) to the field of product development. Such characteristics are for example the ability to react appropriately to changing environments (requirements and boundary conditions) so that new individuals are in general better adapted to the actual environment as their ancestors. The ADT is not another variety of Bionics (where *results* of an evolution, e.g. the structure of trees, are transferred to technical artefacts). Rather, the ADT transfers *procedures* from biological evolution to accomplish both a description and broad support of product development with its processes, requirements, boundary conditions and objects (including their properties).

The main thesis of the ADT is that the procedures, methods and processes of developing and adapting products can be described and designed as analogies to the procedures, methods and processes of biological evolution to create or to adapt individuals. Main characteristics of biological evolution (with the underlying principle of trial and error) are continuous development and permanent adaptation of individuals (living organizations) to dynamically changing targets, which in general have to be accomplished in each case at the lowest level of energy content and with the minimal use of resources, i.e. the evolution process runs optimized in terms of energy consumption and resource employment. The targets can change over time because of (unpredictable) changing requirements, resources, conditions, boundaries and constraints, and they can contradict each other at any time. The evolution leads to an increase in complexity of the individuals, which can happen horizontally (along time), vertically (by application of development processes and aids), or by combinations of these. The evolution biologist CSÁNYI denoted this self-generating complexity increase under the term *Autogenesis* [Csan-1988], from which the ADT got its name.

The result of a biological evolution of a certain species is always a set of unique solutions having the same value but not being of similar type. Consequentially, the

[33] During the on-going research, the scope of the ADT has increasingly expanded from supporting the design process to supporting the whole product development process, i.e. is in change from design theory to development theory.

result of the ADT is for the very most part[34] a set of equivalent, but not similar unique solutions that fulfil the *actual state* of requirements and conditions best.

Furthermore, biological evolution doesn't have prejudices. This means that new individuals (described by their chromosomes) will not be discarded because they are different. Each individual has to prove itself in its natural environment. If it turns out that an individual with a new chromosome set is superior to already existing individuals, then this individual gets a better chance for reproducing. By transferring this behaviour of impartiality to product development, new concepts would not be discarded because they were totally different than former concepts but only if their properties were proven not to be superior.

This suggests that both evolution and product development can be described as a continuous but not straightforward improvement process or as a kind of multi-criteria and continuous *optimization* [BeVa-1994, Wegn-1999].

One may argue that a weakness of the ADT is the processing (creation, evaluation) of a high number of individuals for reaching certain product progress due to the evolutionary-based approach. Compared to other methods, the number of solutions, which need to be created and evaluated, is in fact much higher. But one has to keep in mind that, by exploring this high number of possible solutions (individuals) within a solution space, the chance of finding the really best set of solutions to a given set of requirements, conditions, boundaries and constraints is much higher than with traditional approaches that continuously delimit the solution space and thus result only in a single 'next best' solution [Clem-2005].

The analysis of product development from an evolutionary perspective leads to the following insights [VCJB-2005]:

- In every phase of the product development process, various alternatives are developed and compared by searching, evaluating, selecting and combining. These alternatives are in competition with each other because only the best are selected for further processing.
- The processes of searching, evaluating, selecting and combining are also typical approaches to biological evolution.
- Regardless of the phase of product development or of the complexity level of the emerging product, always a similar pattern of activities is used to modify existing or to generate new solutions, which is comparable with the TOTE-Scheme (c.f. Sect. 1.2.3.2). Self-similarity can be found at all levels of complexity of product development as well as in all stages of the emerging product [Wegn-1999].
- According to chaos theory, small changes or disruptions in a system can cause unpredictable system behaviour [BrPe-1990]. The fact that the result of the development of a product usually can't be predicted definitely because of the influence of the creativity of the product developer leads to the assumption that the product development process also contains elements of a chaotic system or at least shows a chaotic behaviour in some aspects.

[34] Theoretically, it is possible that among the solution set there is one solution that dominates all other.

In this chapter, first, the ADT procedure model is described. Secondly, the solution space is structured. Thirdly, the underlying product model holds the description of how product information is structured and used.

1.7.1 The ADT Procedure Model

There are numerous ideas and concepts aiming on describing the complex and often chaotic process of developing caused by the complexity of most products, the focus within the development process is mostly not on the complete product, but rather on a specific part of the product. This means that each development step is focused on improving or modifying only one specific product property or a specific set of properties (described by so-called design spaces) by varying certain product parameters. These steps should be followed by an intermediate step to ensure product consistency across all design spaces.

The ADT procedure model aims on providing a holistic development procedure model that is also able to describe the processes of partial improvements/modifications, which normally do not follow a predefined pattern. The ADT procedure model describes the development process on two levels.

Level one provides an overall look at the ADT-based product development. It starts with the definition and description of the target function[35] and the solution space (see the next chapter) based on requirements, starting conditions, boundary conditions, conditions of the environment of the solution space and (internal and external) constraints. Within the solution space, possible solution patterns are searched, combined and optimized in random order. To evaluate the actual state of development, the particular fitness of the emerging solution[36] is determined. Because requirements, processes and both internal and external influence factors are all dynamic due to unforeseeable changes, it is clear that it is only possible to describe (rather small) process patterns, which can be combined randomly, instead of specifying a sequence of steps or any predefined 'way' the designer has to follow.

To nevertheless support the process of partial improvements or modifications (and to allow the designer to address only a limited set of properties) without losing both consistency and the overall picture, different partial models can be created (see Sect. 1.7.3). These partial models act like filters that ensure that only a specific set of product properties is considered. Thus, the development process becomes a set of activities, each containing a product improvement or modification under a specific view.

[35]The target function represents the synthesis of the optimization goals derived from the requirements, which need to be fulfilled under certain conditions and in certain environments, even if these requirements contradict or exclude each other.

[36]The particular fitness is realized by a synthesis of the actual levels of the respective fulfilments of the requirement. These are compared to the target function. Deviations from the target function can result in new optimization directions.

Level two describes the activities of improving or modifying a set of properties that are determined by product parameters. The ADT uses the steps *creation and variation*, *assessment,* as well as *update and adaptation* to modify and to improve a product.

In analogy to biological evolution, the creation and variation step consists of the sub-steps selection, recombination, duplication (or replication), gene transfer and mutation.

- During selection, the parent solutions for the next generation were ascertained. In most cases, these will be the most advanced[37] parents. But also less developed have a minor chance of being selected. Especially in the early product development process selecting less developed solutions can help to explore the solution space better.
- Recombination combines the product parameters of two existing solutions to create (in most cases) two more evolved solutions. In biological evolution, the product parameters, which are coded in the respective gene string, are selected randomly. In the ADT, the designer can influence the process of recombination in order to speed up the genesis of the solutions (e.g. by indicating where the two gene strings are to be cut and to be recombined crosswise).
- Duplication (or replication) creates a clone of an existing solution. Creating clones is recommended if solutions with superior properties exist, which should be inherited to the next generation, thus avoiding that the quality of a solution gets lost, e.g. during recombination with a less developed solution.
- Gene transfer is the propagation of gene information. Vertical gene transfer is the propagation of genes within the same species (inheritance), horizontal gene transfer takes place outside sexual reproduction and across borders of species (e.g. the inward transfer of dissimilar genes into a species by genetic engineering).
- Mutation is used to randomly change a solution created by recombination. Just like in biological evolution, mutation is necessary to ensure dynamics in the development process. Mutation offers the chance to create a completely new kind of solution. But it has to be mentioned that the chance for such an effect is rather small.

The creation step is followed by the assessment step. In this step, each new solution is compared and evaluated to determine the fulfilment of the optimization goals described in the target function. Based on this information the actual fitness is calculated. The method to determine the goal criteria depends on the goal criteria themselves. Common methods are, e.g. analytic methods, Finite Element Methods (FEM), Computational Fluid Dynamics (CFD) and ergonomic studies. The calculation of a fitness value for each solution is necessary to compare the different solutions. The challenge here is to adequately represent all goal criteria in just a single value. To resolve this problem, different methods such as weighted goal functions or Pareto based approaches can be applied.

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[37] 'Most advanced' doesn't mean the absolute value, but always a relation to the actual state of fulfilment of the target function (i.e. the actual fitness of the regarded parent).

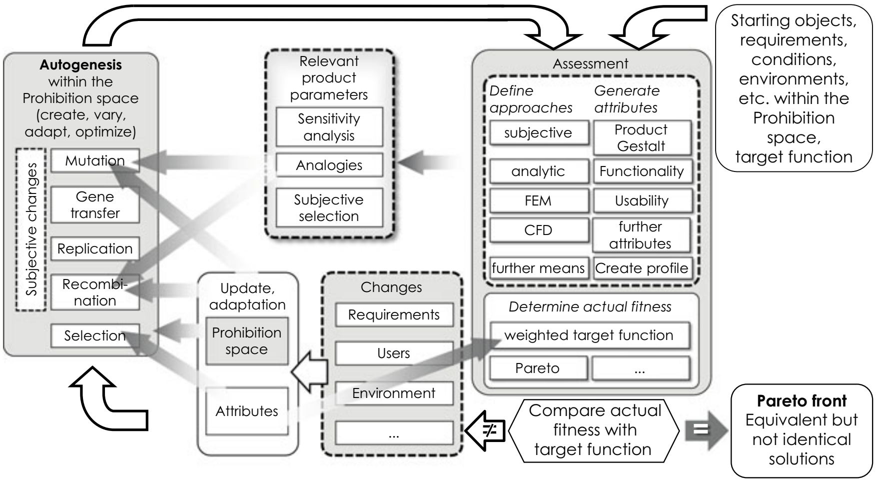


Fig. 1.32 ADT procedure model (boxes with dotted outline: possible direct activities and interventions of the product developer)

The last step is update and adaptation. Update and adaptation of both solution space and target criteria are necessary to take dynamic requirements into account. Often requirements change during the development process. Such a change influences the solution space (with the result that a specific solution is not allowed any further) as well as the target criteria (with the result that a specific target criterion gets less important or that another criterion gets a bigger influence on the fitness).

Figure 1.32 presents the actual state of the procedure model.

The result of an Autogenesis is a set of equivalent, but not identical solutions, of which those holding the best fitness value form a so-called *Pareto front*. Finally, the product developer needs to select the final solution by himself, Fig. 1.33.

1.7.2 The ADT Prohibition Space

In more traditional design approaches, the term 'solution space' is usually understood as an aggregation of all feasible solution elements, which can be used within development when creating a new solution. This space usually is spanned by the requirements in the broadest sense and is limited by starting and boundary conditions. Its inner structure is controlled by constraints, and it may include already existing (partial) solutions as starting points. A product developer may use all such elements for the generation of a solution or several solutions. When the generation is progressing, i.e. solutions emerge by fixing more and more of its parameters, the solution space is therefore continuously reduced until (in the optimal case) only one solution remains within, which becomes the final solution.

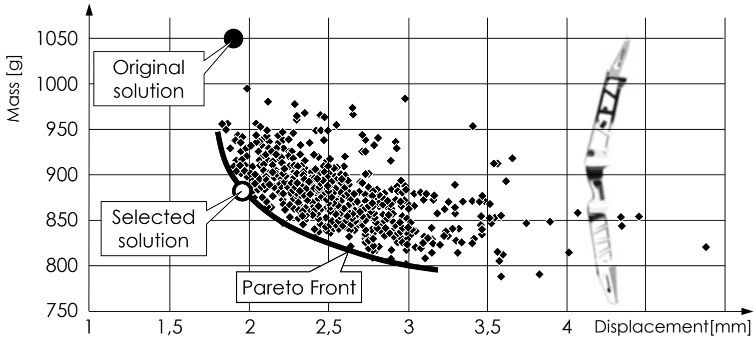


Fig. 1.33 Pareto front of the optimization of the middle part of a sports bow (right side of the figure), which should have a significantly lower weight with preferably the same stiffness as the original solution. However, the stiffness is influenced by volume and distribution of the material, so that these requirements contradicted each other. The stiffness was represented by the size of the displacement of the middle of the component under load. Results of the Autogenesis were changes of geometry and material, which led to a weight reduction of 17% with a stiffness deterioration of only 3%, which was below the given limit of 4% [EHCJ-2005]

Some solution procedures, e.g. TRIZ [Alts-2003] and Gene Engineering [ChFe-2003], use a solution space with a particularly structured dataset. This dataset contains the solution elements for emerging solutions. It is common to all such solution spaces that the product developer is offered only a limited amount of possible solution elements. However, the more limited the quantity and possible configurations and combinations are, the lower is the achievable solution diversity and quality. Parallel to the continuous reduction of the solution space, chances for disruptive solutions are decreasing as well.

Though, in order to improve both solution diversity and quality, it is necessary to not artificially limit the plurality of solution possibilities, but rather to include all permissible elements in the solution space. As the diversity of existing solution elements (materials, manufacturing methods, operating principles, etc.) is immense, a complete solution space description at a reasonable cost and time is in most cases impossible[38]. Since the optimal configuration and combination of solutions elements are not available under these circumstances, the maximal possible solution quality can't be achieved.

In order not to limit the product developer and to permit the maximal possible number of allowable solution elements, both concept and structure of the ADT solution space differ from known solution spaces.

- The only limits of the ADT solution space are the *laws of natural science* in order to enable the discovery of any kind of solution from any discipline within these laws. These limits don't change during an Autogenesis in order to assure this discovery.

[38]Potential exceptions are tasks with very specific requirements, which leave only a very small range for possible solutions.

- Demands and requirements, starting and boundary conditions, constraints, available resources (e.g. qualifications, manpower, time, costs, tools, technologies, etc.), different development and application environments, etc. are *inverted into respective bans*[39]. If one of these holds a certain probability, the respective ban holds the complement to this probability. This approach prevents the creation of invalid solutions without hindering the discovery of any kind of permitted solution.
- All elements usually have dynamic behaviour and may change at any time. The resulting bans have analogous behaviour.
- Similar, adjacent, and/or interlinked bans of any kind are grouped into prohibited areas, the so-called *taboo zones*. On the one hand, taboo zones reduce the available solution space, but on the other hand ensure that only allowed solutions (from any discipline within the laws of natural science) can be discovered. Depending on their characteristics, possible solution features and solution elements can be as well parts of a taboo zone.

This inverted solution space is referred to in the following as the ADT *Prohibition Space*.

The advantage of the Prohibition Space is evident in the early phases of the development process. Due to the lack of knowledge about the relationships between requirements and solution elements during these phases, it isn't often possible to determine the forbidden criteria, based on the forbidden requirements. At the beginning of the product development process, the Prohibition Space, which also includes the original solution, usually contains too few taboo zones. At this time, the product developer is able to for example use product characteristics that should actually be forbidden. If, for example, impermissible solution elements are used, it will be noticed upon assessment that the resulting solution possesses impermissible product characteristics. This newly obtained information can be used to adapt the taboo zones within the Prohibition Space.

A traditional solution space would in the same case be incomplete as well (due to the lack of knowledge about the coherences). Here, however, 'incomplete' means that certain permissible elements are missing, thereby restricting the product developer's solution possibilities. Since a traditional solution space consists by definition of only permissible solution elements, only solutions with the available permissible characteristics and elements will be generated, which results in the creation of the 'next best' solution, not the best possible (or even disruptive) solution, as the provided (limited) solution elements can't enable all possible solutions.

Existence, size and layout of taboo zones can change dynamically if, during Autogenesis, an external event occurs (for example a requirement modification, a change of a condition, etc. by the client or explicitly by the product developer), or internal results create other outcomes than expected. This may lead to changed requirements (which lead to other possibilities for evolution) or even to the omission of existing ones. These result in changes of the respective bans and thus also to

[39]As an example: If a requirement prescribes a non-magnetic material, the resulting ban excludes all magnetic materials but doesn't limit the variety of non-magnetic materials from any discipline.

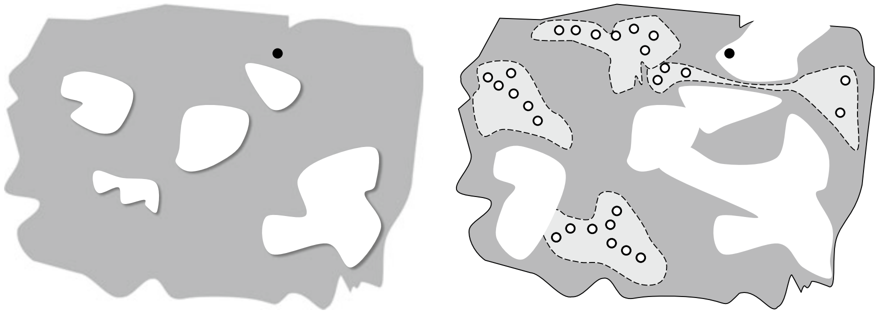


Fig. 1.34 Prohibition space. Left side: initial prohibition space. Right side: space after several Autogenesis runs (black filled circle: original solution. White areas: taboo zones. Light grey areas with dotted line border: areas of most possible solutions. White filled circles: solutions along the Pareto front)

new layouts, changes in number, form, position, structure, interdependencies, etc. of taboo zones. Existing zones can be omitted and new ones added in order to ensure that both content and structure of the prohibition space are always up to date.

Figure 1.34 shows the Prohibition space in two states: On the left side, the initial space with the first set of taboo zones (white areas) and with the original solution, on the right side after several Autogenesis runs. One realizes further and partly altered taboo zones due, e.g. to the dynamic behaviour of inherent elements, to the on-going results of the Autogenesis, and to external changes[40]. In addition, areas developed, in which the probability of finding the most possible solutions is very high. As soon as the respective fitness values of the solutions converge against the target function, the Pareto front consisting of solutions with the same top fitness value but of different characteristics can be set up. From this front, the product developer selects the preferred solution.

1.7.3 The ADT Product Model

The aim of a product model is to provide a framework to capture in a structured way all product data, which are necessary to describe the product and its life cycle. This framework shall be stable for the whole development process so that the data can be complemented step by step. In 'traditional' product development, different data structures arise along with the sequential phases of the product development process. Skipping a phase is not possible.

The ADT product model is based on the extended feature model of the FEMEX group, because this model provides a unified structure, which stores all product

[40]The original solution on the right side is now situated within a taboo zone. This indicates that requirements etc. were properly formulated in order to create an advanced solution of which the quality surpasses the quality of the original solution.

data and information from the whole life cycle [OWVM-1997, VDI-2218]. In this extended model, a product is described by a set of product parameters. Each product parameter describes a fraction of the product. It has to be mentioned that a product parameter can cover more than a geometric parameter. An IDE attribute can be described by a combination of product parameters. The totality of all product parameters clearly defines all product properties and characteristics, but there isn't always a 1:1 correlation. The aim of the product model is to structure the product parameters in order to improve clarity and usability. This is achieved by setting up different partial models of a product, Fig. 1.35.

Each product parameter can appear in a single partial model or in multiple partial models. The assignment of the product parameters is displayed on the horizontal axis, while the vertical axis displays the product characteristics (the product attributes in IDE). This assignment shows, which product parameter(s) is (are) needed to fulfil a certain product property (or an IDE attribute). In order to classify the product parameters in the matrix, a meta-information (tag) can be assigned to each of them. Using tags, each product parameter can be equipped with additional information. This additional information can be the product parameter type or the product property influenced by the product parameter. The system of using tags can be extended to provide the product parameters with a lot of useful information.

An advantage of this representation form is that the influence of product parameters can be quickly determined. It can easily be checked, which product parameter influences which particular property or which characteristic. Product properties that depend only on a single product parameter can be determined at the very beginning of the development process without taking into account dependencies with other product properties (as long as the product parameter is not influencing other properties). This dependence can be checked very simply by analyzing the tags of the product parameters.

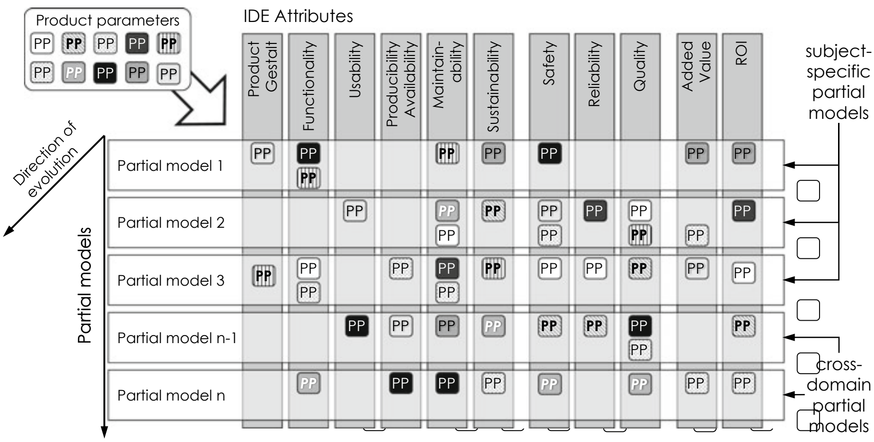


Fig. 1.35 The ADT product model applied to the attributes of IDE

The ADT product model allows the representation of product parameters in a way similar to the form of a biological chromosome. In this context a chromosome contains all product parameters that define a certain property. Accordingly, the ADT product model offers a way to describe a product detached from its actual physical structure, which not only allows the application of the product model even in the early phases of the development process but as well their application for describing performance and behaviour of the product in IDE).

The fulfilment values of the product parameters within the chromosome can vary along the development process, and these parameters can change triggered by different events. Possible types of events are as follows:

- Optimization of a product parameter. The product developer adjusts a product parameter to achieve an improvement of a product property.
- Changes due to dependencies. When a product parameter changes, it is possible that a thereof dependent product parameter must be adjusted, e.g. if a product parameter dictates a material and another product parameter dictates the wall thickness. In this constellation it can occur that the product parameter ‘wall thickness’ has to change when the product parameter ‘material’ changed, because, with another material, not all former wall thicknesses are permitted any longer.
- External event. By a change in the requirements new or adjusted taboo zones arise. This new circumstance can create the need that product parameters need to be adjusted because certain values are not permitted any longer.

1.7.4 Practical Application of the ADT

The first realization of the ADT is the design system NOA[41] for the evolutionary optimization of objects [VaCJ-2002]. NOA relies on the ADT procedure model (Fig. 1.13). The system consists of a self-developed optimization module in which evolutionary algorithms (evolutionary strategies [Rech-1973] and genetic algorithms [GoSE-1991, Gold-1989]) are used in a hybrid combination to find solutions [42], Fig. 1.36. Evolutionary algorithms are suitable for such tasks because they are multi-criteria and always search the entire solution space. NOA also controls a module to generate the current instance of the object to be optimized via suitable product parameters, and a module that evaluates this instance according to different criteria. The result of this evaluation flows into the fitness function, which (in conjunction with the target function in which the global optimization targets are stored) leads to evolutionary changes in the product parameters in the optimization module.

[41] NOA = Natural Optimization Algorithm

[42] More optimization methods (e.g. simulated annealing, particle swarm, deterministic methods for refined solution search in optimized areas as well as their dynamic parallel processing by model decomposition to increase efficiency [Wüns-2017]) are currently being integrated into NOA.

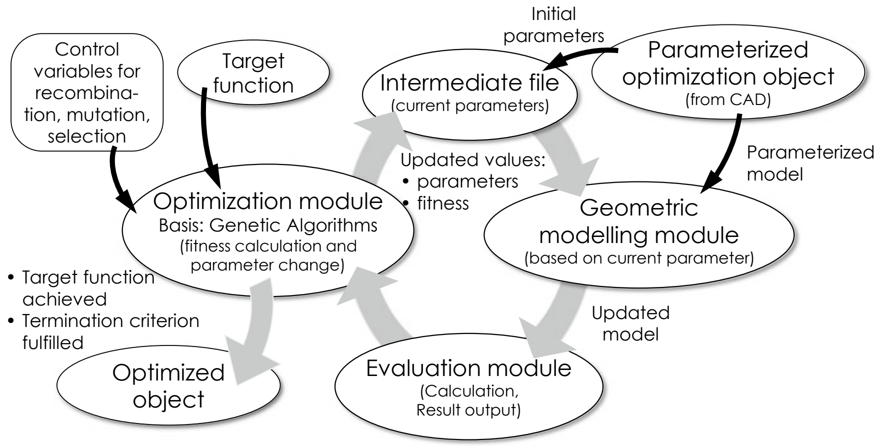


Fig. 1.36 Evolutionary design system NOA

An optimization generates populations of artificial individuals. Each artificial individual is described by a set of appropriate product parameters. Artificial individuals reproduce in a similar way to biological individuals. This leads to new artificial individuals with altered fitness values. In general, higher fitness leads to a higher probability of reproduction, for which the evolutionary operators recombination, mutation and selection are used. NOA stops the optimization as soon as a certain pre-set value of the fitness function is reached (e.g. the target function) or its values robustly converge. If divergences should arise instead of convergences, the user can influence both speed and the convergence of the Autogenesis from the outside by specifying recombination forms, mutation probabilities, number of mutations per individual as well as changing selection criteria (all of which were derived from experiences with similar problems).

With NOA, for example, the intake port in the cylinder head of a three-cylinder diesel engine was redesigned. The filling of the combustion chamber should be achieved by an improved mixing of air and fuel (and thus faster and more homogeneous combustion of the mixture) by generating a wobble flow (simultaneous rotations around the flow axis and perpendicular to it, 'tumble') in the inlet channel, without requiring additional components in the inlet channel, which seemed to be impossible for the manufacturer of the engine.

A total of 23 product parameters were used for the optimization, including the mathematic description of the inlet channel, which allowed any type of change in geometry, various fluid dynamics parameters and characteristics of the possible manufacturing processes for the inlet channel. It is obvious that the selection of the right product parameters and the proper modelling of their interdependencies highly influence both speed and quality of the optimization. The target function was the maximum flow through the channel and the presence of the tumble. The result of the optimization was a local constriction of the cross-section of the inlet channel with a 'braking surface' just in front of the inlet valve (which generates the rotation around the flow axis) which led to a backward twist superimposed by the rotation and thus to the generation of the tumble and thus to an improved filling of the combustion chamber[43].

1.7.5 Summary

Product development activities can generally be comprehensively summarized by search, variation, comparison and evaluation and selection from several alternatives, i.e. by a limited set of development activities. Such activities can be found in all phases of product development and on all levels of solution complexity, i.e. these activities are self-similar and can be described as a general scheme/pattern. Within ADT, the application of these activities is regarded as a continuous product optimization. Biological evolution as well is happening under changing goals and requirements, dynamic starting conditions, boundary conditions and constraints. Those solutions 'survive' that fit the actual situations best, i.e. which provide the best actual fitness value in comparison with the (also dynamic) target function. For carrying out the evolution, a limited set of evolutionary operators is applied.

These findings allow setting up the analogy between biological evolution and product development by formulating the Autogenetic Design Theory. It provides an evolution-oriented approach for modelling and for supporting the product development activities. The ADT points out that evolutionary operators and driving forces of the evolution can be applied and are important for improving both products and the respective development processes.

1.8 Development of Simple Products

Fabian Pilz

Three design principles play an important role in the development of innovative products: They require that a product must be 'unambiguous', 'simple' and 'safe' [BeGe-2020, PaBe-1988]. However, while requirements for unambiguousness regarding product usage and the processes of its creation (development and manufacture) can be implemented without restrictions (provided they have been described in a comprehensible manner) and safety is regulated and specified in laws, standards and directives, there are neither similarly clear definitions nor corresponding specifications for product simplicity. However, the topic of simple products has been

[43]Detailed information of further industrial applications of the ADT in different branches can be found, e.g. in [VCJB-2005, Clem-2005, KiVa-2009]

relevant as a basic principle in methodical and systematic product development for 40 years [PaBe-1977].

The variety of products is constantly increasing, as is the combination of physical products with virtual systems, whose combinations (e.g. Product-Service-Systems, PSS) are becoming more and more diverse. Among other things, this leads to a growing demand for simple and intuitive operability of a product [PrDa-2015, Zeh-2009], regardless of whether it is a tangible or intangible product or mixtures thereof (for the product concept within IDE, see Chap. 2). In all areas of the product life cycle, a need for the simplicity of products and processes can be identified, so that the need for the status ‘simple’ applies to all areas of a product.

The simplicity of a product offers advantages for users and manufacturers. Among others, simple products enable intuitive, low-error and efficient operation. The resulting usage-friendliness contributes to the satisfaction of the user. For the manufacturer, products that are easy to manufacture lower production costs, reduce maintenance and reduce the need for customer-related services, such as comprehensive operating manuals [BrHS-2013]:

- Fast and better understanding of the product context, which leads to fast learning of a (preferably intuitive) use of the product.
- Reduce the likelihood of handling errors to increase user satisfaction.
- Faster purchase decision for powerful but easy to handle products.
- Higher user acceptance.

In addition to these user-specific advantages, which are of course also reflected in the sale of the product, simple products offer advantages that benefit the supplier [Hart-2013]:

- Development and implementation of a simple product are positively influenced by simple processes and thus achieve results faster.
- Reduced assembly effort due to simplified shapes.
- Better comprehensibility through simplified working principles and functional structures.
- Both functional principles and simple forms support the predictability of both the performance and behaviour of the product in delivering its performance.

According to [PBFG-2007], simplicity cannot be unambiguously formulated as a boundary condition. The description of simplicity and its effects is rather general in the literature. A frequently used approach is the description of simplicity via the (increasing) absence of complexity [Pulm-2004, Hart-2013]. However, the boundaries between simplicity and complexity are not clearly defined and not clearly identifiable within different definitions of simplicity and complexity. So far there seem to be no criteria to explain and determine both the degree of simplicity and its resulting quality. Therefore, it seems to be open for the time being how simplicity could be defined, how it can be achieved in products and processes and which strategies and methods can be used to achieve it. According to the current state of research, the question remains why, how and when a product is or can become a simple product.

The first question that arises in this context is that of the definition of simplicity of a product. A common definition describes simplicity by its relation to complicacy and the resulting complexity from this. This definition has its origin in systems theory [Hart-2013], in which a complicated system is described by the degree of diversity of its elements, their number and their connections. It is possible to simplify a complicated system by structuring and clustering components and effects. Thus, a complicated system can consist of a multitude of subsystems that can be interpreted either as complicated or as simple. The understanding of a complicated system depends on both the experience and the knowledge of the person interacting with the product. These are not always comprehensible to the layperson but can be learned.

Complex systems can have a large number of elements and connections between them. Furthermore, they are subject to seemingly random and dynamic changes. Such systems are difficult to decompose, calculate and organize [PiVS-2018]. By further exploring the simplicity within product development, it is possible to identify a much larger number of research areas dealing with this topic. Table 1.2 shows that simplicity can have different meanings and causes at different stages of the product life cycle.

While in systems theory a system can be defined as simple because of the (small) number of its (possibly similar) components and the (also small) number of (possibly linear) relationships between them, the usability of products is mainly evaluated by the quality of their user interfaces. The focus here is on the efficient handling of the products in interaction with the respective product design [Robi-2016, Hass-2004]. From the supplier's point of view, both the manufacturability and the economic efficiency of the product must be the focus. This results in two main definitions for product simplicity (according to [UrVa-2018]), which have to be considered when differentiating [PiVS-2018]:

- From the point of view of a user interacting with the product, a simple product can be said to be simple not only if it can fulfil criteria of simplicity in the design of its components, in their composition and interaction as well as in their composition and structure, but also if its use is intuitively available within a defined time interval, free of disturbances and errors and with the expected range of functions. Such use leads to the fact that the performance of the product is available to the user without negative influences for the user in an expected way and manner. This absence of interference sources gives the user the feeling of a simple product. Simplicity is therefore a passive perception for the user.
- From the manufacturer's point of view, the profitability of the product is the most important factor, which makes it necessary to consider the entire product life cycle. For the manufacturer, a product appears simple when its profitability can be achieved quickly, planned and without disruption [PiVS-2018].

For both definitions, the status 'simple' as well as the status 'complicated' or 'complex' can never be defined as a fixed quantity, but rather the perception lies between these boundary points. The degree of simplicity is always partly dependent on the observer and thus subjective in nature. Thus a product can never be the simplest, rather it can only be tried to make it simple as much as possible.

Table 1.2 Simplicity in the different phases of the product life cycle [PiVS-2018]

Research Field	Core topic	Sources (selection)
Engineering design	Structural complexity: Simplicity results from the number of elements, their relationships and their boundary conditions	[BeGe-2020, EhMe-2017, Hubk-1984]
Product design	The diversity of the individual design elements influences the perception of simplicity and complexity	[Zeh-2009, Schn-2005, Seeg-2005]
Manufacturing	Lean production: employee training, customer loyalty, low hierarchies, manufacturing processes, assembly steps	[DoMi-2015]
Assembly management	Standardization, fragmentation and modularization	[WoJR-1992]
Maintainability	Disassembly, assembly, connection types	[BeGe-2020, EhMe-2017]
Usability	Type of functional execution, effectiveness of execution, efficiency of execution, satisfaction of execution	[Robi-2016, GeJo-2015, ChLe-2012]
User experience	Types of product perception. Interplay of expectation conformity and the mental model	[PrDa-2015, Norm-2013, Quir-2013]
Management	Structural change, insufficient transparency, product expansions, complexity as know-how protection	[OlBa-2005]
General simplification	The ten laws of simplicity, simplifying everyday life	[Maed-2006, Helf-2015]

1.8.1 Simplicity as a Multi-criteria Optimization Task

It follows from the definition of simple products given above that eight of the eleven attributes used within IDE for the neutral description of the performance offer of the product (consisting of its performance and the behaviour when providing its performance, see Sect. 3.2) can significantly influence the state 'simple' (Fig. 1.37). These are the six product attributes, the fulfilment attribute *reliability* (from the perspective of the customer or user) and the profitability attribute *profitability* (from

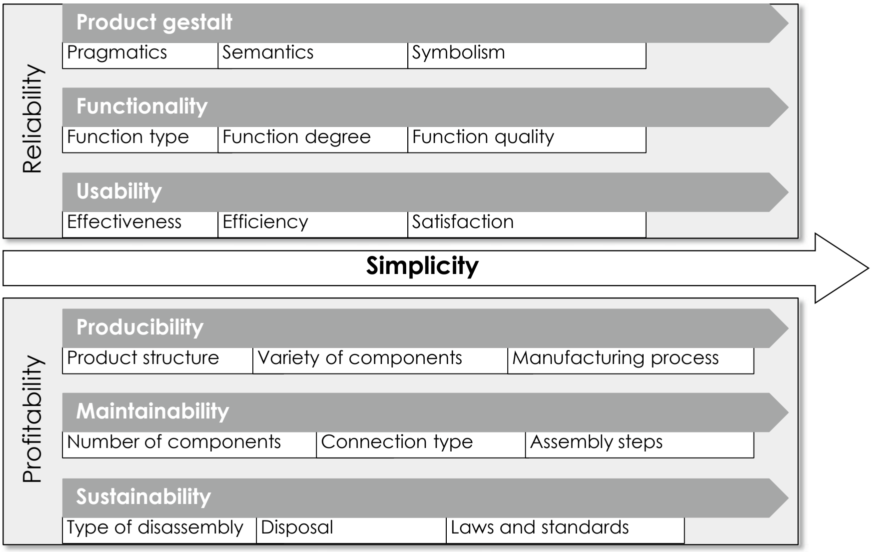


Fig. 1.37 Attributes within IDE (Sect. 3.2) to describe the performance of simple products, with extension of sub-attributes according to [PiVS-2018]

the perspective of the provider). As will be explained in detail later in Sect. 3.2, the attributes are interrelated and influence each other. For example, the product gestalt has a strong influence on the perception of the product and thus also on its usability.

These attributes form individual evaluation variables, which can describe the simplicity of the product in their respective characteristics and combinations with each other. If the characteristic values of individual attributes are changed, whether, through radical changes or slight adjustments, this has an effect on the entire system. By linking the individual attributes, these changes are usually non-linear and difficult to predict. The more pronounced the excellence of the attributes is, the more the product is perceived as 'simple'. This results in a multi-criteria optimization problem when developing simple products. To solve the problem of mutual influences, which can have both amplifying and reducing effects in the performance range, stochastic optimization methods are suitable. The *Autogenetic Design Theory* (ADT, Sect. 1.7) uses such methods and provides the basis for the creation of an evaluation system with implicit definition of the design variables using genetic algorithms [WüPV-2016].

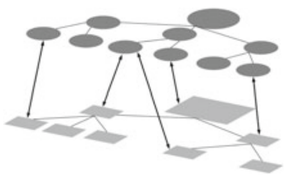
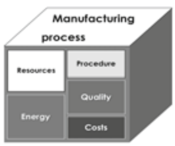
By using partial models, the complex overall task of developing a product is broken down into less complex and thus controllable sub-problems. The product developer does both decomposition and selection of the required partial models. The product parameters that are relevant for the description and solution of a simple product are summarized in a partial model. Analogous to a multidisciplinary optimization strategy, in which different evaluation models are used, the ADT product model also consists of different partial models [Wüns-2017].

Thus it is possible to define attributes and partial models of simplicity as product parameters and to evaluate them iteratively with the help of genetic operators. In contrast to the regular use of genetic algorithms that are self-driven by continuously evaluating the differences between the target function and intermediate fitness functions, the evaluation of individuals here is carried out interactively by an interdisciplinary development team. The criteria of the evaluation are weighted and represented within the target function. This corresponds to the conventional evaluation of variants based on weighting factors and evaluation criteria in product development [PBFG-2007]. Furthermore, solutions for multi-criteria optimization tasks also form the basis of decision models [Geld-2019]. This procedure results in a number of equivalents but different solutions.

1.8.2 *Parameters and Indicators of Simple Products and Processes*

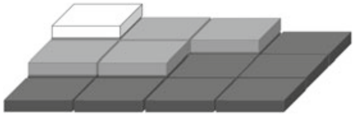
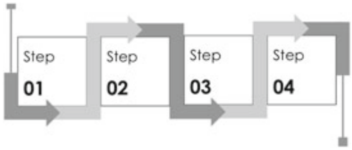
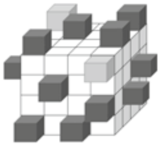
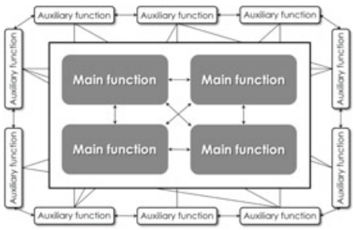
While in the previous sections the basic advantages, evaluation parameters and methods for the development of simple products were discussed, in this section a pragmatic presentation of possible parameters for simplicity on an existing product is given. These parameters can be applied to a product as well as to the development process; they describe the degree of simplicity within and after development. A selection of parameters and indicators of simple products is shown in Table 1.3 (for a more detailed overview, please refer to [BrHS-2013, Helf-2015, Schu-2014, Ashk-2007]).

Table 1.3 Parameters and indicators of simple products and processes

Structuring Simple products have a clear product structure. This structure shows the composition of the product and its components through logical and content-related links and combines these components at different levels The smaller the number of elements and their links are, the easier it is to recognize the structure of the product and therefore it is easier to work with the respective system	
Transparency Simple products and processes require a transparent presentation of information. A lack of transparency about the causes and effects of behaviour leads to an increase in complexity and reduces the understanding of correlations. If required information cannot be retrieved, the system appears inaccessible and difficult to penetrate	

(continued)

Table 1.3 (continued)

Modularization Systems and processes should be arranged in an appropriate hierarchy by reducing the dependencies between individual elements. This creates a separation between specific and standard units, which makes it easier to create variants. For example, modularization can achieve a high-end product variety with good predictability in the manufacturing process by dividing the product into modules and their (almost) arbitrary combination variety	
Predictability Simple products and processes must be predictable in their behaviour and execution. The occurrence of unforeseen reactions must be reduced as far as possible. This enables precise statements to be made about impending reactions	
Standardization Simple products, both in operation and in development, show recurring elements whose handling is already part of the existing knowledge. Standardized elements reduce the number of possible errors and the behaviour of the product is easier to predict	
Controllability By focusing on the core performance of a product (for example, the focus of a mobile phone is on communication), it is possible to control the product and its processes more easily. This controllability depends on the level of knowledge of the user. If the respective product or process lies outside the user's area of competence, this leads to an increase in complexity. Processes are a dynamic mechanism that grows over time. If this happens in an uncontrolled way, friction points arise, which result in excessive demand for competence	
Closed system The more closed a product is in the execution of its performance offering, the easier it is to handle. Interfaces to other systems are complexity drivers, which create the need for an additional product. Closed systems do not require support systems for their main functions. A distinction must be made between interfaces that are not used for the core performance of the product, but for its integration into an existing environment, for example, the presence of CAD data with different file formats that require the use of different CAD systems	

(continued)

Table 1.3 (continued)

Integration By integrating several related functions within a product, simplicity of use of the product can be enhanced. If it is possible to logically combine several functions within one system, this increases the functions of the product and at the same time the effectiveness of its use (for example, a multifunction printer additionally allows scanning and copying). The same applies to processes in a flexible manufacturing system with which several manufacturing steps can be processed in arbitrary orders	
Reliability Simple products and processes show a high degree of reliability so that the performance of the product or process is available for as long as possible. If the product life cycle is shorter than expected, this results in complexity drivers. The reliability of products and processes is at the same time essential for the predictability and to meet expectations, and it is always dependent on the user	
Compliance with expectations Conformity to expectations defines the standard of perception of a simple product. It is formed by knowledge, ideas, goals and experiences that the user has already gained with this type of product. If the resulting expectations are not addressed and/or not fulfilled, delays, operating errors or unattainable goals occur, which are subsequently perceived as complexity. Conformity to expectations forms the basis of the subjective assessment of the product by the observer	
Availability Both the product and all resources needed to use the product must be available to the user. Any delays that prevent the user from using the required services of the product due to the lack of required resources result in increasing complexity. The same applies to the provider, whose request for a specific process or resources should be answered as quickly as possible	

References

[AHAB-2011] Agogué, M., Hooge, S., Arnoux, F., Brown, I.: An Introduction to Innovative Design—Elements and Applications of C-K theory. Sciences de la Conception. Les Presses de l'Ecole des Mines Paris (2014)

[AlEL-2012] Albers, A., Ebel, B., Lohmeyer, Q.: Systems of objectives in complex product development. In: Proceedings of the 9th International Symposium on Tools and Methods of Competitive Engineering (TMCE 2012), Karlsruhe, S. 267–278. University of Technology, Delft (2012)

[Alts-2003] Altshuller, G.: “40 Principles—TRIZ Keys to Technical Innovation” (translated and edited by L. Shulyak, S. Rodman). Technical Innovation Center Worcester, MA, USA (2003)

[AmLi-1997] Ambrosy, S., Lindemann, U.: Methoden und Werkzeuge für die Integrierte Produktentwicklung. Technische Universität München, Shaker Verlag Aachen, Lehrstuhl für Konstruktion im Maschinenbau (1997)

[AnFa-1995] Andreasen, M.M., Fabricius, F.: Innovation by design for manufacture. In: VDI-Berichte Nr. 1212, VDI-Verlag, Düsseldorf (1995)

[AnHe-1987] Andreasen, M.M., Hein, L.: Integrated Product Development. Springer, Berlin (1987)

[AnKL-1985] Andreasen, M.M., Kähler, S., Lund, T.H.: Montagerechtes Konstruieren. Springer, Berlin (1985)

[AnOl-1981] Andreasen, M.M., Olsson, F.: Situation in design and design methodology in the Nordic countries. In: Hubka, V. (ed.) Review of Design Methodology, ICED 81 Rom. Schriftenreihe WDK 5, Seiten 9–16 (1981)

[Ashk-2007] Ashkenas, R.: Simplicity-minded management. Harvard Business Review 85(2007)12, pp S. 101–109

[Baue-2003] Bauer, S.: Design for X—Ansätze zur Definition und Strukturierung. In: Meerkamm, H. (Herausgeber) Design for X, Beiträge zum 14. Symposium Neukirchen (2003)

[BeGe-2020] Bender, B., Gericke, K.: Pahl/Beitz Konstruktionslehre. Methoden und Anwendung erfolgreicher Produktentwickl ung. Springer Heidelberg (2020)

[BeHo-1999] Bercsey, T., Horák, P.: Integrierte Produktentwicklung in der Lehre und in der Praxis. 4. Magdeburger Maschinenbautage. Magdeburg (1999)

[BeVa-1994] Bercsey, T., Vajna, S.: “Ein Autogenetischer Ansatz für die Konstruktionstheorie”. CAD-CAM Report 13, vol. 2, pp. 66–71 and 14 vol. 3, pp. 98–105 (1994)

[BiHa-1953] Bischoff, W., Hansen, F.: Rationelles Konstruieren. VEB-Verlag Technik, Berlin (1953)

[Bjoe-2004] Björk, E.: A Contribution to Insider Action Research Applied on Development of Assistive Products. Magdeburg (2004)

[Bram-2004] Bramklev. C.: Concurrent Development of Product and Packaging—Towards an Integrated Development Procedure. Dissertation Universität Lund, Schweden (2004)

[BrHS-2013] Brügger, C.; Hartschen, M.; Scherer, J.: Simplicity: Prinzipien der Einfachheit: Strategien für einfache Produkte, Dienstleistungen und Prozesse. Gabal-Verlag Offenbach (2013)

[BrPe-1990] Briggs, J., Peat, F. D.: “Die Entdeckung des Chaos”. Carl Hanser Verlag, München (1990)

[Bull-1996] Bullinger, H.-J.: Erfolgsfaktor Mitarbeiter: Motivation-Kreativität-Innovation, B.G. Teubner-Stuttgart (1996)

[Burc-2001] Burchardt, C.: Ein erweitertes Konzept für die Integrierte Produktentwicklung. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[CaVo-2013] Cagan, J., Vogel, C.: Creating Breakthrough Products, 2nd edn. Pearson Education (2013)

[ChFe-2003] Chen, K.Z., Feng, X.A.: A framework of the genetic-engineering-based design theory and methodology for product innovation. In: Norell, M. (ed.) Proceedings of the 14th International Conference on Engineering Design ICED03, presentation 1745, Design Society 31, Stockholm 2003, Abstract p. 671 (2003)

[ChLe-2012] Choi, J. H.; Lee, H.-J.: Facets of simplicity for the smartphone interface: A structural model. International Journ al of Human-Computer Studies 70(2012)2, Pp. 129-142

[Clem-2005] Clement, S.: Erweiterung und Verifikation der Autogenetische Konstruktionstheorie mit Hilfe einer evolutionsbasierten und systematisch-opportunistischen Vorgehensweise. Dissertation Universität Magdeburg (2005)

[Csan-1988] Csányi, V.: Evolúciós rendszerek. Gondolat Könyvkiadó Budapest 1988 (an English translation with several addenda appeared under the title "Evolutionary Systems and Society", Duke University Press, 1989)

[Daen-1992] Daenzer, W.F.: Systems Engineering—Methodik und Praxis. Verlag Industrielle Organisation, Zürich (1992)

[DoMi-2015] Dombrowski, U.; Mielke, T.: Ganzheitliche Produktionssysteme: Aktueller Stand und zukünftige Entwicklungen. Springer Vieweg Berlin (2015)

[EHCJ-2005] Edelmann-Nusser, J., Heller, M., Clement, St, Jordan, A, Vajna, S.: Lightweight Design Optimisation of a Bow Riser in Olympic Archery applying Evolutionary Computing. European Journal of Sports Science 4(2004)3. http://www.humankinetics.com/ejss, (2005)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, 6th edition. Carl Hanser Verlag München 2017

[Ehrl-1985] Ehrlenspiel, Klaus.: Kostengünstig Konstruieren. Berlin, Springer-Verlag 1985. (Dies wurde mit weiteren Autoren bis zur 7. Auflage 2014 jeweils überarbeitet)

[Ehrl-1991] Ehrlenspiel, K.: Integrierte Produkterstellung - Organisation-Methoden-Hilfsmittel. 3. Münchener Kolloquium 1991

[Ehrl-1995] Ehrlenspiel, K.: Integrierte Produktentwicklung. Carl Hanser Verlag München (1995)

[EWDS-1998] Eisleben, T., Wiesenberger, P., Dauner, A., Saal, D.: Die Dialektik bei Hegel. Referat im Seminar Wissenschaftstheorie Dialektik, Universität Mainz WS 1998/99. http://www.uni-mainz.de/FB/Philosophie_Paedagogik/agas/content/HA/hegel/index.html, Zugriff am 02. Mai 2013

[Ferg-2000] Ferguson, D.: Therbligs: The Key to Simplifying Work. The Gilbreth Network 2000. http://gilbrethnetwork.tripod.com/therbligs.html, Zugriff am 02. Mai 2013

[FoSt-2003] Ford, D.N., Sterman, J.D.: Overcoming the 90% syndrome: iteration management in concurrent development projects. Concurrent Eng. Res. **11**(3), 177–186 (2003)

[FrBB-1998] Frankenberger, E., Badke-Schaub, P., Birkhofer, H. (eds.): Designers—The Key to Successful Product Development. Springer, Berlin (1998)

[Frei-2001] Freisleben, D.: Gestaltung und Optimierung von Produktentwicklungsprozessen mit einem wissensbasierten Vorgehensmodell. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[GaNa-2004] Gatzky, T., Naumann, T.: Industriedesign und Arbeitswissenschaft im Integrierten Produktentwicklungsprozess als eine Profillinie der Fakultät Maschinenbau. In Quaas, W. (Herausgeber): Kolloquium 40 Jahre Arbeitswissenschaft an der Otto-von-Guericke-Universität Magdeburg (2004)

[GeBa-2002] Gerwin, D., Barrowman, N.: An evaluation of research on integrated product development. Manag. Sci. **48**(7), 938–953 (2002)

[Geid-2000] Geidel, H.: Bedeutung der Prozesse bei der Entwicklung komplexer Produkte, dargestellt am Beispiel Triebwerke. In: Köpplinger, H., Vajna, S. (eds.) Tagungsband der European Engineering User Conference (e.e.u.c) München (2000)

[GeJo-2015] Geis, T.; Johner, C.: Usability Engineering als Erfolgsfaktor. Beuth Verlag Berlin (2015)

[Geld-2019] Geldermann, J.: Multikriterielle Optimierung. http://www.enzyklopaedie-derwirtschaftsinformatik.de/lexikon/technologien-methoden/Operations-Research/Mathematische-Optimierung/Multikriterielle-Optimierung, Accessed on 05.03.2019

[Gige-2008] Gigerenzer, G.: Bauchentscheidungen. Die Intelligenz des Unbewussten und die Macht der Intuition. Goldmann, München (2008)

[Gilb-1914] Gilbreth, L.M.: The Psychology of Management—The Function of the Mind in Determining, Teaching and Installing Methods of Least Waste. The MacMillan Company, New York (1914)

[Gold-1989] Goldberg, D.E.: Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley, Reading, MA (1989)

[GoSE-1991] Goldberg, D.E., Smith, R.E., Earickson, J.A.: SGA-C: A C-Language Implementation of a Simple Genetic Algorithm. TCGA Report (1991)

[Hans-1974] Hansen, F.: Konstruktionswissenschaft Ð Grundlagen und Methoden. Hanser München (1974)

[Hart-2013] Hartmann, S.: Ein Beitrag zur frühzeitigen Abschätzung der Produktkomplexität und zur Definition einfacher Produkte. Dissertation Otto-von-Guericke Universität Magdeburg (2013)

[Hass-2004] Hassenzahl, M.: The Interplay of Beauty, Goodness, and Usability in Interactive Products. Human-Computer Interaction, 19(2004)4, pp 319-349

[HaWe-2003] Hatchuel, A., Weil, B.: A new approach to innovative design. An introduction to C-K theory. In: Norell, M. (ed.) ICED03, Research for Practice—Innovation in Products, Processes and Organisations, p. 14 (2003)

[HaWe-2009] Hatchuel, A., Weil, B: C-K design theory: An advanced formulation. Res. Eng. Des. **19**(4), 181–192 (2009)

[Helf-2015] Helfrich, C.: Das Prinzip Einfachheit: Reduzieren Sie die Komplexität. Expert Verlag Renningen (2015)

[Hell-1978] Hellfritz, H.: Innovationen via Galeriemethode. Königstein/Ts. 1978 (Eigenverlag)

[Heym-2005] Heymann, M.: Kunst und Wissenschaft in der Technik des 20. Jahrhunderts. Zur Geschichte der Konstruktionswissenschaft. Chronos, Zürich (2005)

[HPAO-1984] Hein, L., Pedersen, F.M., Andreasen, M.M., Olsson, F.: Integrated product development: new potential products. In: Langdon, R. (ed.) Design and Industry, volume 2 (from 6), Proceedings of Design Policy, held at Royal College of Art in London, 20–23 July 1982. The Design Council, London, pp. 86–90 (1984)

[Hubk-1973] Hubka, V.: Theorie der Maschinensysteme. Springer, Berlin (1973)

[Hubk-1976] Hubka, V.: Theorie der Konstruktionsprozesse. Springer, Berlin (1976)

[Hubk-1980] Hubka, V.: Allgemeines Vorgehensmodell des Konstruierens. Schriftenreihe WDK, Heurista Zürich (1980)

[Hubk-1984] Hubka, V.: Theorie technischer Systeme: Grundlagen einer wissenschaftlichen Konstruktionslehre. Springer Vieweg Berlin, Heidelberg (1984)

[HuEd-1992] Hubka, V., Eder, W.E.: Einführung in die Konstruktionswissenschaft. Springer, Berlin (1992)

[IABG-2013] Leitseite der Industrieanlagen-Betriebsgesellschaft mbH Ottobrunn. http://v-modell.iabg.de. Zugriff am 23. Mai 2013

[Kess-1954] Kesselring, F.: Technische Kompositionslehre. Springer, Berlin (1954)

[Kiew-1991] Kiewert, A.: Der Konstruktionsprozeß als Rückkopplung - Formalisierung von Teilaspekten des Konstruktionsprozesses. In: Hubka, V. (ed.) Proceedings of the International Conference on Engineering Design (ICED 91) Heurista Zürich, pp. 70–76 (1991)

[KiVa-2009] Kittel, K., Vajna, S.: Development of an evolutionary design method. In: Leifer, L., Skogstad, Ph. (eds.) Proceedings of ICED 09", vol. 6, Design Methods and Tools, Part 2, pp. 147–156 (2009)

[KoHo-2001] Koch, M., Hochmuth, R.: Mehrkörpersimulation unter Berücksichtigung nicht-idealer Gelenke und Integration dieser in das Konstruktionssystem mfk. In: Meerkamm, H. (ed.) Design for X - Beiträge zum Symposium (2001)

[Kolle-1976] Koller, R.: Konstruktionsmethode für den Maschinen-Geräte- und Apparatebau. Springer, Berlin (1976)

[LBSV-1999] Lindemann, U., Bichlmaier, C., Stetter, R., Viertlböck, M.: Verbesserte Umsetzung der Integrierten Produktentwicklung in der industriellen Anwendung. Konstruktion **52**, 9 (1999)

[Lehr-2009] Lehrer, J.: Wie wir entscheiden. Das erfolgreiche Zusammenspiel von Kopf und Bauch. Piper, München (2009)

[Maed-2006] Maeda, J.: The laws of simplicity. MIT Press Cambridge (2006)

[MaWH-2017] Le Masson, P., Weil, B., Hatchuel, A.: Design Theory—Methods and Organization for Innovation. Springer International Publishing AG. ISBN 978-3-319-50277-9 (2017)

[Meer-1994] Meerkamm, H.: Integrierte Produktentwicklung im Spannungsfeld von Kosten-, Zeit- und Qualitätsmanagement. VDI-Bericht 1136 VDI-Verlag Düsseldorf 1994, S. 1–13

[MePa-2005] Meerkamm, H., Paetzold, K.: Integrierte Produktentwicklung (IPE) – Philosophie, Konzept und Umsetzung. In: Institut für Maschinenelemente und Konstruktionstechnik (Herausgeber): Festschrift zum Ehrenkolloquium anlässlich der Emeritierungen von Univ.-Prof. Dr.-Ing. habil. Dr. h.c. Günter Höhne und Univ.-Prof. Dr.-Ing. habil. Hans-Jürgen Schorcht, Ilmenau 2005

[MiGP-1991] Miller, G.A., Galanter, E., Pribram, K.H.: Strategien des Handelns. Pläne und Strukturen des Verhaltens (2. Auflage). Klett-Cotta Stuttgart 1991

[Mile-1972] Miles, L.D.: Techniques of Value Analysis and Engineering. McGraw-Hill, New York (1972)

[Müll-1970] Müller, J.: Grundlagen der systematischen Heuristik. Dietz-Verlag, Berlin (1970)

[Müll-1990] Müller, J.: Arbeitsmethoden der Technikwissenschaften. Springer, Berlin (1990)

[Naum-2005] Naumann, T.: Adaptive SYSTEM MANAGEMENT. Ein Ansatz für die Planung und Steuerung von Produktentwicklungsprozessen. Dissertation Otto-von-Guericke-Universität Magdeburg (2005)

[Nore-1999] Norell, M.: Managing integrated product development. In: Mortensen, N., Sigurjónsson, J. (eds.) Critical Enthusiasm—A festschrift for Mogens Myrup Andreasen. DTU (1999)

[Norm-2013] Norman, D.: The design of everyday things. Basic Books New York (2013)

[OlBa-2005] Olbrich, R.; Battenfeld, D.: Variantenvielfalt und Komplexität — kostenorientierte vs. marktorientierte Sicht. In Journal für Marketing, 44(2005)3, pp. 161-173

[Olss-1976] Olsson, F.: Systematisk Konstruktion (Systematic Engineering Design), Dissertation am Department of Machine Design, Lund Institute of Technology at Lund University (1976)

[Olss-1981] Olsson, F.: Machine design procedure related to product development procedure. In: Hubka, V. (ed.) Review of Design Methodology, ICED 81 Rom. Schriftenreihe WDK 5, 1981. Seiten 229–238 (1981)

[Olss-1985] Olsson, F.: Integrerad Produktutveckling - Arbetsmodel (in Schwedisch). Series 21 Produktutveckling. Sveriges Mekanförbundet, Stockholm, Schweden (1985)

[Otto-1996] Ottosson, S.: Dynamic product development—findings from participating action research in a fast new product development process. J. Eng. Des. **7**(2), 151–169 (1996)

[Otto-1998] Ottosson, S.: Planetary organizations. Tech. Int. J. Technol. Innov. Entrepreneurship **19**(2), 81–86 (1998)

[Otto-2003] Ottosson, S.: Participation action research—a key to improved knowledge of management. Tech. Int. J. Technol. Innov. Entrepreneurship **23**, 87–94 (2003)

[Otto-2004] Ottosson, S.: The development and research of DPD—a historical review. In: Rohatynski, R. (Herausgeber) Proceedings of the Fourth International Seminar and Workshop on Engineering Design in Integrated Product Development, Zielona Góra (Polen) (2004)

[Otto-2013] Ottosson, S.: Frontline Innovation Management (zweite Auflage). Tervix Göteborg (2013)

[OtWo-2001] Otto, K.N.; Wood, K.L.: Product Design: Techniques in Reengineering and New Product Development. Pearson/Prentice Hall (2001)

[OWVM-1997] Ovtcharova, J., Weber, C., Vajna, S., Müller, U.: Neue Perspektiven für die Feature-basierte Modellierung. VDI-Z **140**(3), 34–37 (1997)

[PaBe-1977] Pahl, G., Beitz, W.: Konstruktionslehre. Springer, Berlin (1977)

[PaBe-1988] Pahl, G., Beitz, W.: Konstruktionslehre. Springer Heidelberg Berlin (1988)

[PBFG-2007] Pahl, G.; Beitz, W.; Feldhusen, J.; Grote, K.-H.: Konstruktionslehre. Grundlagen erfolgreicher Produktentwicklung; Methoden und Anwendung. Springer Heidelberg, 2007

[PDMA-2011] Glossar der Product Development and Management Association (Chicago, USA). www.pdma.org, www.pdma.org/npd_glossary.cfm, Zugriff am 18. Mai 2011

[PiVS-2018] Pilz, F.; Vajna, S.; Schabacker, M.: Bewertbarkeit unscharfer Mengen am Beispiel der Eigenschaft Produkteinfachheit. In Proceedings of the 29th Design for X-Symposium (2018)

[PrDa-2015] Preim, B.; Dachselt, R.: Interaktive Systeme: Band 1. Springer Vieweg Berlin, Heidelberg (2015)

[Pulm-2004] Pulm, U.: Eine systemtheoretische Betrachtung der Produktentwicklung. Dissertation Technische Universität München (2004)

[Quir-2013] Quirmbach, S.: Suchmaschinen: User Experience, Usability und nutzerzentrierte Website-Gestaltung. Springer Vieweg. Berlin Heidelberg (2013)

[Rech-1973] Rechenberg, I.: Evolutionsstrategie – Optimierung technischer Systeme nach Prinzipien der biologischen Evolution. Friedrich Frommann Verlag, Stuttgart (1973)

[Robi-2016] Robier, J.: Das einfache und emotionale Kauferlebnis: Mit Usability, User Experience und Customer Experience anspruchsvolle Kunden gewinnen. Springer Vieweg Wiesbaden (2016)

[Rode-1970] Rodenacker, W.G.: Methodisches Konstruieren. Springer, Berlin (1970)

[Ropo-1975] Ropohl, G.: Systemtechnik – Grundlagen und Anwendung. Hanser, München (1975)

[Roth-1982] Roth, K.: Konstruieren mit Konstruktionskatalogen. Springe, Berlin (1982)

[Schl-2008] Schlingensiepen, J.: Korporative IT-Systemarchitektur zur Unterstützung unternehmens-übergreifender kooperativer Produktentwicklung. In: Vajna, S. (Herausgeber): Integrierte Produktentwicklung, Band 14 Magdeburg (2008)

[Schn-2005] Schneider, B.: Design – eine Einführung: Entwurf im sozialen, kulturellen und wirtschaftlichen Kontext. De Gruyter Basel (2005)

[Schr-2000] Schrage, M.: Serious Play—How the World's Best Companies Simulate to Innovate. Harvard Business School Press, Boston (2000)

[Schu-2014] Schuh, G.: Produktkomplexität managen: Strategien; Methoden; Tools. Carl HanserVerlag München (2014)

[Seeg-2005] Seeger, H.: Design technischer Produkte, Produktprogramme und -systeme. Springer Vieweg Berlin, Heidelberg (2005)

[Simo-1997] Simon, H.A.: The Sciences of the Artificial, 3rd edn. MIT Press, Cambridge (USA) (1997)

[Smed-1994] Smedberg, M.: Om stridens grunder – fran Waterloo till kryssningsrobotar (Über die Gründe zum Streit – von Waterloo bis zu Marschflugkörpern; in Schwedisch). Page One Publishing Stockholm (1994)

[Ullm-1992a] Ullman, D.G.: The Mechanical Design Process. McGraw-Hill New York (1992a)

[Ullm-1992b] Ullman, D.G.: A taxonomy for mechanical design. Res. Eng. Des. **3**(3), 179–189 (1992b)

[UrVa-2018] Urakami, J.; Vajna, S.: Human Centricity in Integrated Design Engineering. In Proceedings of the 15th International Design Conference. Dubrovnik, 2018, pp. 679–690

[VaBu-1998] Vajna, S., Burchardt, C.: Integrierte Produktentwicklung. Konstruktion **51**(4), 45–50 (1998)

[VaCJ-2002] Vajna, S., Clement, S., Jordan, A.: Autogenetic design theory: an approach to optimise both the design process and the product. In: Proceedings of the 2002 ASME Design Engineering Technical Conferences September 29–October 2, Montreal (Quebec, Canada) (2002)

[VBCA-2005] Vajna, S., Bercsey, T., Clement, St., Jordan, A.: The autogenetic design theory: an evolutionary view of the design process. J. Eng. Des. **16**(4), 423–440 (2005)

[VCJB-2005] Vajna, S., Clement, St., Jordan, A., Bercsey, T.: The autogenetic design theory: an evolutionary view of the design process. J. Eng. Des. **16**(4), 423–444 (2005)

[VDI-2206] VDI-Richtlinie 2206: Entwicklungsmethodik für mechatronische Systeme. Beuth Verlag, Berlin (2004)

[VDI-2218] VDI Guideline 2218: Feature Technology, within the series Information technology in product development. VDI Düsseldorf (2003)

[VDI-2221/2019] VDI Guideline 2221 Sheet 1: Entwicklung technischer Produkte und Systeme – Modell der Produktentwicklung. VDI, Düsseldorf, 2019

[VDI-2221/93] VDI Guideline 2221: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte. Beuth Verlag, Berlin (1993)

[VDI-2222/97] VDI-Guideline 2222, Sheet 1: Konstruktionsmethodik - Methodisches Entwickeln von Lösungsprinzipien. Beuth Verlag, Berlin (1997)

[VDI-2800] VDI Guideline 2800 Sheet1: Wertanalyse/Value analysis. Beuth-Verlag, Berlin (2010)

[VWZH-2018] Vajna, S., Weber, Ch., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S.: CAx für Ingenieure, eine praxisbezogene Einführung (dritte neu bearbeitete Auflage). Springer, Berlin (2018)

[Wach-1993] Wach, J.-J.: Problemspezifische Hilfsmittel für die Integrierte Produktentwicklung, Konstruktionstechnik. Technische Universität München, Carl Hanser Verlag, München Wien (1993)

[Wall-1995] Wallace, K. (Herausgeber) Engineering Design 2. Auflage der englischen Ausgabe der "Konstruktionslehre" von G. Pahl, W. Beitz, übersetzt von K. Wallace, L. Blessing, F. Bauert, bearbeitet von K. Wallace

[WaOB-1998] Watkins, T.A., Ochs, J.B., Boothe, B.W.: Integrating design arts, engineering and business curricula through multidisciplinary product design projects. In: Proceeding from the Second Annual NCIIA Conference, Washington, März (1998)

[Wart-2000] Wartzack, S.: Predicitive Engineering—Assistenzsystem zur multikriteriellen Analyse alternative Produktkonzepte. Dissertation Universität Erlangen-Nürnberg (2000)

[Wegn-1999] Wegner, B.: Autogenetische Konstruktionstheorie – ein Beitrag für eine erweiterte Konstruktionstheorie auf der Basis Evolutionärer Algorithmen. Dissertation Universität Magdeburg (1999)

[Wien-1970] Wiendahl, H.-P.: Funktionsbetrachtungen technischer Gebilde - Ein Hilfsmittel zur Auftragsabwicklung in der Maschinenbauindustrie. Dissertation RWTH Aachen (1970)

[Wöge-1943] Wögerbauer, H.: Die Technik des Konstruierens. Oldenbourg-Verlag München (1943)

[WoJR-1992] Womack, J. P.; Jones, D. T.; Roos, D.: Die zweite Revolution in der Autoindustrie: Konsequenzen aus der weltw eiten Studie aus dem Massachusetts Institute of Technology. Campus-Verlag Frankfurt am Main (1992)

[Wüns-2017] Wünsch, A.: Effizienter Einsatz von Optimierungsmethoden in der Produktentwicklung durch dynamische Parallelisierung. Dissertation Universität Magdeburg (2017)

[WüPV-2016] Wünsch, A.; Pilz, F.; Vajna, S.: Morphix: An Evolutionary Way to Support Conceptual Design. In Proceedings of the 14th International Design Conference (DESIGN 2016). Dubrovnik 2016, pp. 769–778

[Zeh-2009] Zeh, N.: Erfolgsfaktor Produktdesign. Dissertation Universität zu Köln (2009)

[Zwic-1982] Zwicky, F.: Entdecken, Erfinden, Forschen im Morphologischen Weltbild. Droemer Knaur, München (1982)

Chapter 2
Products and Product Life Cycle in IDE

Sándor Vajna

One of the main goals of a company is to bring products to the market, whose performance and behaviour in providing this performance is desired by customers and users, and which, due to these characteristics, help the company to achieve continuously high profitability and financial stability, high acceptance by all social groups and possibly also market leadership. In order to achieve this goal and secure it in the long term, products, processes and organisations in the company must be designed accordingly. However, products, processes and organisations are interlinked in many ways and constantly influence each other. An isolated consideration of these three elements does not lead to the desired goal.

The product and its structure are the result of co-operating structures and processes that take place in an appropriate organisation. Reciprocally, the product primarily influences the design and content of the processes via its product structure, and secondarily the design of the organisation. On the one hand, it provides the necessary structures and resources for the development of a product in an appropriate and timely manner; on the other hand, it limits the variety of solutions through a limited selection of possible resources and technologies, Fig. 2.1

An organisation is divided into an organisational structure and a process organisation (for more details see Sects. 15.2 and 15.3).

- The structural organisation represents the links between basic organisational elements and a structure in an enterprise and the regulation of relationships between these elements. Therefore, a company is divided into positions and departments and the arrangements are reflected by relationships of management, staff and communication. The structural organisation can be implemented in various forms, such as a line-and-staff organisation, in which the staff supports the operating line, as well as the division and matrix organisation. These support the realisation of objectives for the provision of services rendered with content

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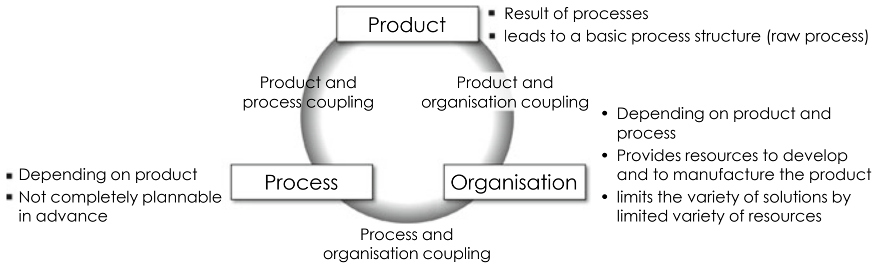

Fig. 2.1 Interaction and mutual dependencies of product, process and organisation

over time, at a point-in-time, with a certain composition and volume as well as for the implementation of corporate objectives, such as profit maximisation or cost recovery.
- The process organisation represents work, time and space relationships in their respective contexts and thus ensures the processes of task processing under consideration of factual-logical, personal and spatial-temporal aspects.

2.1 Product Term

A product is the result or outcome of human work, human knowledge and ability, something which has not been produced naturally but artificially, an *artefact*[1]. The product may be a tangible (physical or material) artefact; a non-tangible (immaterial) artefact; or combinations thereof, and it may consist of components from different disciplines (e.g. mechanics, electronics, software). Each product has its own life cycle.

Real artefacts can be piecewise (discrete) or continuous (continuous) and can be composed of individual parts and assemblies.

- Discrete artefacts are, e.g. screws, computer hardware, mobile phones, wheelchairs, complete machines and their related technologies as well as buildings of any kind, transportation facilities (e.g. bridges) and further constructional facilities.
- Continuous artefacts are, for example, raw materials from the chemical industry, fossil fuels and electricity, which are not produced discretely but continuously.

Non-tangible artefacts and services include:

- Procedures and models for designing, adapting and optimising artefacts, processes and (arbitrary) procedures and technologies,
- Any kind of research results and teaching achievements in educational institutions in any level of detail,

[1]Product: Participle Perfect of the Latin verb *producere*, 'generate, produce'. Artefact: From the Latin *(per) arte factum*, 'made by art'.

- Software and software systems with subroutines and software modules,
- Writing texts, composing, arranging and performing music, creative activities (e.g. painting and sculpture, creating films).
- Any kind of service, for example consulting (also with subsequent implementation of the consulting proposals), social care, dental treatment or police security measures at a football match.

Products can also consist of any combination of these different artefacts, for example

- Computer systems as a combination of hardware, electronics and non-tangible software modules,
- Products with their own service (PSS, Product Service System), in which, for example, results, findings and methods of product development and service engineering are linked together (for example, a machine tool for a special product family, in which installation, commissioning, continuous maintenance and updating of the components are included in the price), until the focus is no longer on the actual product but on the service that can be provided as a result,
- Mechatronic products, i.e. the intelligent combination and simultaneous and equal consideration of solution concepts from mechanics (including drive technology and machine dynamics), hydraulics, pneumatics, optics, measurement and control technology, electrics, electronics (sensors) and information processing, for example, for self-propelled vehicles [VWZH-2018] (see also Chap. 23), and
- Cyber-physical systems (CPS), which are the further development of mechatronic products. CPS describes the integration of computers and physical processes in which the physical processes are monitored, regulated and controlled by embedded computer systems and networks. Through mutual feedback, computer systems and physical processes interact with each other. The challenge lies in the overlapping or overlapping area of computer systems and physical processes as well as in their fusion, which goes far beyond mere interconnection [VWZH-2018].

Although products differ in purpose, content, structure and appearance, there are a number of similarities. Every product

- Has an (individual) performance capability and a behaviour to deliver this performance in response to customer interactions, changes in operational environment and metrics, or timing constraints. The performance is made up of the quality of the shape, both quantity and quality of the available functions, the usability and other characteristics of the product, such as sustainability. A role of their own play the so-called affordances, i.e. those performance components of the product, which can arise in the form of additional interaction possibilities between the product and the user in his current environment, relative to his abilities and current needs, but which were not specified in the design of the product[2]. The product thus makes a performance promise to the user and provides him with suitable interfaces for the provision of services.

- Must be unambiguous, simple[3] and safe in rendering its performance to the user in terms of usability, behaviour, manufacturability, maintainability and sustainability. The property 'unambiguous' is objectively measurable and thus predefinable. The characteristic 'simple' can be experienced subjectively and depends on the educational level and cultural circle of the customer or user as well as on possible areas of application and their possibilities and limitations. The resulting simplicity of a product can manifest itself in various forms [PiVS-2019]. The property 'safe' can also be objectively measured on the basis of specifications (standards, laws, general habits).
- Can be structured and modularized using the same approaches and procedures.
- Has a limited service life and working life.
- Requires investments for its creation, deployment and return, which must be compensated by the benefit from the deployment.
- Is located throughout its life cycle in an environment characterised by cultural, perceptual, regulatory and physical contexts (Sect. 4.2).

It is, therefore, permissible to look at products of the most diverse kind together and treat them with the same approaches, strategies, methods, procedures and tools. If adjustments are necessary, they are made with the help of the knowledge used and developed during the product life cycle, and with the methods and procedures used in the individual phases of the product life cycle.

2.2 Product Life Cycle

The product life cycle comprises product planning, product development, production, product utilisation with product support as well as product re-circulation, which are divided into the phases and activities shown in Fig. 2.2.

Product planning, product development, production and product re-circulation all take place at the institution that realises the product and offers it to the customer ('provider'). The product use phase takes place at the customer (Sect. 4.2). In the product life cycle, not all phases have to be run through sequentially to the same extent

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[2]For example, a tablet computer can easily be used as a chopping board when chopping onions in the kitchen because of its tough glass surface—a capability that was not intended when formulating both performance and behaviour of the device.

[3]On the subject of *simplicity*: Albert EINSTEIN (1879–1955) is credited with saying that everything should be made as simple as possible, but not simpler (i.e. simplicity cannot exist without complexity). Antoine de SAINT- EXUPÉRY (1900–1944) is credited with having to move from the complicated to the ingenious to the simple. The Soviet rocket-maker Sergey KOROLJOV (1907–1966) stated that the genius of a product lies in its simplicity.

and inevitably. It is possible that for different products individual phases are omitted, are parallelized or additional phases are added due to new or changed requirements.

In addition to the complete representation of the product life cycle in Fig. 2.2, a simplified representation is also used in this book, Fig. 2.3.

The product life cycle is supported by three flows, the information flow, the material flow and the financial flow [VWZH-2018].

- The information flow describes in all phases and processes of the product life cycle (from research to delivery or handover of the product to the customer) the

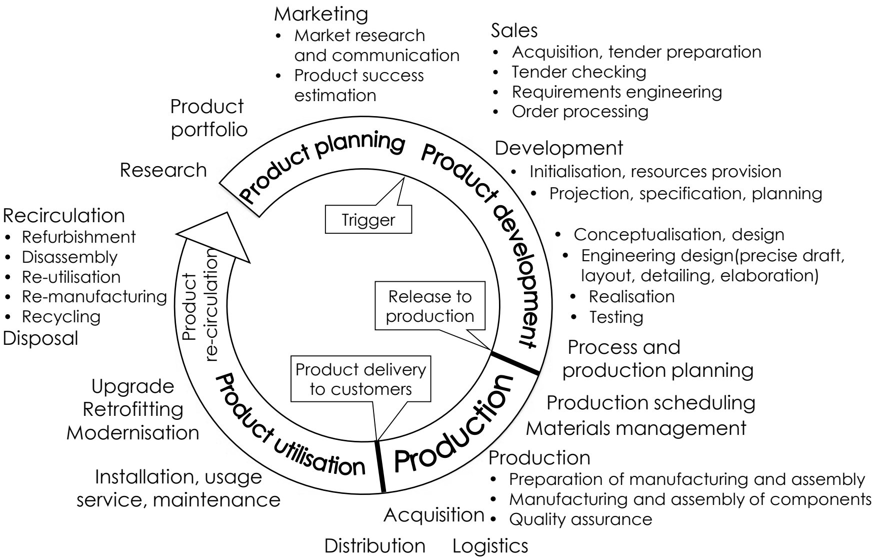


Fig. 2.2 Life cycle of a product

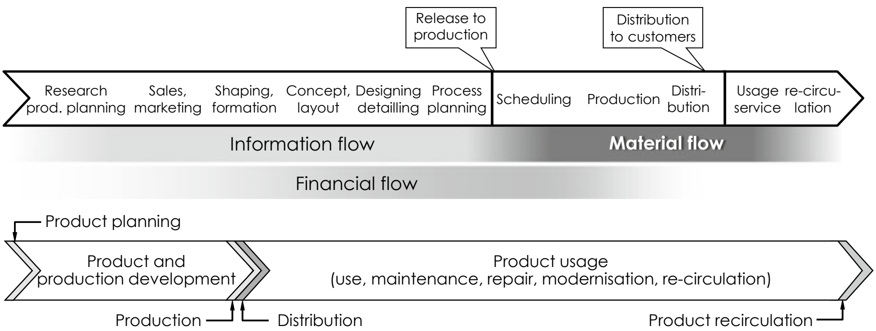


Fig. 2.3 Simplified representation of the product life cycle (PLC). Above: PLC with supporting flows. Below: PLC with the real temporal relations of the individual phases using the example of the life cycle of a passenger car [VWZH-2018]

generation, processing and passing on of information of any kind. It is implemented by corresponding IT systems (CAx systems, simulation and animation systems, PDM systems, ERP systems; see also Chap. 18), which communicate with each other via networks and which make it possible in product development to think ahead, to secure and to document products and their properties in advance in a virtual world (up to a complete model of the product to be developed for all phases of the product life cycle, the so-called ‘digital twin’). The main areas of application for the information flow are the phases prior to release to production. It shall also ensure that the knowledge gained in the life cycle phases of the product and both findings and experience of qualifications, strategies, practices, methods and tools, etc., can be used for the product life cycles of further products.

- The material flow has analogous tasks as the information flow but applies these to material objects. The material flow is realised by appropriate processing and logistic systems. Its main areas of application are the phases after release for production. At the end of the product life cycle, the material flow should ensure that the components used in the product are reused or reconditioned.
- The financial flow provides the financial resources for all the above activities and documents their use for business management purposes within the company. It also ensures that, for example, potentials and benefits achieved with a product are made available for subsequent products.

In addition, the simplified representation does not show a correct representation of the duration of the individual phases. In the lower part of Fig. 2.3 these are shown, for example, for a passenger car. For such a car, product planning and product development currently take about three to five years, production (without preparation for the new model) a few days, usage up to 15 years and product re-circulation only a few weeks.

In addition to the (and more technical) product life cycle described here, there is also the business product life cycle, which is discussed in Chap. 25.

2.2.1 Product Planning

The product life cycle starts with product planning, consisting of the research, product portfolio creation and marketing phases. Product planning serves to shape a company’s range of products and services depending on its target markets and the profitability and market leadership that can be achieved there (see also Chap. 24).

- On the one hand, research can act as a source of ideas in advance and provide the basis for innovations in products and processes. This can take place within the company or in cooperation with external research institutions. On the other hand, in-house applied research or technology departments are possible [BSSK-2008], which develop solutions for more fundamental and medium-term problems.
- To create the product portfolio, the strategic planning and all activities of the systematic search for as well as the selection and development of promising

product ideas for the relevant market segments of the company are first carried out. This includes analysing the history of comparable products in the market segment under consideration, the development and behaviour of potential customers' needs that could be satisfied with future products in the current market segment or with existing products but in other market segments, the behaviour of competitors and the situation regarding existing patents and utility models [HaGo-2004, Andr-2005]. Opportunities for longer-term market exploration taking into account a wide variety of situations, developments and their (hypothetical) interrelations (scenarios) can be captured using appropriate techniques [GrSP-2017] (see also Chap. 20). If marketability and profitability for the company or the expected added value for the customer are given (whereby the added value is a rather subjective variable compared to the objectively determinable profitability) are designed as well as the range of services of the possible products in the portfolio, the respective appearance (which as a rule is coined by the shape and behaviour of a product, in each case dependent on application areas and target groups) together with the interfaces to the planned user groups. Finally, it plays a role in how the relationship between product price and product service life will look in individual cases so that the development of successor products can be initiated in good time.

- Marketing comprises all tasks of consistently aligning the entire company to the needs of the market [Gab1-2020]. Market research is constantly on the lookout for future products and innovative ideas that can help the company to achieve economic success. A high level of marketing competence in the company promotes the success of the company at least to the same extent as product development and production, especially when identifying innovation potentials. On the one hand, marketing continuously monitors the demand situation in the markets and thus influences the development of the product through targeted information and specifications (communication). On the other hand, it conducts market research as soon as reliable ideas from product planning or product development are available as to whether and to what extent the planned environments or market segments in which the product could be placed are suitable. Chapter 21 deals with marketing in more detail.

2.2.2 General Triggers for a Product Life Cycle

The trigger for the product life cycle is an external and/or internal need situation that is caused by a demand for a product, whereby performance and behaviour in providing this performance are in the foreground of this demand. Such a situation arises, for example, from

- Orders from external and internal customers,
- A new constellation of the product environment (e.g. changes in environmental protection, scarcity of resources, legislation),
- The identiciation of market opportunities that could be served by the provider's capabilities,

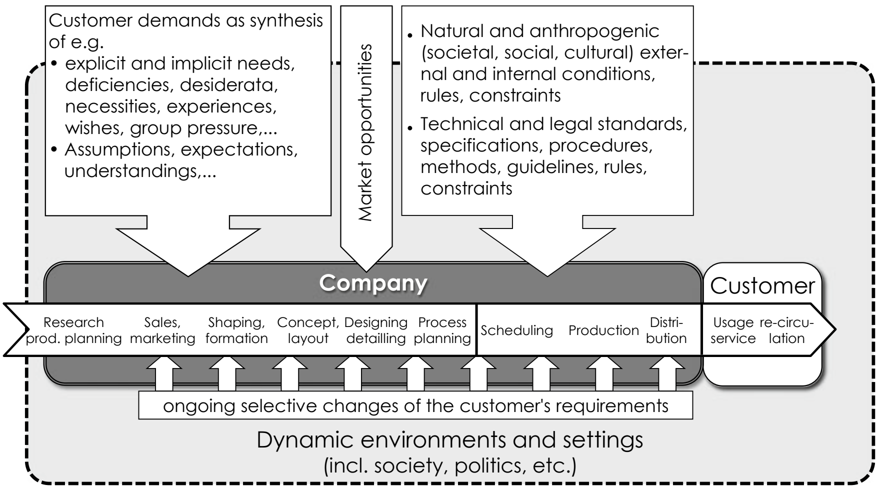


Fig. 2.4 From customer demands to a product

- A (concrete or unspecific) dissatisfaction with existing products and the desire for their improvement or further development,
- The human urge for new products (even if existing products meet the requirements but are no longer subjectively up to date) and
- Imitation drives which lead to the procurement or preference of certain products, even if these have objectively no further use than already existing products[4].

OTTOSSON [Otto-1996] subdivides the demand situation into

- Urgent needs[5] as (immediate) *needs to* be met,
- Needs resulting from an unspecific need or dissatisfaction, to be met in the medium term, through alternatives or accumulations[6] (wants), and
- The (not absolutely necessary) shaping of the necessity, an addition[7] to it or a (rather longer-term) *wish* for further development (*wishes*).

All these triggers can lead to product and business ideas. A summary of the most frequent possibilities for triggers is shown in Fig. 2.4. The company in which the product is to be created is embedded in its environment and settings (of which the most frequent influences are summarised in the right arrow), which is not stable but

[4]A burlesque and exaggerated example of this impulse to imitate can be found in *Obélix et Compagnie* by GOSCINNY and UDERZO [GoUd-1976].

[5]Analogue terms: Fixed claim, must-have criterion, compulsory subject.For example, Because it's cold, you need something to wear.

[6]Analogue terms: Minimum criterion (not only in the numerical sense), elective subject. For example, In cold weather, a thick sweater or a heavy coat or a thermal jacket (alternatives) or a thin sweater and a light coat (accumulation) serve the same purpose.

[7]Analogue terms: Desire criterion, elective subject. For example, The sweater should have a Norwegian pattern but does not have to.

can behave dynamically due to any and unforeseen influences. Similarly dynamic can also be the customer demand, which can change during the development of a product, for example, due to its increasing concretization.

2.2.3 Product and Business Ideas

Product and business ideas cannot be completely distinguished from each other. A product idea usually describes a product for a new or already existing field of application in the market, while a business idea must above all have the potential to establish an existence as a company. However, their development and treatment are comparable. They can be triggered either by the points described in Sect. 2.2.2 or by in-depth knowledge and intensive observation of the market and its needs, in particular through product planning (Sect. 2.2.1). However, they can also arise in any other area of the product life cycle, such as customer service and product re-circulation.

In principle, the following steps should be taken to develop a product or business idea.

- Determining the market potential of the product or business idea and the resulting options for action.
- Specification of the product or business idea in close observation of the market development.
- Creation of a first product strategy or the vision of the market application of the business idea (business field vision), the definition of the possible value chains.

If a business plan based on the previous steps shows sufficient profitability, then product development can start. The following sections describe these steps in detail, depending on the triggers.

Various methods are suitable for evaluating product and business ideas, of which the SWOT analysis [Gab3-2020] is very widespread. It is a portfolio with four quadrants with the following content:

- Strengths (S),
- Weaknesses (W),
- Opportunities (O) and
- Threats (T)

of/to the product or business idea, Fig. 2.5.

A SWOT analysis links external market opportunities or threats with the company's internal strengths or weaknesses. Only when the opportunity is one that could exploit the strengths of the company or improve the market position of the product, the opportunity should be seized. If the opportunity is good, but the product or company has weaknesses, then these must be eliminated. If the product is good, but the market shows risks beforehand, then the market should be observed. If there are

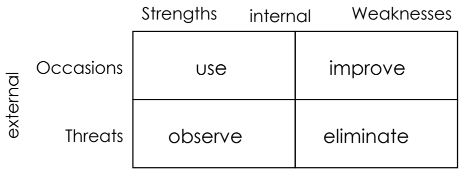
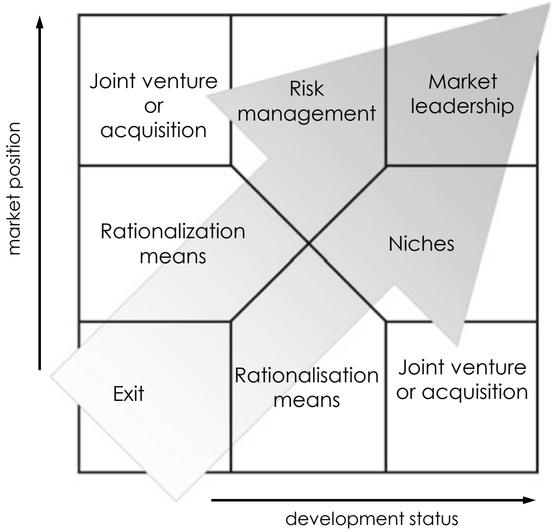


Fig. 2.5 SWOT analysis portfolio [Gab3-2020]

Fig. 2.6 Alternative competitive strategies



dangers and the product shows weaknesses, then the weaknesses must be eliminated or the market entry does not take place at all.

When developing a product or business idea with which one does not move alone in the market, potential competitors must be taken into account. Figure 2.6 shows the resulting alternative competitive strategies.

- If the company's market position is low and the current business idea too vague, it makes economic sense to opt-out.
- With a medium market position and medium development status, the realisation of the business idea can be improved by appropriate rationalisation measures and the cost structure of the company can be rationalised in order to be competitive with this business idea on the market.
- If either the market position or the development status is high, a merger with a competitor or the strategic purchase of the competitor should be considered.
- In case of high development status and medium market position, the company should concentrate on niches[8].

[8]One of the essential foundations of the economic success of German companies is that they repeatedly discover or create such niches and become international market leaders in them.

- If the market position is good but the development status only medium, then the risk of introducing a new product or service must be examined before further steps are taken.
- If market position and development status are equally high, then the company must strive for leadership in the targeted market by anticipating demand situations.

In the case of a product or business idea that is in the top left-hand corner of the SWOT analysis (i.e. in the first quadrant), but for which there is no concrete demand situation yet, a company acts proactively by

- offering innovative (partial) solutions for existing and introduced products, which as distinguishing features offer higher added value for the customer and higher profitability for the company.
- identifying latent, emerging demand situations through continuous market observation (market opportunities) and evaluates them on the basis of suitable indicators (scouting), influences them in its sense and is the first to satisfy the market with suitable innovations if this situation proves to be economically viable.
- facilitating subjective worlds of experience as well as the increase of the emotional attitude of life and well-being by owning the product[9].
- creating new needs in the market itself or even a new market in order to satisfy them as the first and (for a longer period of time) only supplier with own products[10].

If there is a problem to be solved, YANNOU proposes the following procedure to satisfy the resulting needs [Yann-2001]:

- The first step is to document the problem without redesigning an idea or adapting existing solutions.
- Second, to estimate possible savings, added value and profitability (see Sects. 3.4.1 and 3.4.2 and Chap. 25) that would arise if the problem were solved successfully. This estimate provides the maximum possible financial framework for product development.
- If a prospective consideration of costs and benefits shows that the product can be realised within this financial framework with the company's available resources, product development can begin.

Further aspects that influence both market and demand situation are procedures, conditions and constraints that may result from the legal environment or from generally accepted moral and ethical concepts. Responsibility for the new product, for example in terms of sustainability, must not be neglected.

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[9] For example, You are one of the first, chosen or coolest people to own this product.

[10] These include products that are developed in line with the 'Blue Ocean' strategy, for example. Such products are not built for an existing market ('red ocean') but create their own market ('blue ocean'), still unoccupied by competitors [KiMa-2005]. A prominent example is Apple's products (see also Footnote 30 in Sect. 1.6.1).

2.2.4 Triggers in the Capital Goods Industry

The capital goods industry manufactures products in which other industries invest in order to produce additional products for end consumers in different markets or, on the other hand, for further industries. In this case, the product life cycle is triggered by a specific customer, who places a specific order to a specific manufacturer (business-to-business relationship, B2B, 1:1 relationship), if the customer gets the impression that this product is able to generate economic and ideational added value for him.

First, the customer's requirements for the performance and behaviour of the product when performing are recorded (Sect. 2.1). This must be done carefully, especially if the customer and not the manufacturer[11] has the final product liability.

The specifications are formulated on the basis of the manufacturer's particular circumstances and jointly agreed upon with the customer. If necessary, requirements and specifications are updated in the event of changes to the customer's specifications, changes in the environment (e.g. legal situation, new scientific findings, etc.), Fig. 2.7.

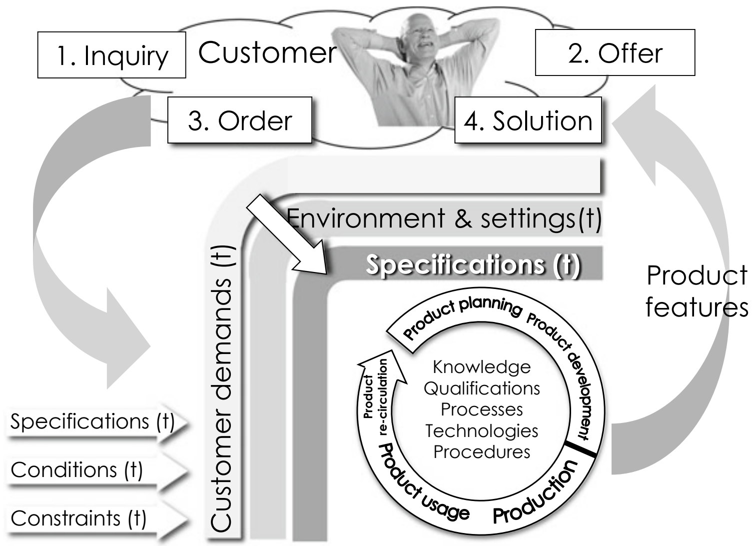

Fig. 2.7 Triggers of the product lifecycle in the capital goods industry. The actions are numbered according to their chronological order (see also Fig. 2.4)

[11] As a rule, this is the case with customers, who build their own products from components from their suppliers and assume full product liability for the resulting product themselves vis-à-vis their own customers.

2.2.5 Triggers in the Consumer Goods Industry

The consumer goods industry produces products directly for the end customer (user or consumer[12]). In this case, potential customers usually form relatively heterogeneous groups, which usually do not express their ideas about the product precisely but rather vaguely. Nevertheless, as mentioned in Sect. 2.1, a consumer expects a product with certain performance and with certain behaviour in providing this performance, both of which promise him a subjective added value. In order to survive in this environment, the company must dispose on extensive and continuously updated knowledge of the market and the market participants (potential customers, opinion-makers/influencers, peer groups, competitors, etc.). It can acquire this knowledge, for example, through market observations, analyses and research.

In the consumer goods industry, a company works without a direct sales order. If it wants to offer a product for this vague demand situation, it must check in advance,

- what characteristics the product should have so that it can succeed on the market (scouting),
- whether it is morally[13], technically, organisationally and economically capable of developing and manufacturing the product. In addition to technical feasibility and investment capability, this also includes adherence to the time window in which the product must be on the market in order to be successful (time-to-market),
- whether the sales potential is sufficiently large and lasting for economic success, and whether the company is in a position to ensure the (changing) demand of the market at all times with a sufficient number of products,
- whether it is opportune to launch the product on the market now and thus define its area of influence, even if the sales potential cannot yet be assessed in the short term, and
- whether other markets could be served with the same product without major adjustments.

If the company has gained the impression that it is economically profitable and strategically sensible to launch the product (and that this is in line with the possibilities and capabilities of the company), an internal order to trigger the product life cycle takes place, Fig. 2.8.

[12]Present participle of the Latin word *consumere* (consume, use up).

[13]Example, No use of child labour or wages of an exploitative nature.

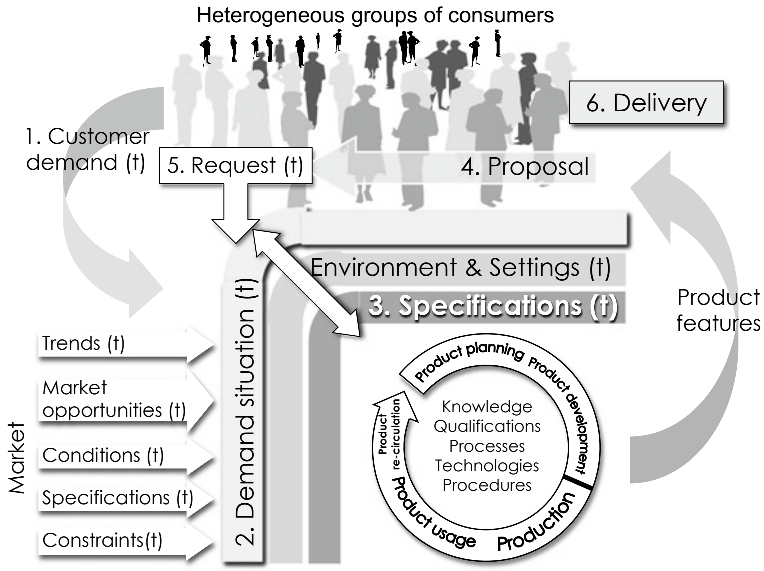

Fig. 2.8 Trigger for a product life cycle in the consumer goods industry. The actions are numbered according to their chronological order (see also Fig. 2.4)

2.2.6 Product Development

The phases of the product development are by far the most important phases in the product life cycle because here all relevant characteristics and data of a product for all other areas of the enterprise and for all phases of the product life cycle are specified[14], Fig. 2.9 (see also Fig. 1.1). These phases contain all activities for the geometrical, material, IT and structural implementation and design of a product idea up to the elaborated product. In doing so, it does not matter whether it is a completely new development (new design), a modification of existing solutions, also with partial new design (adaptation design) or the creation of a new solution from existing and possibly adaptable components (configuration and combination).

The sales phase is the link between product planning and product development. It covers all tasks from customer acquisition to maintaining relationships with existing customers and selling old and new products [VDMA-2008]. Above all, customer demand is of great importance, as it provides information about future chances of success on the market. Offers are prepared for interested parties after they have been checked for technical feasibility and economic benefit for the company. If an external or internal order is received, the sales department manages the requirements relevant

[14]However, it may well be possible that the implementation of the specifications from product development in the following areas deviates considerably from the specifications with regard to quality, deadlines and costs [EhMe-2017].

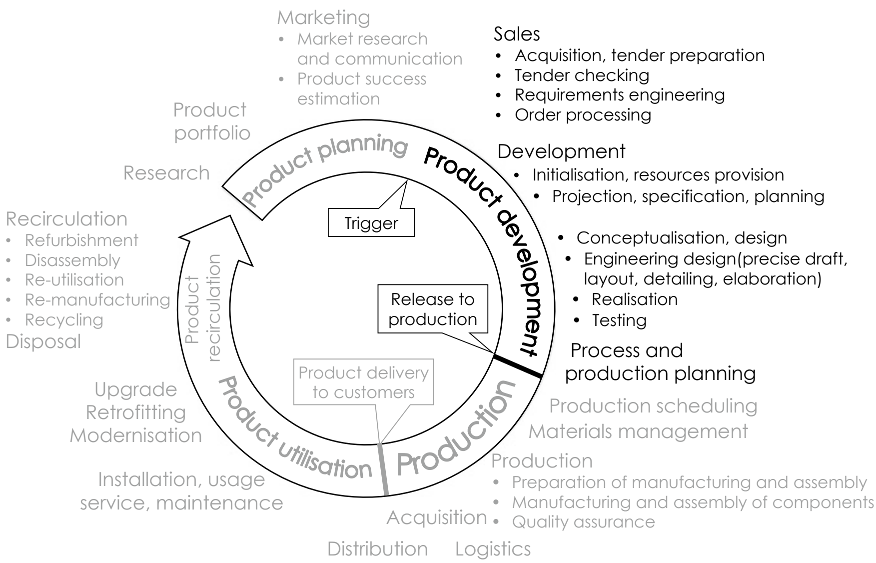

Fig. 2.9 Product development

to the order together with the development department (requirements engineering, Chap. 19) and ensures communication with the respective customer.

Development starts with initializing and allocating capacities and resources. Afterwards, the development project can be specified and planned, using, for example, the holistic procedure model of IDE (Chap. 16). Ideas for innovative products are found either in isolation in the company, in cooperation with customers, with development partners and suppliers, or in mixed forms.

The following activities usually take place in parallel in strands (or threads), whereby these strands are often multiplicatively interlinked with each other.

- The first strand of activity comprises industrial design for the aesthetic and appropriate designing of the product.
- The second strand of activities includes the conceptual design, layout and concrete engineering design of the product with the aim of providing all the necessary documentation for its production, use and recycling.

The different approaches in these two strands of activities can lead to organisational and communication problems (see also Fig. 1.27, Sect. 1.5.2). Both result from the fact that in industrial design a geometric-material entirety is already developed in the early phases, because only in this way can the overall effect of the industrial design concept be analysed, evaluated and further developed. At this point, however, there are still no engineering design concepts in the other strand of activities.

To harmonise the cooperation between industrial design and the other strand of activities, a variety of co-ordinations, a sufficient number of iterations as well as a

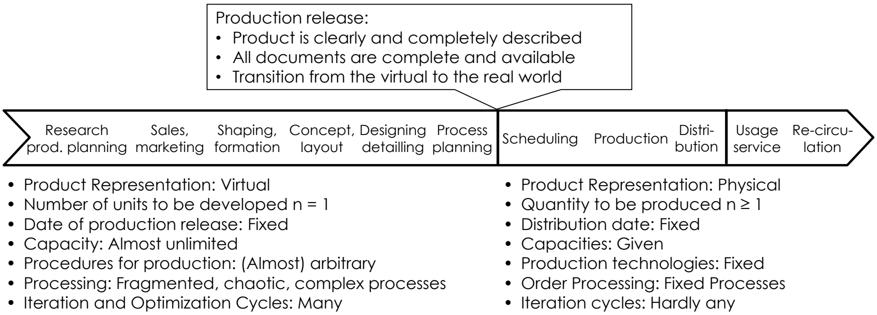

Fig. 2.10 Different conditions and machining strategies in product development and production

common database and powerful interfaces between the tools of computer support are used (e.g. CAID, CAx, simulation, Chap. 18; additive manufacturing, Sect. 9.2).

Iteration loops should always be used in all activities to optimise the current solution. Usually, after major progress in development, it is evaluated whether the resulting product is still promising.

- The (usually prototypical) realisation and testing of the product serve to secure the developed concepts.
- In process and production planning, it is first ensured that the product can be manufactured and assembled using the company's existing manufacturing capabilities (including external procurement of components). If this is not the case, the (strategic) decision must be taken as to whether the product should not be pursued further or whether production facilities should be adapted to the new requirements or new ones procured. In addition to determining raw part contours and creating control information, production planning also includes availability checks of an organisational, logistical and calculatory nature as well as the design of manufacturing aids and resources, in which the innovative design of plants and series prototypes is in the foreground [VDMA-2008].
- At the time of release for production, all documents relating to product manufacture, use and recycling must be fully described. The documentation can be done on different media[15]. The release triggers the start of production (SOP). At the SOP, the transition from the virtual world of product development, which is predominantly characterised by the flow of information, to the real world of production, which is predominantly determined by the flow of materials, takes place, Fig. 2.10.

[15] As of today, this documentation is provided completely in digital format as virtual models (see also Fig. 2.3). These can have a bandwidth ranging from individual, loosely linked computer-internal partial models to the complete product model, which covers not only the product in its respective development and deployment states but also the corresponding processes ('digital twin').

During the processing of these phases, external and internal influences and constraints can lead to a change in the requirement profile and the framework conditions. In this case, it must be checked whether the product still provides added value for the customer in order to maintain profitability for the enterprise. If this is not the case, there must be serious reasons (e.g. the strategic conquest of a market) for the development not to be interrupted.

2.2.7 Production

In production, the product created in product development is materialised on the basis of its documents on production, use and re-circulation, Fig. 2.11.

- Production scheduling deals with the planning of partial aspects of production. This includes parts production with order release, capacity control, sequencing and assembly. In summary, all measures for production and assembly preparation are associated with production scheduling [Lödd-2008].
- Materials management includes all activities for procurement, warehousing, disposition of (raw) materials, goods and services in appropriate quantity and quality, which are necessary for the creation of the product [VDMA-2008].
- Manufacturing carries out all operations necessary for the creation of the real product [Lödd-2008]. This includes parts production and assembly as well as test series required for quality assurance depending on the product.

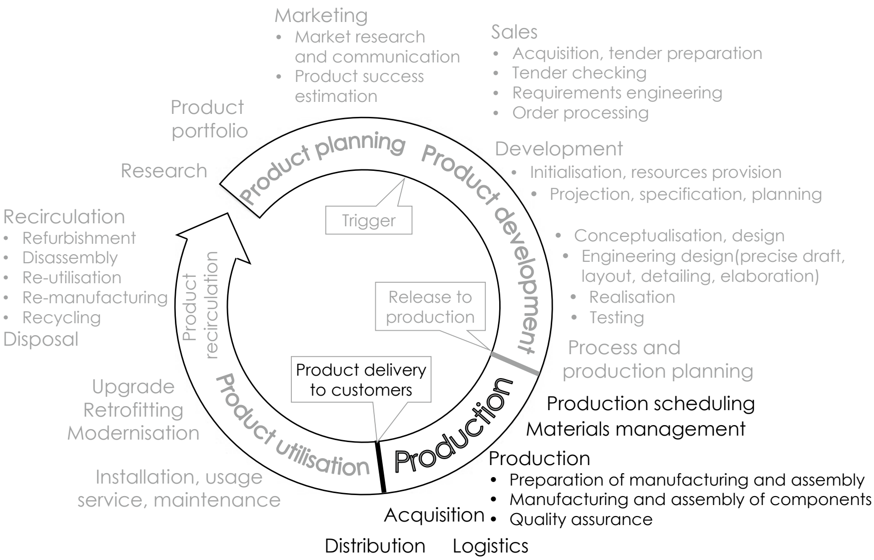

Fig. 2.11 Production

- Logistics includes all activities for the planning, coordination, execution and control of flows of goods and goods-related information in order to ensure, in the interests of smooth and efficient production, that the required objects are made available at the right time, at the right place and in the right quantity and quality [Gab2-2020].
- Distribution is the link between the company and its customers. It ensures that in the capital goods industry the products reach the customer and go into operation in accordance with the requirements, in the consumer goods industry a sufficient number of products are available in time for the start of sales at dealers and distributors.

2.2.8 Product Utilisation and Product Re-circulation

The longest phase in the product life cycle is the utilisation of the product, in which the use of the product provides the customer with the expected added value. At the end of product utilisation, there is the return of the components of the product and the materials used, Fig. 2.12.

- Product use includes the time interval from delivery and installation of the product at the customer, through utilisation, to its re-circulation [EhMe-2017].
- The service phase includes all types of customer support offered by the product manufacturer. Maintenance describes all measures of (preventive) maintenance to preserve and restore the condition of the product at the time of sale [DIN-60300].

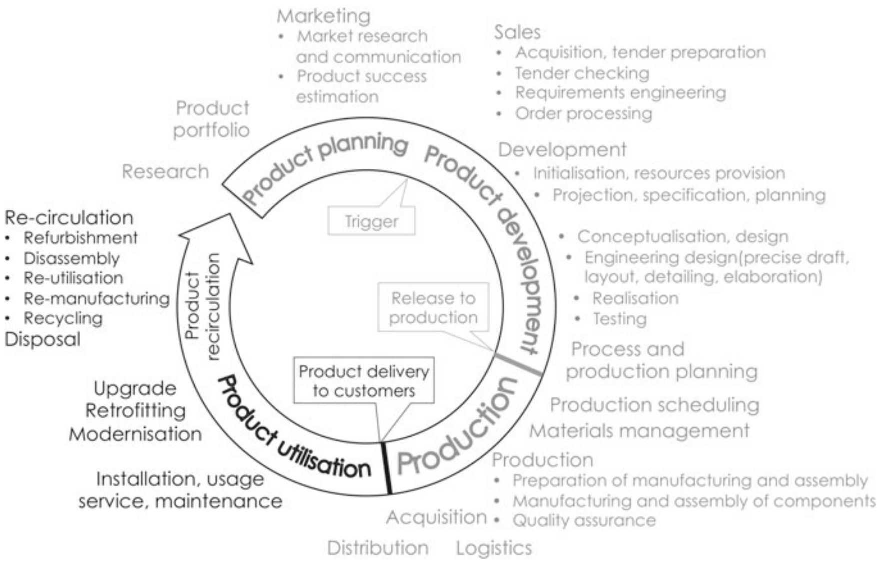

Fig. 2.12 Product use and product re-circulation

- Updating, retrofitting and modernisation describe all activities required to adapt the product to the state of the art or to the customer's wishes [VDMA-2008].
- The re-circulation of the product at the end of its useful life consists of dismantling, which includes all processes for disassembling the product as completely as possible into its individual parts (as unmixed as possible) [VDMA-2008], and the reprocessing of such components that can be reused. If reuse is not possible, the component must be disassembled into its components and these must be recycled, provided that recyclable materials have been selected for the product in the product development phase and that these materials are not inseparably combined in production.
- Disposal includes all activities for the professional disposal of products or product components [VDMA-2008].

2.2.9 Cross-Sectional Processes

To support product planning, product development and production, there are numerous cross-sectional processes [VDMA-2008], which can be applied in any phases of the product life cycle if required.

- Requirements management handles external (from the customer) and internal requirements (e.g. from another phase) as well as product development in relation to a specific order (order monitoring; see also Chap. 19).
- Change management describes any form of product change (recording, collecting, evaluating, deciding, planning, implementing and maintaining in the product documentation) in the form of firmly interlinked work steps (so-called workflow) and makes these available to project management.
- Project management comprises all measures and activities to achieve the project objective [DIN-69901], even under changing conditions (more details in Chap. 15).
- Quality management consists of measures for planning, steering and control, assurance, testing and improvement of quality in all phases in the sense of on-going quality assurance. It also includes the improvement of products and work processes in organisations [DIN-9000] (see also Sect. 13.2).
- Risk management plans and controls the handling of different types of risk (entrepreneurial, financial, technical, etc.) in each activity. If problems occur, it compiles information that can be used to make a comprehensible decision about how to proceed in the activity.
- Administrative processes ensure the provision of personnel (human resources department), information and material resources (information technology, office communication), cost and investment planning (controlling) as well as the creation and verification of invoices and delivery notes (accounting) [Scha-2001].

2.3 Generalisation of the Product Life Cycle

Section 2.1 stated that products can be a variety of artefacts from different disciplines and their (almost arbitrary) combinations, which can be considered together because of their similarities in performance and behaviour in performance delivery. In this chapter, it is examined whether the phases and processes for producing products differ or whether a generalised view of the activities for product development and production can also be derived.

As shown in Fig. 2.2, a number of phases are passed through the product life cycle. The adaptation to the concrete product to be developed takes place by the knowledge used for its realisation and the respective methods, procedures and tools used. This flow is in the rarest of cases sequential, but for reasons of prioritization and scheduling and capacity planning, it mostly flows in parallel. In addition, the requirements for the product and the environment in which it is realised may (and do) change as a result of new circumstances. The resources required for the production cannot always be made available on time and in the required quantity and quality.

The following figures refer to the simplified life cycle of a physical product in Fig. 2.3.

Just like the life cycle of a physical product, the life cycle of software[16] also begins with research and sales and marketing, the contents of which are largely identical to the corresponding phases in the product life cycle of a physical product. In the case of an order, the specifications are drawn up and may be subject to change. The subsequent phases up to release are also summarised under the terms decomposition and definition. These phases are interface design, requirements analysis with the specification, and design and release for modelling.

- The interface design defines the interface between the software and its user (either a human, a software, hardware, ort combinations of these). Both the actors and the software application area(s) influence the interface.
- In the requirements analysis and specification, the contents of the specifications are evaluated in order to specify the concrete requirements for the software. It may be necessary to program the first (very rough) prototypes.
- With the emergence of the software architecture, its structure and its components as well as the network of interrelationships between the components are designed and developed in the system design phase. The modelling designs the corresponding data structures.

After the release for programming and implementation as well as the (quite extensive) testing of the developed software at the manufacturer, the software is delivered to the customer, where it is implemented and introduced. These phases are followed by the software utilisation. At the end of the software life, either a change to a new version or a replacement by another software (migration) takes place. These phases are also referred to as integration and verification. After the software

[16]This description and Fig. 2.13 are based on the essential contents of the V-model, an international development standard for IT systems, which has its origin in software development [IABG-2013].

has been included in the maintenance, the software content is changed at certain times (troubleshooting, improvement of individual software components, preventive replacement of potentially error-prone components) and versioned (determination of a new version, i.e. a larger change status of the software as a new working basis), and then the new software version is distributed to the users, Fig. 2.13.

The life cycle of a service also begins with research, sales and marketing. Requirement analysis and specification refer to the target group and application area of the service to be developed, followed by its design and fixation in appropriate documentation and training documents for the persons who will provide the service, as well as release for use in the application area. This is followed by the implementation of the service and, if required, testing in a prototypical area of application, followed by training of the providers, the actual market entry, the application of the service and its further development (if required). The life cycle ends with the withdrawal of the service from the market (Fig. 2.14).

The lifecycle of a consultancy contains essentially the same phases as the lifecycle of the service. However, consulting differs in the different relationship between provider and user, since a consultant usually develops his concepts only for the phases up to design or fixation and is only available for the implementation of his consulting if required (and at additional cost) (Fig. 2.15). Frequently, implementation is also carried out by third parties, e.g. by the company itself.

Figure 2.16 shows a comparison of the activities of the life cycles described here. The grey arrows in the software products, service products and consulting products

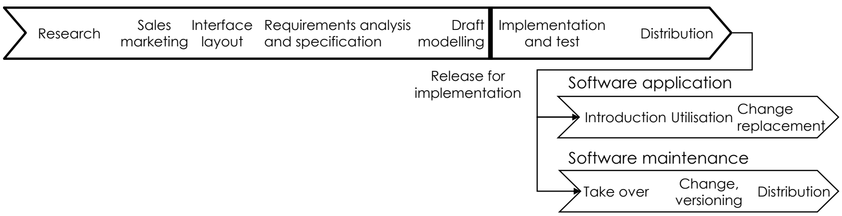

Fig. 2.13 Software life cycle

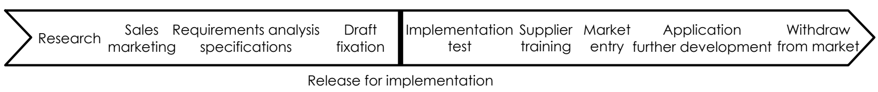

Fig. 2.14 Service lifecycle

Fig. 2.15 Life cycle of a consultation (the phases shown in grey are usually not part of a consultation)

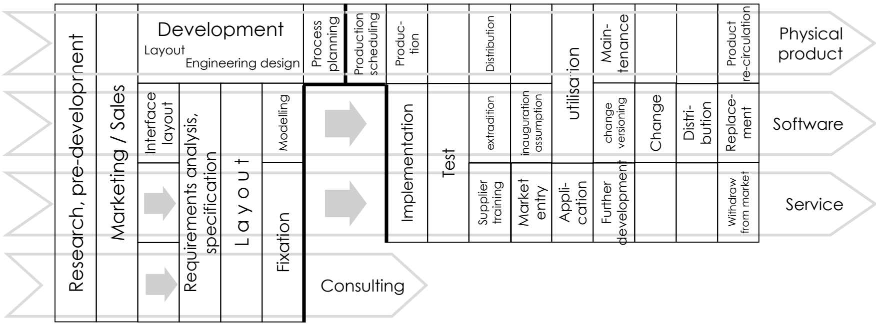

Fig. 2.16 Comparison of the four life cycles

indicate that there are no direct correspondences between the phases process planning and production scheduling in the life cycle of physical products and the other life cycles due to the work with intangible objects so that a direct transition takes place from the phase of modelling or fixing into the phase of implementation.

The conformance of the individual phases in the four life cycles is great. Differences between the phases can only be found with very detailed consideration of individual artefacts. This allows the generalisation of the process description. Since products are the result of processes, the generalisation of processes is followed by the generalisation of products (in addition to the similarities mentioned in Sect. 2.1).

As will be described in Chap. 3, Integrated Design Engineering and its approaches, methods, procedures and tools can be used to produce arbitrary artefacts as well as for a generalised description and management of the required processes.

References

[Andr-2005] Andreasen, M.M.: Vorgehensmodelle und Prozesse für die Entwicklung von Produkten und Dienstleistungen. In: Schäppi, B., Andreasen, M.M., Kirchgeorg, M., Radermacher, F.J. (eds): Handbuch Produktentwicklung. Hanser München, S. 247–263 (2005)

[BSSK-2008] Balzert, H., Schäfer, C., Schröder, M., Kern, U.: Wissenschaftliches Arbeiten: Wissenschaft, Quellen, Artefakte, Organisation, Präsentation. W3L Witten-Herdecke (2008)

[DIN-69901] DIN 69901, Projektmanagement – Projektmanagementsysteme. Beuth, Berlin (2009)

[DIN-9000] DIN EN ISO 9000, Qualitätsmanagement – Grundlagen und Begriffe. Beuth, Berlin (2005)

[DIN-60300] DIN EN 60300-1 Zuverlässigkeitsmanagement – Teil 1: Leitfaden für Management und Anwendung. Beuth, Berlin (2010)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, 6. überarbeitete und erweiterte Auflage. Hanser München (2017)

[Gab1-2020] Gabler Wirtschaftslexikon, https://wirtschaftslexikon.gabler.de/definition/marketing-39435. Accessed 28 July, 2020

[Gab2-2020] https://wirtschaftslexikon.gabler.de/definition/logistik-40330. Accessed 38 July 2020

[Gab3-2020] Gabler Wirtschaftslexikon, https://wirtschaftslexikon.gabler.de/definition/swot-analyse-52664/version-142312. Accessed on 28 July, 2020

[GoUd-1976] Goscinny, R., Uderzo, A.: Obélix et Compagnie. Une Aventure d'Astérix le Gaulois, Band 23. Dargaud Éditeur Paris (1976)

[GrSP-2017] Gräßler, I., Scholle, Ph., Pottebaum, J.: Integrated process and data model for applying scenario-technique in requirements engineering. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), vol. 3: Product, Services and Systems Design, Vancouver, Canada, p. 21. 25.08.2017

[HaGo-2004] Hales, C., Gooch, S.: Managing Engineering Design, 2nd edn. Springer, London (2004)

[IABG-2013] Homepage of the company Industrieanlagen-Betriebsgesellschaft mbH Ottobrunn, http://v-modell.iabg.de. Accessed 23 May 2013

[KiMa-2005] Kim, W.C., Mauborgne, R.: Der Blaue Ozean als Strategie: Wie man neue Märkte schafft, wo es keine Konkurrenz gibt. Hanser München (2005)

[Lödd-2008] Lödding, H.: Verfahren der Fertigungssteuerung, 2nd edn. Springer, Berlin (2008)

[Otto-1996] Ottosson, S.: Dynamic product development—findings from participating action research in a fast new product development process. J. Eng. Des. **7**(2), 151–169 (1996)

[PiVS-2019] Pilz, F., Vajna, S., Schabacker, M.: Achieving simplicity: a consideration of a systematic approach. In: Proceedings of the ASME 2019, IDETC2019- 97143 Anaheim

[Scha-2001] Schabacker, M.: Bewertung der Nutzen neuer Technologien in der Produktentwicklung. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[VDMA-2008] VDMA: PLM-Leitfaden. VDMA-Verlag Frankfurt (2008)

[VWZH-2018] Vajna, S., Weber, C., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S.: CAx für Ingenieure – Eine praxisbezogene Einführung, dritte Auflage. Springer, Berlin (2018)

[Yann-2001] Yannou, B.: Préconception de Produits. Memoire d'Habilitation à Diriger des Recherches (discipline Mécanique). LPL; Ecole Centrale Paris (2001)

Chapter 3
Foundations of Integrated Design Engineering

Sándor Vajna

Integrated Design Engineering (IDE) is the further development and extension of the Magdeburg model of Integrated Product Development [Burc-2001, Sect. 1.5]. It also contains elements of dynamic product development [Otto-1996, Sect. 1.4], user-centred design [e.g. ISO 9241-210], sustainable product development [e.g. Rutt-2012, Chaps. 5 and 12], Design for X [BoDe-2003, Meer-1994] (Sect. 14.1.1) and work and organizational psychology [Aamo-2015]. IDE is human-centred, because the human being with his abilities, possibilities and qualifications is in the centre of all considerations within IDE with all his activities concerning planning, development, production, use, maintenance and re-circulation of products (and the possible impairments linked to these activities). In IDE, humans can take on different roles, namely those of the customer (buyer, user[1], sponsor, patron) or those of the provider (developer, manufacturer, distributor, etc.) or they can be affected by activities in the product life cycle of the product (Chap. 4). Only humans can generate, acquire, apply and pass on knowledge and thus design and control all activities within IDE. IDE enables the development of such products that are limited to the essential in every respect (sufficiency); it thus contributes to the sustainable development of sustainable products (see Chap. 12). Due to its many possible applications, IDE is embedded in the (active and latent) knowledge associated with the respective topic (for knowledge integration, see Chap. 17).

- While IPD primarily focuses on the development of mechanical products, IDE can design and develop both arbitrary material and immaterial products described in Chap. 2 from all possible disciplines and in all conceivable combinations.

[1]In the context of IDE, a user is not a person whose actions are determined by the respective product. On the contrary, the user acts, when dealing with the product, autonomously, on his own responsibility, self-determined, appropriately and independently [following SuRK-2020, Frit-2020].

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- Within IDE, a product is described by its *performance offer*. This is composed of the performance of the product and its behaviour when providing this performance.
- The description of the performance offer is carried out in a neutral, non-prejudicial form with *attributes*, with which a partial to complete as well as general to concrete description is possible, which does not (but can) specify a certain form of realization (in one or more disciplines). Thus, the attributes form a *neutral interface* between customers and providers. Over this interface, both can exchange and compare the desired (customer) and/or existing performance offer (provider) with each other (Sect. 3.4). For the customer, the description with attributes offers advantages: As the names of the attributes are derived from the customer's daily vocabulary, it is easy both to create the description and to adapt it simply and consistently to changed desires, requirements, conditions and defaults (e.g. changing desires, future developments, other conditions)[2]. The description does not need to be complete and does not need to have a certain level of detail. The task of the provider is the realization of the concrete product based on the customer's description with attributes. This approach is beneficial, because the provider is free to choose and organize the realization of the product. He can choose both resources and the disciplines for the realization according to his own possibilities, he can decide on the concrete realization forms at the latest possible time and thus choose the most favourable forms and procedures for him[3]. As soon as the product is developed, he now describes the actual performance offer himself with attributes in order to be able to compare his own description with the customer's description.
- Organizations and processes used in IDE are characterized by intensive communication, interdisciplinary teamwork of all groups involved in IDE (also across physical and cultural borders), dynamic forms, structures and procedures with little hierarchy and procedures that can be parallelized to a high degree if necessary, so that it is possible for the human being to act holistically in the product life cycle. The IDE procedure model (Chap. 16) ensures that each task can be considered and performed appropriately.
- The methods from different disciplines, which are independent of products and processes, include not only well-known methods and procedures of product development, but also creativity techniques, learning and problem-solving methods and time management for holistic and integrated solution finding, taking into account the relational and dependency networks that occur in the process, which are discussed in Chap. 22.
- Procedures and technologies used for support (today usually computer supported) enable a holistic support of activities, processes, methods and procedures. This concerns the adequate and appropriate use of modern information processing

[2] A customer formulates his demand for a product on the basis of his current needs and expectations, using his current level of knowledge. All these can change. The topicality and validity of his request are therefore limited in time. If these change, it must be possible to simply adapt the demand.

[3] For example, the requirements for mobile phones in terms of performance, operability and usage behaviour, energy consumption, size and weight can only be met at a high level by interacting realizations in the disciplines of mechanics, electrics, electronics and software (=mechatronics).

systems, which include production systems (mainly CAx systems), data and activities management systems (e.g. PDM, ERP), knowledge processing systems, storage systems (archives and databases) and networks. Available technologies are presented in Chap. 18.

The components of the name *Integrated Design Engineering*[4] have the following meanings:

- *Integrated* stands for the integration of views and intentions, concepts, areas, domains and disciplines, products, organizations and processes, methods, knowledge, applications and information, etc., with the aim of completing them into a whole in the sense of HEGEL'S dialectical approach with the argumentation triangle thesis–antithesis–synthesis (Sect. 1.5.2 and footnote 27). These different aspects are described using eleven integration types.
- *Design* includes intention, plan and pattern, purpose, result and arrangement of objects or artefacts. DYSON describes design as the whole of what makes a product, namely the technology, the engineering design, the materials, the reliability, the ergonomics, the joy of using the product, the software [Dys-2010]. Eleven attributes are used to describe the performance of a product and the associated behaviour when providing this performance in the respective area of application in a neutral manner.
- In addition to the planning, engineering design, and documentation of artefacts, *engineering* includes the application of knowledge, methods, procedures, tools for the realization (formation, design, positioning) of objects, artefacts, technologies, methodologies, etc., and thus the interaction of all activities and the disciplines and domains involved for the realization of the defining properties of a product in a dynamic environment of changing demand situations, combined with modelling and controlling influences of process and project management [Webs-1983, ECPD-1947]. For the holistic planning and execution of product development, eleven basic activities are available in IDE procedure model (Chap. 16).

IDE with its axioms human centricity , solution-neutral product description by attributes, integration and interdisciplinarity provides a holistic model for describing, designing and predicting the life cycle of a product that is sustainable in every respect, including its realization and use in the broadest sense (Fig. 3.1), taking into account the concerns of economic product development.

Similarities and commonalities of IDE with other overarching approaches such as Systems Engineering (e.g. Daenz-1992) and Design Thinking [e.g. Burc-2017] are the interdisciplinarity of the approaches, the early and comprehensive involvement of the customer and his requirements, the processing by multidisciplinary teams and the ex-ante consideration of the life cycle of the (emerging) product.

The main distinguishing features of IDE, on the other hand, are the consistent human-centred approach, the uniform product concept across disciplines and areas

[4] When developing IDE, it was discovered during the naming process that the semantics of the English terms "design" and "engineering" can be used to cover a wider range of meanings than the German terms "Konstruktion" and "Ingenieursarbeit".

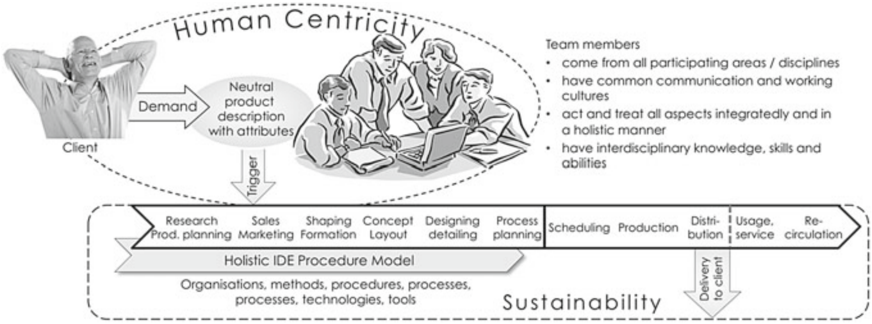

Fig. 3.1 Basic structure of Integrated Design Engineering

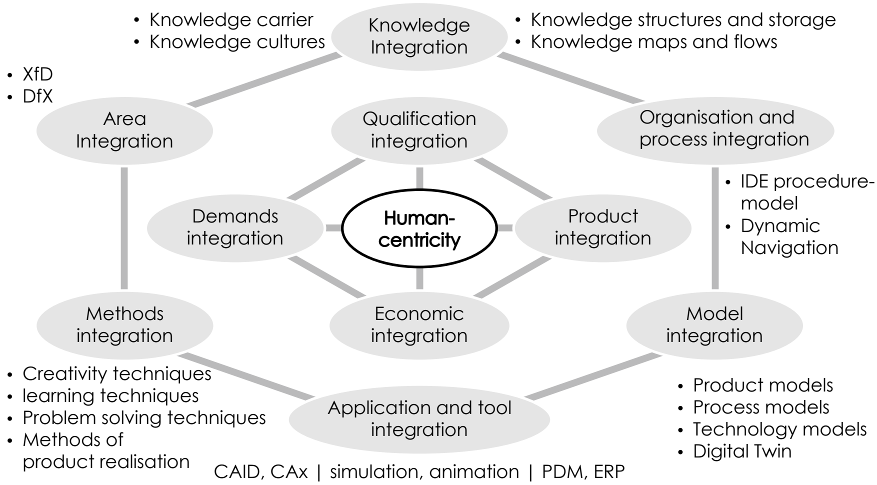

Fig. 3.2 Integration types within IDE (with selected content for individual integration types)

of application, the solution-neutral description of a product by its performance capability and its behaviour in the performance provision by attributes without specifications for the implementation of the product, as well as the fundamental dynamic approach for all activities in the field of product development with holistic recording of all influences from the product life cycle.

3.1 Integration Types in IDE

From the basic structure of IDE in Fig. 3.1, eleven integration types can be derived, Fig. 3.2. All integration types can influence each other and thus ensure that definitions and activities in IDE remain holistic and consistent.

The focus is on human centricity (Chap. 4), surrounded by an inner and an outer circle of integrations. The inner circle consists of the integration of qualification (Sect. 4.3), demand (Sect. 2.2.2), resulting products (Chap. 2) and product integration through attributes (Sect. 3.2) as well as economic integration (Chap. 25).

The outer circle contains the types of integration for knowledge, areas, organizations and processes, methods, models, as well as the integration of applications and the (usually computer-aided) tools used for them.

- Knowledge integration (Chap. 17) describes the provision of the complete knowledge about the product in a holistic knowledge base. This also includes all conceptualization, development, processing, manufacturing, distribution, utilization and re-circulation processes, methods, procedures and technologies as well as the environment in which the life cycle of the product is intended to run. Knowledge integration ensures that the knowledge components required for a current task or process step are provided appropriately, at the right place, at the right time and for the right people.
- Area or department integration (Chap. 14) includes all employees and divisions that are directly involved in the genesis of the product, as well as customers, partners and suppliers, as required. Thanks to the interdisciplinary co-operation of the groups of people involved, trends and definitions of all kinds, especially those that affect the entire product life cycle, can be made together at appropriate times and the results or alternatives compared with the expected results, in order to finally make a meaningful decision as late as possible. To support such decisions, product life cycle areas are continuously simulated and evaluated.
- Organization and process integration (Chap. 15) comprises all measures that are necessary to describe, combine and improve organizational forms as well as business and development processes. These concern both the structure of an organization and the way in which and under what conditions tasks are carried out within it. In IDE, organization and task processing must be flexible in order to be able to proceed in a focused manner on the one hand and to react appropriately to changes in requirements and environment on the other.
- Method integration (Chap. 22) brings together all flexible and powerful problem-solving methods as well as creativity and learning techniques with context-sensitive delivery.
- Model integration (Chap. 18) deals with physical and digital models (and hybrids thereof) that are created and processed during product development, for example design models made of clay and wood, physical and digital prototypical models (mock-ups) up to the complete computer-internal model of a product through all phases of its life cycle and in any completeness and granularity, the so-called digital twin.
- Application and tool integration (Chap. 18) describes the networked use of IT systems for continuous computer support in all phases of product development. It ensures that the appropriate IT application system is available for each task and at any time. In addition, there is a uniform, complete, consistent and continuous

information base for redundancy-free storage and the avoidance of interfaces to a large extent.

3.2 Attributes Within IDE

A product must be able to fulfil the demands expressed by a customer[5] in the broadest sense by its range of services (Fig. 2.4). For this purpose and for its (hopefully successful) use in a given (and possibly changing) environment, each product has individual characteristics that define its nature (for the product concept, see Sect. 2.1). These indicators can appear as *characteristics* and as *properties*.

- Characteristics describe the appearance of the product in various forms. These are geometric shape, dimensions, material, weight, surface texture and colour as well as the product structure, if the product consists of several components. Weber states in his design theory *Characteristics-Properties Modelling/Properties-Driven Development* [CPM/PDD Webe-2005, Webe-2011] that only the characteristics can be directly influenced by the developer, Fig. 3.3.
- Properties result from the interaction of characteristics, for example the tolerances showed in Fig. 3.3 as a result of the interplay of shape, material and production technologies. According to Weber, therefore, they cannot be influenced directly, but only by changing characteristics. However, a co-ordinated mixture of characteristics and properties has a significant influence on the performance and behaviour of a product.

However, the strict separation between characteristics and properties postulated by Weber cannot always be maintained. Characteristics can become properties if, for example, the customer requires a certain surface finish.

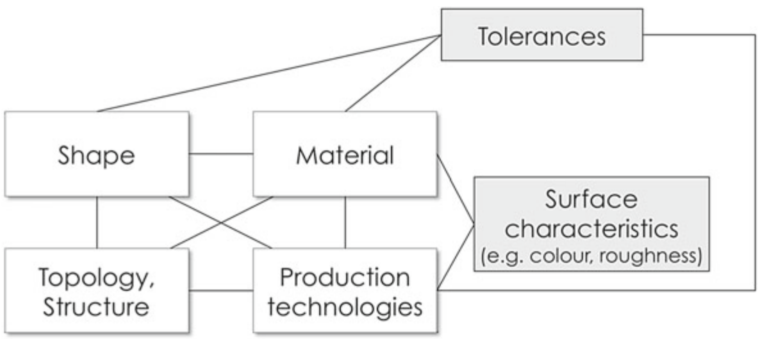

Fig. 3.3 Characteristics of a product (can be directly influenced by the product developer). Grey boxes: product characteristics resulting from the interaction of individual features [according to Tjal-1979]

[5]For the different roles of a customer (buyer, user, sponsor/patron, affected persons), see Sect. 4.3.

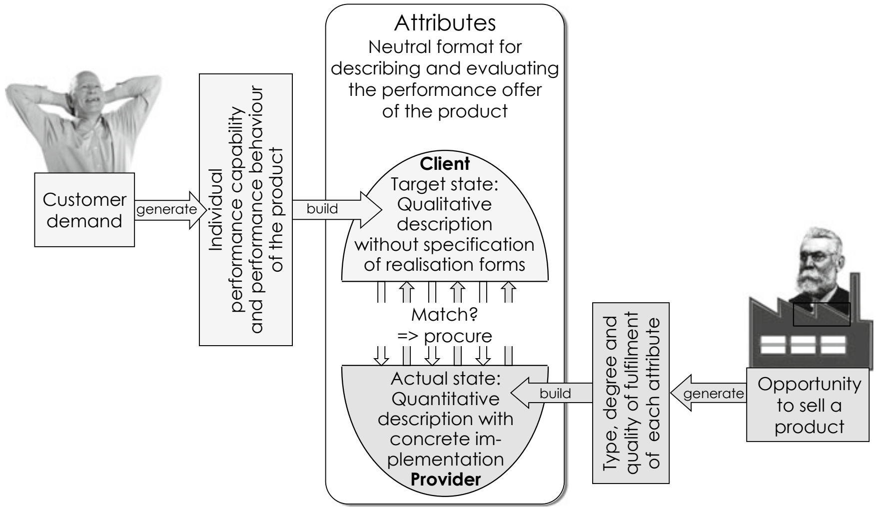

Fig. 3.4 Basic role of the attributes

Instead, IDE follows an integrated approach, in which characteristics, properties, features and nature types of a product are described with *attributes* of this product, evaluated according to the respective level of fulfilment and combined to an attribute profile. From the customer's point of view, the resulting attribute profile (target profile) describes a target state of the desired product in the form of a *qualitative* description, independent of possible types of realization[6]. From the provider's point of view, the resulting attribute profile (as-is profile) describes the current as-is state of the offered product in *quantitative* form with concrete types of realization, Fig. 3.4.

The characteristics of attributes described in the following ensure that both development and realization of a product can generally be carried out "backwards" from the perspective of customer demand or market opportunities (customer pull). In individual cases, this does not exclude the creation of new needs in the market and their (simultaneous) satisfaction by the provider (push). In both cases, a higher consistency in the fulfilment of customer demands by the provider as well as an increased flexibility to master (increasingly frequent) changes of demands and specifications during the already on-going product development is also achieved.

Attributes in IDE[7]

- serve for the neutral, complete, holistic and multi-criteria description and evaluation of the performance offer (i.e. performance and performance behaviour) of a product as a result of the interaction of its attributes. This neutral presentation

[6]The target profile plays the same role as the specifications list used in other product development models, for example the VDI Guideline 2221 (Sect. 1.1.2; see also Sect. 19.2.1).

[7]German and English names of the attributes have been chosen so that they can be interpreted unambiguously. This enables a clear and reproducible evaluation of the respective fulfilment of each attribute and the comparability of the attribute profiles of different products with each other.

allows products to be compared with each other at any time via their respective attribute profiles (target profiles and as-is profiles), without possible realizations (divided into discipline, type, form, process and time) playing a role. Rather, this approach makes it possible to decide on the realization of the performance offer at the latest possible point in time. Up to this point, the choice of the concrete realization of each attribute remains open. Due to this temporal decoupling, the product developer in IDE is not restricted in his creativity by the boundary conditions of realizations from the outset when designing and developing the product. Rather, he can develop his creativity freely and act individually. In addition, advances in technologies, organizations and processes can be incorporated into the realization of the attributes at any time. On specific customer request, however, concrete realization forms of the product can be determined by specifications.

- take into account that customer demand today goes far beyond the mere provision of functions. Rather, there are not only demands and expectations on the customer side with regard to product functions, but also demands and expectations on sustainability in the production and user-friendly application of the product, on an aesthetic and pleasing design, on adequate availability at the desired time of procurement of the product and on high reliability and quality in the use of the product. All this ensures that the customer gets a high added value from owning and using the product. Accordingly, a provider expects to be able to develop, manufacture and distribute the product using the capabilities of its business and that this will result in a reasonable return on investment.
- are always present in the product and throughout the entire product life cycle.
- each have the same meaning, importance and value for a product, as there is no hierarchy of attributes. However, attributes are not identical, since there are always several equivalent possibilities for the realization of a requirement [VaKB-2011], although not always in the same discipline in which a solution was originally sought. For example, many mechanical solutions can now be replaced by electrotechnical, electronic, pneumatic and software solutions (the most obvious example being mechatronics, Chap. 23).
- are not prioritized, as is the case in more traditional approaches to product development[8]. Rather, in IDE no attribute subordinates itself to another, but all attributes support each other in a symbiotic way to create the best possible solution under the current circumstances.
- are divided into six *product attributes*, three *fulfilment attributes* and two *profitability attributes*, which are orthogonal to each other. For easier handling, their names were derived from the everyday language of the customer.

The assignment of the customer demand to the attributes for determining the desired performance profile of the product and its behaviour as well as the construction of the as-is state by the provider can be carried out with different procedures,

[8]In conventional approaches, the priority is usually on the fulfilment of the function, to which all other attributes must be subordinate, expressed in the statement that the form (as the most obvious characteristic of a product) must be subordinate to the function ("form follows function").

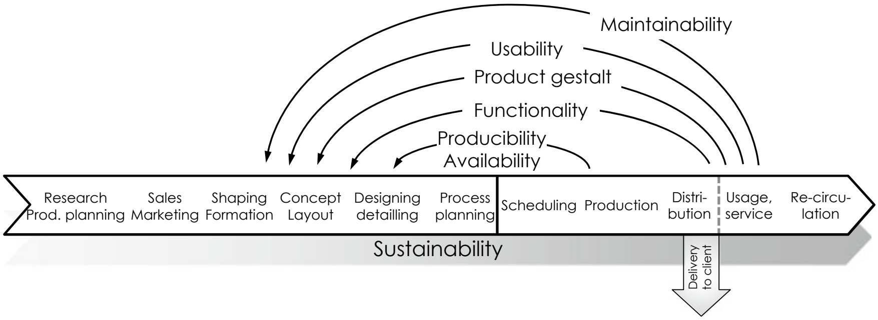

Fig. 3.5 Origin of product attributes

which will be discussed in more detail in the presentation of the fulfilment attributes (Sect. 3.2.2).

In the following sections, the individual attributes are briefly introduced. Separate and more detailed descriptions of the attributes can be found in separate chapters.

3.2.1 Product Attributes

The six product attributes originate from the life cycle of the product, mainly from the usage phase, Fig. 3.5.

These attributes describe both performance and behaviour of the product on the basis of customer demand and (usually diffuse) expectations[9], taking into account influences and boundary conditions from the product life cycle and from the environment in which it is used (Fig. 2.4). From the customer's point of view, these are attributes that describe the usability of the product, namely the shape of the product, the functions it contains, and the quality of the user interfaces and the reparability of the product. From the provider's point of view, these are primarily properties of the product's producibility. For both groups, both the sustainability of the product and its availability are important.

The six product attributes are derived from this (characteristic questions in brackets):

- *Product Gestalt*[10] (what does the product look like? What perceptible information is offered?) grants objects culture, identity, aura and presence. Product Gestalt describes shape, form, appearance, impression and aesthetics of a product, in short

[9]Expectations are fed by recurring experiences that led to the same result. For example, experience has shown that a lever mounted to the left of the steering wheel is the turn signal lever for right-hand-driven vehicles.

[10]*Product Gestalt* describes the conditions of perception to be created in the form of the design elements form, colour, material and surface and the design structure, in order to enable the use of a product in the sense of a perceptive human–product relationship.

the visual and emotional “charisma” of a product as the most important interface to the user. This attribute offers the fulfilment of requirements such as sensuality and sensitivity in order to realize product characteristics that meet the individual needs and possibilities of the user. In any case, however, the only yardstick for creating the shape of the product is the human being, never the technology. Form does not necessarily follow function, since functions alone are not capable of conveying the individual sensory experience of a product. The product developer can directly influence the form of the product by freely selecting shape, material, colour, structure and surface finish. According to Weber [Webe-2011], Product Gestalt is a product characteristic, unless a customer expressly wishes it as a product property. This attribute and its environment are described in Chap. 6 in the context of industrial design.

- *Functionality* (what can the product do?) describes existence, interaction and mutual influences of all direct and indirect functions that a product provides for use. It is part of the performance offer of the product to transform functionality requirements into corresponding user-related functions in order to adequately meet requirements. This is independent of whether functions are implemented as mechanical, electrical, electronic, hydraulic, optical or software functions or as combinations thereof. This attribute and its environment are described in Chap. 7.
- *Usability* (is the product intuitive and easy to use? Is the usage satisfactory?) describes in a broad sense the performance, benefit and quality of the interfaces between user and product. A powerful and versatile usability is crucial for the success of the product. Therefore, it must be intuitive, reasonable and understandable. On the one hand, usability is closely linked to Product Gestalt, as this attribute influences the way the product is handled through shape, material, colour and surface structure. On the other hand, it influences Functionality, since the functions can only be made available to the user via the provided interfaces (à propos, it goes without saying that in IDE products are adapted to humans and not vice versa). This attribute and its environment are described in Chap. 8 in the context of product and system ergonomics.

If the product provides the functionality as expected, one can use it for one’s purposes. But if (on top) the Product Gestalt of the product is fascinating, then one wants to use it.

The two following attributes *Producibility* (from the provider’s point of view) and *Availability* (from the customer’s point of view) are the two sides of the same coin. They do not complement each other, but act as alternatives. Producibility and Availability are therefore treated as one attribute. Both are directly influenced by the product developer and are therefore product characteristics, unless a customer explicitly specifies them as product properties.

- *Producibility* (can the product be manufactured with the given possibilities?) provides information on whether, how and under which technical, organizational, logistical and financial conditions a product can be produced. This can be done internally with the available options of the provider or the product or parts of it must be produced externally. Another possibility is for the provider to procure additional manufacturing equipment if the potential profitability of the product is promising. Productivity is thus primarily in the interest of the provider, because if a product cannot be produced, it cannot be supplied to a customer or to the market and thus cannot generate profitability (this includes also customers who, for example, are interested in fair and sustainable production of the product, demand this from the provider and are also prepared to pay higher costs for it). A customer will not buy a product that cannot be produced according to his needs and expectations. This attribute and its environment are described in Chap. 9 with a focus on additive manufacturing.

- *Availability* (is the product easy to get within the expected time frame?) means on the one hand that the product is available to the customer in the time window specified by him, is delivered to him and is installed within the agreed time. On the other hand, this means that the product must always be ready for use in the intended field of application, according to the requirements and during the expected service life (i.e. readiness for use). This attribute and its environment are described in Chap. 10.
- *Maintainability* (can the product easily be serviced and adapted?) describes the ability and ease with which a product can be modified to quickly correct faults, to meet new requirements, to improve maintenance or to adapt to a changed environment [ISO 25000]. It must be possible to take these measures without restriction in order to restore the product to an operational state and thus ensure its availability. This attribute and its environment are described in Chap. 11.
- *Sustainability* (are there negative impacts on the environment in the broadest sense?) means that a product takes into account environmental requirements throughout its life cycle, as well as technical, social and economic requirements (which is why sustainability runs parallel to the product life cycle in Fig. 3.5). This approach leads to a balance between economic, social and environmental objectives [Beys-2020]. Sustainability shows the high responsibility of product development, because it creates the conditions for a sustainable product in its phases[11]. This attribute and its environment are described in Chap. 12.

Of all the attributes, Product Gestalt can be influenced and designed in the most diverse ways. The attributes Product Gestalt, Functionality, Usability and Maintainability can be summarized under the generic term “suitability”. Here the focus is on the sufficient and appropriate use of a product by the intended user and in the planned application context.

3.2.2 Fulfilment Attributes

The three fulfilment attributes *Safety*, *Reliability* and *Quality* describe different degrees of fulfilment of requirements and specifications by the respective product

[11] As early as 1976, Hubka demanded ethical responsibility towards society and economy from the product developer [Hubk-1976].

attribute. In IDE, these scopes are called *fulfilment levels*. According to Fig. 2.4, requirements and specifications originate from current customer demands, from the provider's current ideas, goals, circumstances and boundary conditions, for example, corporate strategy and corporate identity, profitability expectations and code of conduct (corporate social responsibility), from possible market opportunities and from the current circumstances and boundary conditions of the respective environments in which development and production take place and into which a product is to be inserted, Fig. 3.6.

Product attributes and their respective levels of fulfilment describe the target state of the product from the customer's point of view and the as-is state of the product offered from the provider's point of view.

- *Safety* (is the user protected from harm?) describes the minimum level of fulfilment of a product attribute required to ensure that the product cannot harm the user (or an affected person) when used as intended (including a certain robustness to misconduct and abuse). If a product consists of components, then the safety of the entire product results from the synergetic interaction of the levels of fulfilment of the individual components within the product. Another element for determining the level of fulfilment is the ability of the artefact to prevent the failure of one component from spreading to other components or from one product to other products. The provider is primarily responsible for establishing safety for the customer, as he has access to all documents and specifications in which the requirements for product safety are described and regulated.
- *Reliability* (does the product provide the requested performance reproducibly along the expected life cycle?) is the level of fulfilment at which the product can always be used and stored reliably and in accordance with its intended purpose over the specified or expected service life and with a certain degree of robustness (tolerance against incorrect operation or misuse) [DIN-40041]. The reliability of a product arises analogously to the phenomena addressed in the attribute Safety. The provider is also primarily in demand when it comes to ensuring the reliability of the product, since he can determine and implement the requirements for reliability from the attributes Product Gestalt, Functionality and Usability when developing the product.

It may also be the case (e.g. in complex systems or where components from different disciplines are used) that safety requires a higher level of fulfilment than the level of fulfilment for reliability.

- *Quality* (does the product meet the user's expectations and assumptions regarding the desired performance and behaviour?) describes the level and excellence of

Fig. 3.6 Levels of fulfilment with the fulfilment attributes safety (S), reliability (R) and quality (Q)

fulfilment in the performance of the product and its behaviour in relation to the (subjective) expectations and assumptions that a customer has of the product[12]. Quality is not only a physical but also a transcendent quantity [Garv-1988], because here the sum of the relevant characteristics and properties of a product from the user's view and in a specific application environment (taking into account the aspect of diversity) is of importance. This importance varies along the product life cycle [EhMe-2017]. Quality is always a subjective value, since expectations and assumptions about the product, procedures of use in the respective environment and the evaluation of the performance and behaviour of the product are made by individually acting people and are therefore of a subjective nature.

If one considers the fulfilment attributes from the perspective of evaluation criteria, then

- safety is a fixed or exclusion criterion, because if an artefact does not meet the safety requirements and specifications, it cannot be used under any circumstances.
- reliability is a minimum criterion.
- quality can be understood as the sum of (subjective) desired criteria.

A customer, whether it is in the capital goods or consumer goods sector, will specify his expected levels of fulfilment for product attributes, primarily using the Quality fulfilment attribute. This may result in requirements and specifications of varying completeness and quality, which may need to be supplemented or edited by the provider (Sect. 2.2.2). A provider must therefore not only react to enquiries from potential customers, but also anticipate both development and realization of possible products either from demand situations or opportunities in the markets. He must take into account other influences, not only his internal possibilities and conditions of implementation, but also technical and legal standards, specifications, procedures, methods, guidelines, rules and constraints, as well as those that may be of a societal, social and cultural nature (see also Fig. 3.21).

To capture all influences, the provider implements the fulfilment attributes by selecting options from his existing technologies and processes. These options, which realize the transition from the qualitative target profile of the customer to the quantitative as-is profile of the provider, are divided into fulfilment type, fulfilment degree and fulfilment excellence.

- The *fulfilment type* describes the way in which a requirement can be realized/has been realized (by selecting suitable technical realization types from a set of alternatives resulting, for example, from the processes and technologies from different disciplines at the provider and/or with suitable partners)[13].

[12]This description corresponds to the definition of quality in ISO 9000:2005, according to which quality is the totality of the characteristics of a company with which (in relation to their usefulness) defined needs and implicit needs are met [DIN-9000].

[13]For example, a multi-function lever on the steering wheel of a passenger car, which controls the indicators, windscreen wipers and various light functions, can be made of metal or plastic and mechanical and/or electronic switches can be used.

- The *degree of fulfilment* describes the relationship between a requirement and its (proportionate) realization from the desired range of services with the selected processes and technologies (what was realized and to what extent?)[14].
- The *fulfilment excellence* describes nature and value of the fulfilment; i.e., it evaluates the type and degree of fulfilment (how well has the performance offer been realized?)[15].

The selection of each fulfilment is influenced not only by the producibility of the artefact and the availability of the necessary raw materials, raw and purchased parts, production and distribution facilities, but also by financial and strategic issues. For example, it may be desirable for certain markets to offer the product with different levels of configuration. All levels must meet the attribute Safety (fixed criterion), but for Reliability (minimum criterion) and Quality (desired criteria) different equipment can be offered.

Since, in contrast to the specifications for the safety of a product, the specifications for availability and quality can have different bandwidths (e.g. with different levels of configuration), the correct implementation of the fulfilment attributes must be checked again for each new combination of fulfilment type, degree and excellence. In this respect, this is an iterative procedure in product development, which can be realized holistically through the use of computer-aided systems for modelling, calculation, simulation (Chap. 18) and expenses analysis (Sect. 25.1).

Fulfilment attributes and their respective environments are described in Chap. 13.

3.2.3 Profitability Attributes

The third group of attributes describes the material and non-material aspects of the product and thus (in the broadest sense) the profitability of the product. From the customer's point of view, this is the *added value*, and from the provider's point of view, it is the return on investment or the *profitability*. These are two complementary attributes, both of which must be present in any product, because only when the provider can expect a reasonable return on investment will he produce the product. Only if the customer can expect a reasonable added value from the product will he or she buy it.

- *Added Value* is the relationship between the performance offer of the product (performance capability and performance behaviour of the product, recorded in the as-is state of the product attributes with different levels of fulfilment) and the expenditure for procurement, application, maintenance and return of the product.

[14]For example, in the case of the multi-function lever, the number of steps to vary the length of the interval between two movements of the windscreen wiper may differ from the required number for reasons of cost, scheduling, etc.

[15]The performance excellence of the multi-function lever is expressed, for example, in the operability, detent, repeatability and durability of the gear steps.

Added value describes not only the financially measurable increase in value (e.g. through a favourable price or low usage costs), but also the idealistic increase in value through ownership and use of the product, such as prestige and status, attitude to life and a certain preference (e.g. for a certain provider, for a certain product or for certain innovations). While the added value for customers in the capital goods industry is predominantly valued in monetary terms, idealistic reasons play an increasingly important role for customers in the consumer goods industry, Fig. 3.7.

- *Profitability* is the quotient of achieved profit from the as-is state of the product attributes in relation to the expenses for the realization of the product in an accounting period. For the provider, the expected profitability (for the determination of profitability, see Sect. 25.3) is one of the main reasons for choosing to develop and manufacture a product. Usually, the provider must continuously and successfully launch new products on the market so that the initial investment in this product (due to its development, production and distribution) can be pre-financed by profits from other products, Fig. 3.8.

The assessments for both attributes can be made, for example, with the cost-benefit analysis, the Balanced Scorecard and the multi-criteria BAPM method (Chap. 25).

3.3 Attributes and Their Context

The product attributes, fulfilment attributes and profitability attributes presented in Sect. 3.2 are orthogonally related to each other in the context, Fig. 3.9.

As indicated above, the level of fulfilment for the safety of a product must be above the corresponding fixed criterion and the reliability must meet the corresponding minimum criterion, otherwise the product cannot be used. However, it can happen (as

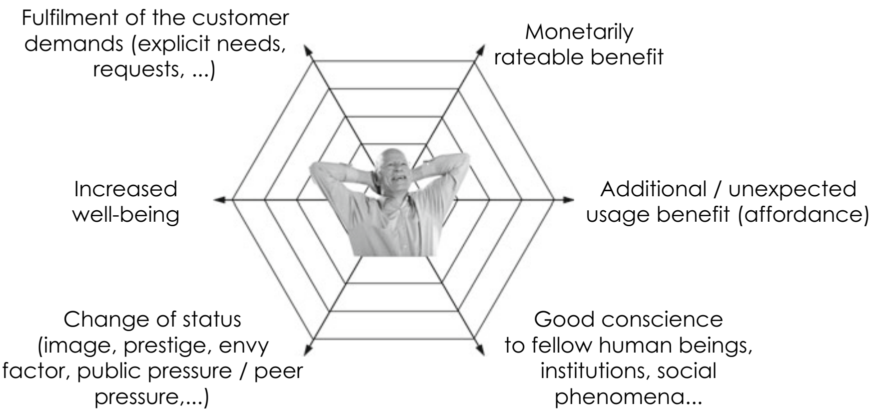

Fig. 3.7 Selected components of added value for the customer

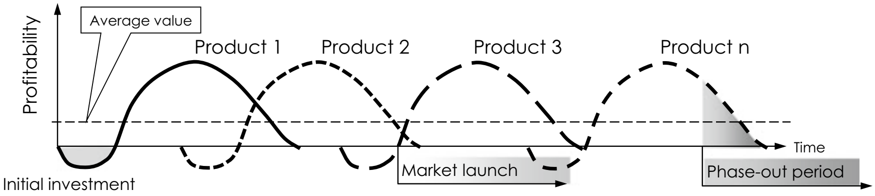

Fig. 3.8 Course of profitability over time for the provider

in Fig. 3.9 for the attribute Functionality) that a lower level of fulfilment is sufficient to achieve reliability than to fulfil the fixed criterion for safety. The individual attributes and their fulfilment levels lead to different added values and profitability. This is illustrated by the different positions of the attribute columns along the axis of the profitability attributes in Fig. 3.9.

All attributes influence each other to varying degrees, with the two attributes Product Gestalt and Producibility/Availability having the greatest influence on the other attributes, since both are product characteristics that can be changed directly by the product developer (see Fig. 3.3). These two attributes are therefore preferable for product changes, since they have the greatest effect on the product (and can thus save adaptation effort), as long as the corresponding boundary conditions are met, which can be modelled, for example, with design rules or with the approaches of Design for X [(DfX) [Meer-1994], Fig. 3.10.

As already mentioned in Fig. 3.3, only the attributes Product Gestalt and Producibility can be directly influenced by the product developer. In addition to Product Gestalt, the characteristics material, topology and product structure are also influenced. With Producibility, the characteristics manufacturing process, surfaces and tolerances (which in turn influence the material) as well as possible colours are

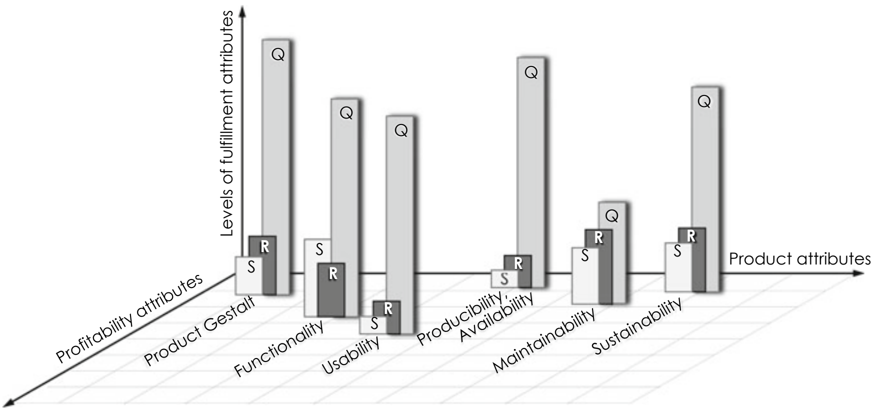

Fig. 3.9 Correlation of product attributes, fulfilment attributes and profitability attributes (S: Safety, R: Reliability, Q: Quality)

from \ to	PG	F	U	P	A	M	S
PG	Aesthetics, impression, perceivable information (product promise)	Effective areas	Offers for shaping & forming	Size, requirements	Product use at any time	Aesthetically pleasing disassembly and separation joints	Freedom of design without threats
F	Feasibility	Adequate realization of functional requirements	Guidelines, standards	Production of necessary moulds for the fulfilment of functions?	Functions available at time of use	Implementation of functions in modules?	Characteristic values for sustainable functions
U	Ergonomic requirements	Ergonomic requirements	Appropriate, intuitive use of the user-product interfaces	Available possibilities for production	Product interfaces intuitively available	Demountable Modules	Specifications and parameters for sustainable usability
P	Producible, available shapes and surfaces	Producible, available shapes and dimensions	Producible shapes, sizes, surfaces	Available possibilities for production and distribution	Proprietary and purchased parts for realisation available on demand	Demountable Modules	Specifications, parameters for sustainable usability
A	- no influences-	- no influences-	- no influences-	- no influences-	Availability of product & modules in expected time windows	Reasonable repair times and spare parts availability	Technological options
M	Easy and safe disassembly and maintainability	Can functions be linked to modules?	Easy disassembly, replacement	Easy disassembly, exchange of modules?	Adequate availability of maintenance services & spare parts	Simple, adequate repair, maintenance, update	No release of hazardous substances / objects during maintenance
S (No environmental and ecological hazards when)	using the shape	using the functions	using the product	producing	providing the product or its components	repairing, maintaining, updating	Sustainability in all phases of the product life cycle

Fig. 3.10 Selection of mutual influences of attributes (PG: Product Gestalt, F: Functionality, U: Usability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability)

influenced. All other attributes result as properties from the interaction of Product Gestalt and Producibility.

For a simple representation of the fulfilment levels of all attributes, these are entered into a spider diagram, which shows, from the customer's point of view, the qualitative *target profile* for the desired performance and performance behaviour of the product and the quantitative *as-is profile* offered from the provider's point of view. In the spider diagram, the fulfilment levels increase from the inside to the outside. With the two attribute profiles thus created, it is also possible (independently of the customer or provider view) to create a comparison of the performance offers of different products by overlapping their profiles, for example to support a procurement decision, Fig. 3.11.

- The qualitative target profile shows the attribute profile of the product strived for by the customer (or the profile of a class of products from different providers, for example) in a specific market, for a specific time or period of time. It should be borne in mind that the availability of the product to the customer takes precedence over producibility (which is of interest to the provider), because in the case of a product offered on the market, producibility must be given in advance.
- The quantitative as-is profile is a (prospective) attribute profile of the product proposed or the (already) realized profile by the provider with the respective levels for the three fulfilment attributes safety, reliability and quality. This profile is intended for a certain point in time or a comparable period requested by the customer, for a requested market or for the market in which the customer is located. These distinctions may be particularly useful in the case of consumer goods if

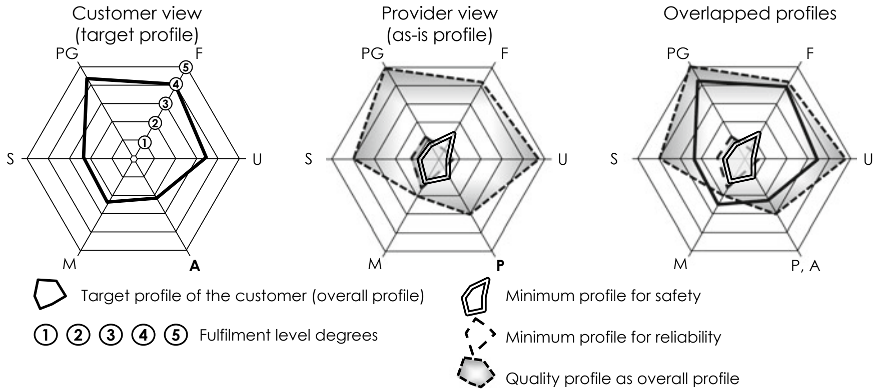

Fig. 3.11 Attribute profiles from the customer's and the provider's point of view as well as the overlapping of both profiles (PG: Product Gestalt, F: Functionality, U: Usability, A: Availability (customer's point of view), P: Producibility (provider's point of view), M: Maintainability, S: Sustainability)

the product is to be offered in different markets with different environmental conditions. For the provider, the producibility of the product is usually more important than its availability. Exceptions are, for example, the ability to deliver (and thus the availability) of products in certain time windows (e.g. at Christmas). The availability and its various possibilities are discussed in detail in Chap. 10.

- The overlapping of the target profile and the as-is profile enables their direct comparison. It can be used, for example, to model and support purchasing decisions. In the example on the right side of Fig. 3.11, the target profile is surrounded by the quality profile of the as-is profile, except for a small overhang of the Maintenance attribute.

Depending on the product, the market it targets (capital goods or consumer goods) and its areas of application, different attribute profiles result. In the case of *capital goods* (Sect. 2.2.4), expectations and forecasts for the product are usually clearly and fully defined, whereas in the case of *consumer goods* (Sect. 2.2.5), expectations and forecasts must be projected onto a market that is sometimes unknown and unpredictable, since the product must cover a wide range of very different expectations and forecasts. Figure 3.12 shows the as-is profiles of a capital good and a consumer good from the perspective of the provider as well as the target profile of a consumer goods market in which the provider wants to sell his product.

- Capital goods are purchased by customers, who use them to produce other capital goods or consumer goods. The useful life of capital goods is generally long. In the case of a machine tool (left-hand side of Fig. 3.12), for example, this is about 25 years. Such a machine must have high safety and high reliability. It must provide its own functions at the highest quality level, and it must be meaningful, consistent, without too much learning effort and robustly usable. By means of producibility, the provider ensures that the realization of the customer's request is

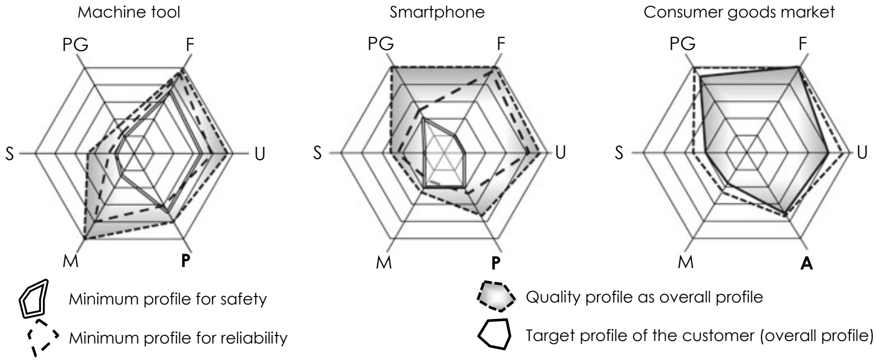

Fig. 3.12 Attribute profiles from the provider view (as-is profiles). Left: Machine tools (capital good). Middle: Mobile phone (consumer product). Right: Target profile of a customer/consumer goods market (solid line), overlaps with the offered quality profile of the as-is profile in the middle (PG: Product Gestalt, F: Functionality, U: Usability, A: Availability (customer view), P: Producibility (provider view), M: Maintainability, S: sustainability)

guaranteed. In order to keep downtimes as short as possible, there must be a wide range of options for rapid maintenance. In the case of a machine tool, Product Gestalt and Sustainability (due to the long running times) are usually not very important. Since a capital good is newly designed for a customer or is adapted from a basic machine and specially manufactured, the as-is profile of the provider is largely identical with the target profile of the customer.

- In the consumer goods sector, the provider offers the product for one or more target markets. The profile should be able to meet the current customer demand of the target group(s) in the target market by taking into account the previous experiences from the success of the product or a class of similar products, i.e. sales, distribution, application, customer satisfaction, recommendation, etc.
  The as-is profile in the middle of Fig. 3.12 describes with the smartphone a typical consumer product of today. This product shows that the statement "form follows function", which originated in the USA at the end of the nineteenth century, is no longer true today. Smartphones have a minimalist design, which is used by all providers, but which does not reflect all the functionality of the smartphone. This is possible both through the increasing miniaturization of components and through the replacement of mechanical functions by electrical, electronic and software functions, etc.[16], for example to achieve high and continuous availability during the lifetime of the device. All smartphones use essentially the same usage logic, even if it was not designed for different cultures. At least a quite robust usability can be achieved with it.

[16]Since such decisions are not made at the beginning of product development, the need to decide on the final realization forms of the product as late as possible in the development process is once again evident here.

For the provider, good producibility is the key to maximum profitability. Availability is also important (although not as dominant as producibility), because in consumer goods markets a product must be available on the market at the right time in order to be successful. However, maintainability and sustainability of smartphones (and of consumer electronics products in general) are not the focus of attention, even though a Dutch company has been producing and selling sustainable smartphones quite successfully since June 2013 [Fair-2020].
If a competitor offers a comparable product in the targeted market, the as-is profile of the own product must be better than that of the competitor's product and the current target profile for this market must be completely surrounded by the as-is profile of the own product in order to provide a higher incentive to buy (right-hand side in Fig. 3.12).

A customer decides to buy a product if it promises him added value, if the as-is profile of the product offered appears to him to be better than his own subjective target profile and if the product meets his (possibly vague) expectations. This assessment is the result of own experiences with the same or similar products and from external sources of knowledge such as test and experience reports from various sources (magazines, friends, internet, etc.). This can lead to different decision alternatives (Fig. 3.13).

- In a consumer goods market, a provider offers a product that is described by its as-is profile. The as-is profile must be larger than the minimum attribute profile of the consumer goods market (dark grey area) in order for the product to have a chance of being bought.
- At the beginning of the decision-making process, a customer often has ideas about his desired target profile. However, because his expectations are not always

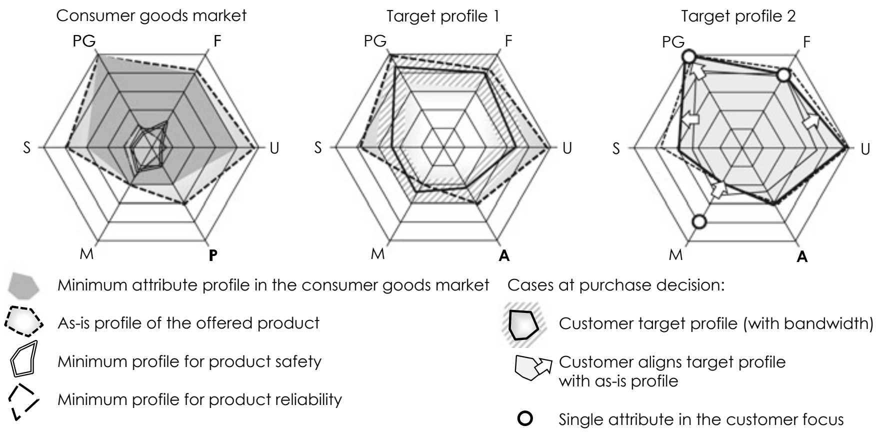

Fig. 3.13 Decision alternatives when purchasing a product. Left: offered as-is profile for a consumer goods market (provider view). Middle: Target profile 1 (customer view). Right: Adjusted target profile 2 (customer view)

concrete, he combines this profile with a certain bandwidth (hatched band in target profile 1 in Fig. 3.13). If the target profile has such a bandwidth, then it fits into different as-is profiles, so that the customer can examine products from several providers.

- In the decision phase, it may happen that a customer, on the basis of the knowledge acquired during the selection process, reweights and balances both the existence of individual attributes and their respective levels of fulfilment in the as-is profile of the product individually. In the specific case in Fig. 3.13, the customer reduces his requirements for Maintainability, but compensates this by increasing requirements for Product Gestalt and Usability. This leads to a changed target profile that can now fit better into the as-is profile ("Target profile 2"). If the offered as-is profile now offers more than the adjusted target profile, the corresponding product is purchased. If there are several suitable as-is profiles (i.e. product alternatives), then the product with the highest expected added value is chosen.
- A customer is only interested in the performance of individual attributes with a certain degree of fulfilment that he or she at least expects (bold circles in target profile 2). Other properties and their fulfilment are not in the focus of the customer in this case.

Often a product offers the customer a high level of emotional satisfaction, e.g. through a preference for a certain company or product, expected prestige or a desired status. Although the customer does not yet have a concrete idea of whether and how he wants to use the product, he must "buy" it—a so-called must-have product. In this case, the fulfilment of the individual attributes does not play a significant role. However, the as-is profile offered should not fall below a minimum profile that is either a generally accepted one or one subjectively recognized by the customer as sufficient.

3.4 Working with Attributes

As shown, attributes and the resulting profiles (customer view: qualitative target or target profile and provider view: quantitative as-is profile) serve to compare the respective range of performance offers of desired and offered products, whereby the way in which a product is realized at this point is irrelevant. Due to the different interests of customer and provider, the procedures for creating the respective attribute profiles differ. In the following, the creation of an attribute profile as a target profile from the customer's point of view, then the creation of the as-is profile from the provider's point of view and finally the process of procuring a product in the interaction between customer and user are described.

3.4.1 Customer View: Qualitative Target Profile

In order to capture the desired performance capability and performance behaviour of the product and the resulting respective levels of fulfilment from the customer's perspective, the customer demand must be decomposed and the desired characteristics must be assigned to the product attributes. This can be done with the co-creation approach (Sect. 15.9), where representatives of interested parties in the product (customers, users and other stakeholders) work together in the IDE team (Sect. 15.6), with user stories (requirements formulated in the everyday language of the future user, Sect. 15.3.3), on the basis of benefit representations with weighting possibilities oriented towards user value analysis according to ZANGENMEISTER (Sect. 25.2), with classical forms of recording via benefit and criteria lists, questionnaires, example solutions, etc., applying methods and approaches of BREIING and KNOSALA [BrKn-1997], or with combinations of these, as well as other suitable procedures.

Since the target profile is a qualitative profile, there is usually a concentration on the fulfilment attribute quality, because the customer can usually assume that a provider fulfils market requirements and specifications for safety and reliability. Of course, it is also possible for a customer to make additional special specifications regarding safety and reliability of attributes. The determination of the individual levels of fulfilment from the customer's perspective can be done, for example, using the following scheme in Fig. 3.14. Its contents are merely notes; further and more detailed information can be found in the chapters on the respective attributes.

The aspired fulfilment options allow the mapping to the product attributes with the respective fulfilment levels and thus result in the coded target state of performance capability and performance behaviour of the product that the customer expects, Fig. 3.15.

Assignment and specification of the level of fulfilment of each attribute are also supported by a matrix [Hehe-2011] based on the Quality Function Deployment (QFD), whose individual cells contain different characteristics and properties as well as the resulting levels of fulfilment including evaluation (comparable to a morphological box [Zwic-1982]. In Fig. 3.15, the expected fulfilment heights were entered as black crossbars.

- In the case of consumer goods, the customer very often only specifies the quality profile (as is the case in Fig. 3.15), because a customer usually assumes that the provider guarantees the safety and reliability of the product. A customer will also not always occupy all the attributes, because some of them are not (currently) relevant to him[17].
- For capital goods, the customer usually provides the supplier with all product attributes and all fulfilment attributes with the respective fulfilment levels.

[17]For example, mobile phones are purchased primarily on the basis of appearance and ease of use (attributes Product Gestalt and Usability), because the user assumes that the required functions are available, the availability of the mobile phone is given and he is not interested in the maintainability or sustainability of the phone.

	0	1	2	3	4	5
PG		Available	Appealing, predominantly user-focused Product Gestalt	Attractive, user-focused Product Gestalt	Good fulfilment of the product promise	Best shape, appearance, impression, aesthetics
F		Basically usable	Reasonably usable	Can also be used in other areas of application	Additional, originally unplanned functionality, further areas of application, everything very well usable	Maximum distinctive, functionality very well usable, unexpected fields of application, high affordance
U		Cumbersome usability, no consideration of the specifica of user groups	→			Intuitive and self-explanatory use, context-sensitive support if required, max. robustness
P		Resources basically available, product must be adapted	Product can be classically produced with 80% fulfilment	Several production alternatives (resources, sites, cultures,...)	Complete fulfilment without any restrictions	Sustainable materials, technologies, procedures are applied
A		According to provider specifications	→			Immediate availability at the customer
M	No maintenance: throw-away mentality	→	Easy maintenance due to constructive layout, such as usable modules	→	Long service life, completely maintainable, as well by users	Long service life with automatic maintenance without efforts for users
S	No sustainability	No use of harmful materials in all postcode phases Long duration of product life Complete re-circulation of all components and waste during use Minimized energy consumption during production and use Appropriate overall financial balance of expenses and benefits along the PLC Neutral balance from production to re-circulation of all resources along the life cycle				

Fig. 3.14 Assignment scheme for determining the fulfilment levels of the quality of the individual attributes from the customer's point of view (PG: Product Gestalt, F: Functionality. U: Usability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability, 0, 1, 2, 3, 4, 5: Levels of fulfilment, arrow: Continuous transition between two positions)

3.4.2 *Provider View: Quantitative as-is Profile*

At the provider, development and realization of a product are initiated from demand situations and opportunities in the market as well as from enquiries from potential customers, which lead to requirements and specifications of varying completeness and quality, which may need to be prepared (Sect. 2.2.2). In all these cases, the provider must take further influences into account, such as internal company possibilities and conditions of implementation, technical and legal standards, specifications, procedures, methods, guidelines, rules and constraints, as well as such external rules and constraints, which may be of a societal, social and cultural nature.

The provider differentiates the realization of the respective requirements by the possibilities of type, degree and excellence of fulfilment available to him (Sect. 3.2.2). The resulting fulfilment levels for each attribute (Fig. 3.6) can be determined, for example, according to the following scheme, Fig. 3.16. Here, too, its content is indicative; further and more detailed information can be found in the chapters on the respective attributes.

The three correspondingly designed fulfilment possibilities of type, degree and excellence allow the mapping to the product attributes with the respective fulfilment levels and thus result in the coded as-is state of performance capability and performance behaviour of the product that the provider is able to deliver, Fig. 3.17.

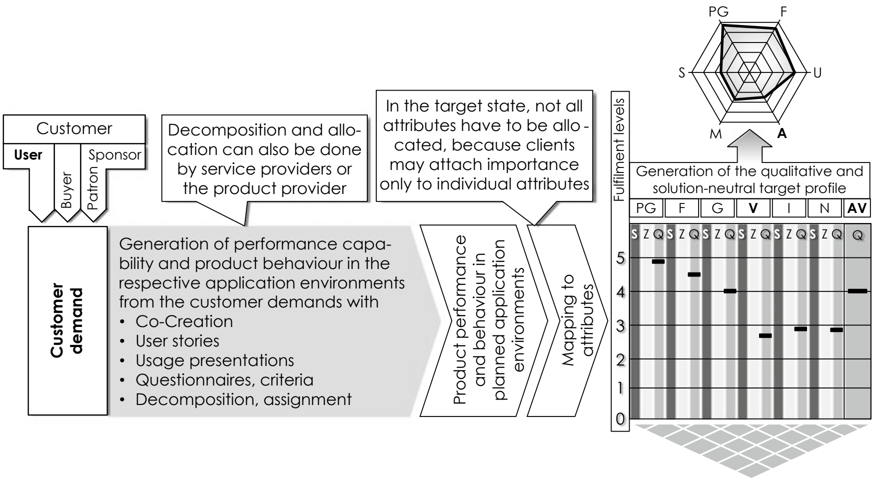

Fig. 3.15 Generation of the realization-neutral and qualitative target state of performance and performance behaviour coded in the target profile by decomposition and assignment of the customer demand to product attributes with different levels of fulfilment, in the target profile primarily regarding quality (Q). Attributes: PG: Product design, F: Functionality, U: Usability, A: Availability (as seen by the customer), M: Maintainability, S: Sustainability, AV: Economic efficiency attribute added value (AV, as seen by the customer), S: Safety, R: Reliability. The upside down "roof" of the QFD-like matrix is used to take into account the mutual influences of the product attributes

• In Step 1a, current and potential customer demands as well as opportunities in the market are mapped via the resulting requirements on the performance offer (performance capability and performance behaviour) to the realization possibilities at the provider, supplemented or restricted by the conditions, rules and constraints to be observed. In Step 1b, essentially the same procedure is carried out, whereby the target profile of the customer serves as input here.

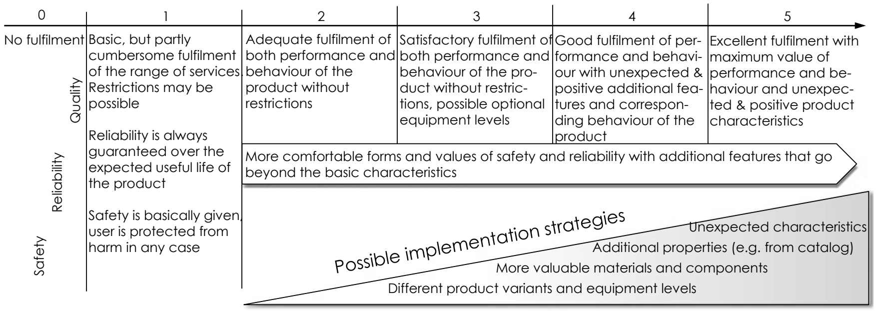

Fig. 3.16 Assignment scheme for determining the fulfilment levels of attributes from the perspective of the provider with possible measures to increase the product's performance (0, 1, 2, 3, 4, 5: Levels of fulfilment)

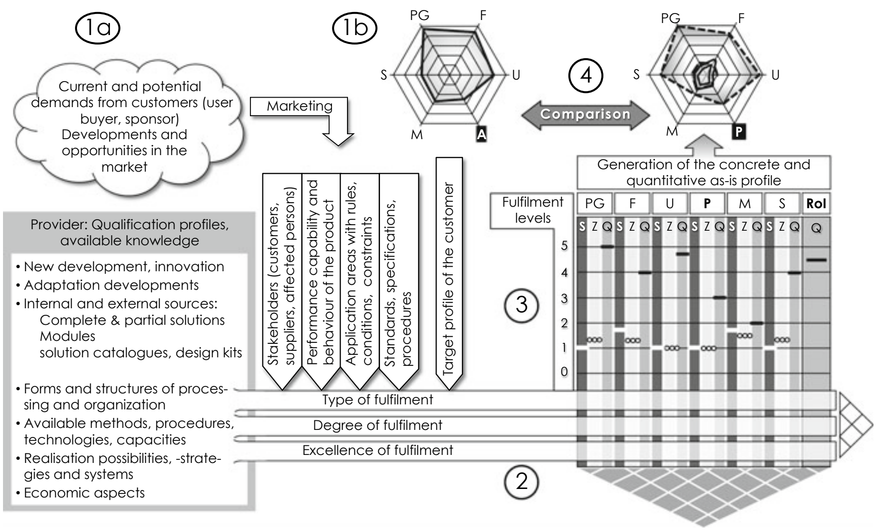

Fig. 3.17 Generation of the quantitative as-is profile of the product's performance and performance behaviour on the basis of the provider's capabilities (PG: product gestalt, F: Functionality, U: Usability P: *Producibility* (from the provider's perspective), M: Maintainability, S: Sustainability, RoI: Return on Investment/profitability (provider's perspective), S: Safety, R: Reliability, Q: Quality). Fulfilment level for safety: White crossbars. For reliability: Dotted crossbars. For quality: Black crossbars). The "roofs" of the QFD-like matrices take into account the mutual influences of the respective categories

- In Step 2, the realization options selected on the basis of the specifications are assigned to the respective fulfilment types, fulfilment degrees and fulfilment excellences. This assignment can be done, for example, with the Autogenetic Design Theory (ADT, Sect. 1.7). The specifications determined in Step 1a are used to formulate the ADT target function, which is supplemented by the economic requirements of the provider. The technological and organizational possibilities of the provider's existing implementation serve to structure the ADT prohibition area. This also covers the possibilities of using (partial) solutions already existing at the provider and their configuration and combination options. As a result, the best possible combination of type, degree and excellence of the respective fulfilments are available for the current set of requirements, which of course must be updated whenever the requirements change. In this respect, this is an iterative procedure in product development, which additionally can be holistically supported by the use of computer-aided systems for modelling, calculation, simulation (Chap. 18) and effort analysis (Chap. 25) (see also Sect. 16.2).
- In Step 3, the fulfilments are mapped to the product attributes with their respective fulfilment levels and thus the as-is state is displayed. When describing the as-is state, all attributes must always be occupied (in contrast to describing the target state) and they cannot be prioritized. The correct implementation of the fulfilment attributes must be checked again for each new combination of fulfilment

type, degree and excellence. In this respect, this is an iterative process in product development, which can be realized holistically through the use of computer-aided systems for modelling, calculation, simulation (Chap. 18) and expenses analysis (Chap. 25).

- If a target profile was used as input according to Step 1b, the target profile and the as-is profile can now be compared in Step 4 (see also Fig. 3.11). If the product is a capital good, there should be no difference between the as-is state and the target state. If it is a consumer good, differences “upwards” may occur as long as the minimum target profile of the targeted market is met. Such (targeted) differences can also be used to better distinguish the product from potential competitors. However, if there is only a partial overlap or no suitable overlap between target profile and as-is profile at all, Step 2 is processed until the actual profile meets the target profile.

The provider always determines all product attributes and all fulfilment attributes with the respective fulfilment levels.

3.4.3 *Procedures for Product Procurement*

As mentioned at the beginning of this chapter (and described in detail in Chap. 4), the human being in IDE can assume the role of a customer, a provider or a person affected. For this purpose, the possible relationships and interactions between customers and providers in the procurement of a product are presented. Figure 3.18 shows possible

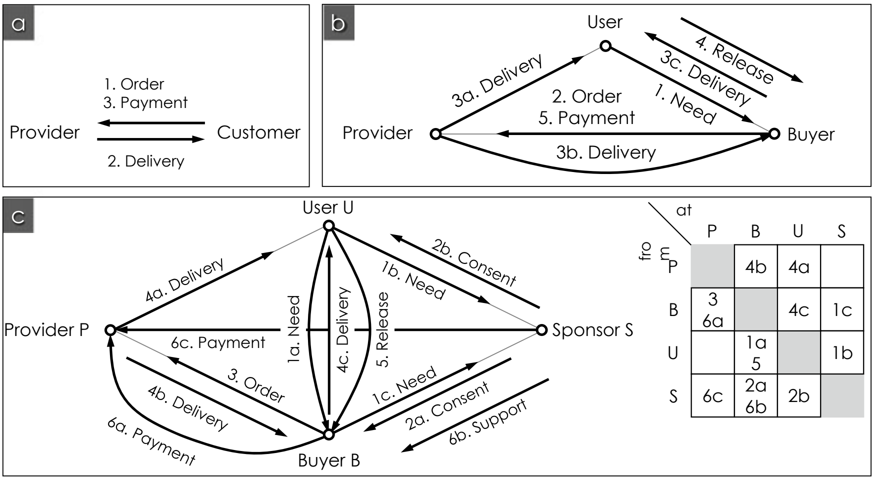

Fig. 3.18 Interactions between customer and provider (based on Björ-2003). Explanations in the text

cases of interaction between customers (who may act as buyers, users, combinations of the two and as a sponsor) and providers when procuring a product.

- Case a: If the customer is buyer and user at the same time, then he orders the development of a product from the provider (Step 1. *Order*), gets the product delivered (2. *Delivery*) and pays the provider (3. *Payment*).
- Case b: If buyer and user are not identical, the user registers a need with the buyer (1. *Need*). This division between user and purchaser is found, for example, in the case of products in the medical sector, where a health insurance company purchases supporting aids (e.g. a wheelchair) that are used by a patient[18]. If the buyer wants to meet the demand, he orders the product from the provider (2. *Order*). The latter delivers the product either to the user (3a. *Delivery*) or to the buyer (3b. *Delivery*), who in turn delivers it to the user (3c. *Delivery*). After the user released the product (4. *Release*), the buyer pays the provider (5. *Payment*).
- Case c: If a sponsor is available (for e.g. if the sponsor gives a sum of money to an organization in whose distribution he has a say), the user reports his needs either to the buyer (1a. *Need*) or to the sponsor (1b. *Need*). If the user has made the request to the buyer, the buyer must in turn ask the sponsor (1c. *Need*). If the sponsor wants to meet the need, he gives his consent to the person who asked him (buyer: 2a. *Consent* and user: 2b. *Consent*). Afterwards, the buyer orders the product from the provider (3. *Order*) (usually the sponsor does not order directly). The provider delivers the product either to the customer (4a. *Delivery*) or to the buyer (4b. *Delivery*). In the latter case, the buyer delivers the product to the user (4c. *Delivery*). If the user releases the product (5. *Release*), the buyer usually pays for the product (6a. *Payment*), for which he receives support from the sponsor (6b. *Support*). In rare cases, the sponsor also pays in full or in part with the buyer (6c. *Payment*). The interaction described here is also shown in the matrix shown on the right in Fig. 3.18.

The capital goods industry is characterized by direct sales (for contract development and production and for large investments), through wholesalers (e.g. in the case of standardized or quasi-standardized products sold in varying quantities to different customers) and through brokers who, by combining several customers, pool buyer power or may act as agents for the provider. Figure 3.19 gives an overview of the process of procurement in direct contact between customer and provider as the most frequent case for capital goods.

Purchasing is carried out in six steps[19]:

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[18] In such cases, usually the requirements of buyer and user are not overlapping. In the example, the buyer is interested in a robust, long-living product with low maintenance needs that can be used by several persons one after another. On the contrary, the user is looking for a wheelchair that can be easily and with high diversity customized to his individual needs.

[19] For the sake of clarity, these steps are shown here in linear form. In fact, the implementation is partly carried out in parallel and in close co-ordination with the customer in order to take into

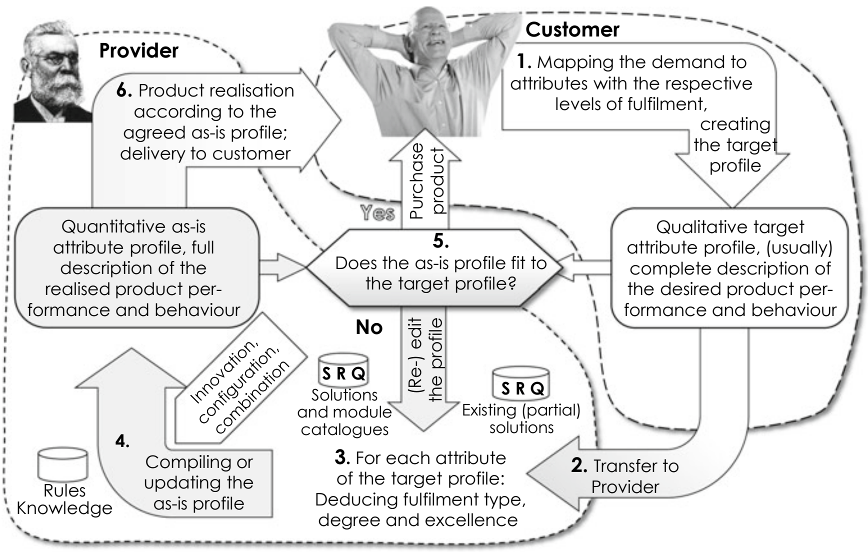

Fig. 3.19 Procedure for purchasing a capital good

- Steps 1 and 2: The customer maps his demand to the qualitative target profile (Fig. 3.15) and transfers it to the provider.
- Steps 3 and 4: Identification of implementation possibilities at the provider. These can consist (in varying proportions) of checking for any existing complete or partial solutions and their configuration and combination as well as development work of varying scope and combinations thereof. Once the concept and (initial) implementation options for the product have been defined, the type, degree and excellence of fulfilment are derived for each attribute and the quantitative as-is profile is created.
- Step 5: The target profile is compared with the as-is profile. If the as-is profile overlaps the target profile and if the economic circumstances (profitability for the provider and added value for the customer) are acceptable to both parties, then the product is procured. If, on the other hand, there are still differences between the two profiles to the detriment of the customer, then either the provider can rework his as-is profile to make it successful or the customer changes the target profile based on new findings from the procurement process (Fig. 3.13, target profile 2), so that both profiles match. The final possibility is that there is not a match of the two profiles and this there will be no purchase.
- In Step 6, the provider realizes the product according to the agreed as-is profile and delivers the product to the customer.

account possible changing conditions early and in time, for example with the methods of Dynamic Navigation (Sect. 15.7).

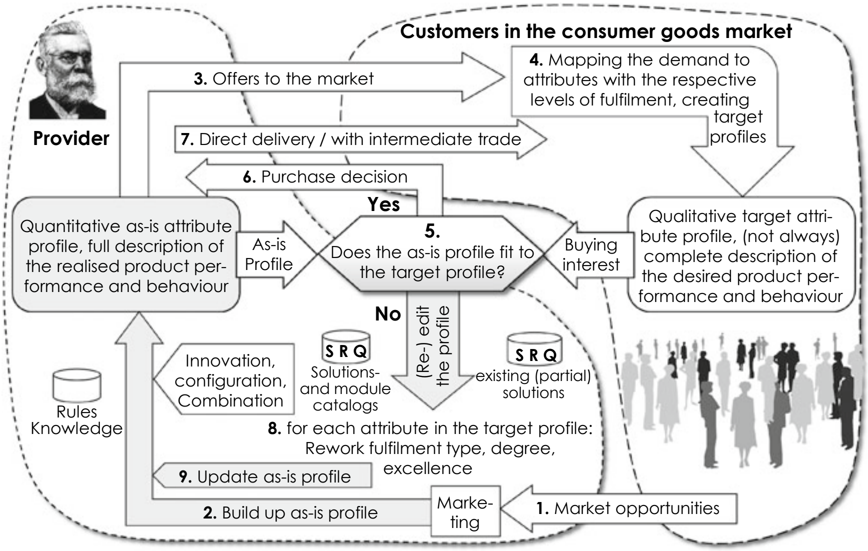

Fig. 3.20 Procedure for purchasing a consumer good

In the consumer goods industry, the purchasing also takes place in several steps. Figure 3.20 shows the corresponding overview.

- In Step 1, the provider reacts to possible opportunities in the market, which may consist of concrete demands for a product (or product family) and emerging needs in the market. The provider acts prospectively if he creates new so far unknown needs in the market for an already existing own product and thus sales opportunities for his product[20].
- In Step 2, the provider builds the quantitative as-is profile of his product based on the findings of his marketing (see Fig. 3.17). To this end, the provider will normally provide a certain minimum number of the product (either as a completely finished product or as a modular system from which a deliverable product is created in a reasonably short time by configuring and combining the modules).
- In Step 3, the product is offered to the market or to groups of potential customers.
- Based on the stimulation from Step 3, potential interested parties create their (usually incomplete) target profiles in Step 4 and compare these with the as-is profile offered.
- If in Step 5, the as-is profile of the product matches the target profile of a prospective customer and then a purchase decision is made in Step 6.
- In Step 7, the (prompt) delivery of the product to the interested party who has become a customer takes place. In the consumer goods industry, the usual delivery route to the customer is through distributor channels (wholesalers and/or retailers),

[20]This was the case, for example, with the introduction of the iPhone in 2007, because before that there was no need for a smartphone on the market—this was first created by Steve Jobs (Apple).

although there have been efforts on the part of the providers to increase their own profitability through direct sale channels (usually via the Internet) by bypassing wholesalers and retailers. The customer pays for the product after reception (or via possibilities that were agreed with the provider beforehand).

- If, on the other hand, the as-is profile does not match the target profiles, the provider, if he is interested in the market opportunities, will rework the as-is profile in Step 8 by changing the fulfilment levels and redefining the respective fulfilment types, degrees and excellences accordingly. Analogous to Step 2, the updated as-is profile is now created in Step 9. The further procedure is carried out again with Step 3.

The development, manufacturing and procurement processes for products required for product realization do not take place in a "vacuum" in IDE either, Fig. 3.21.

Rather, they are influenced by an extensive network of relationships consisting of the most diverse components. In Fig. 3.21, these are divided into four groups.

The upper horizontal bar shows different framework conditions within which the life cycle of a product takes place. The vertical bar on the left shows the different requirements from the user's point of view. The vertical bar on the right shows possible approaches, methods, procedures, aids and tools for the phases of the product life cycle. These three bars require the skills and knowledge (in the broadest sense) of all people involved in or affected by the product life cycle as indicated in the horizontal bar below.

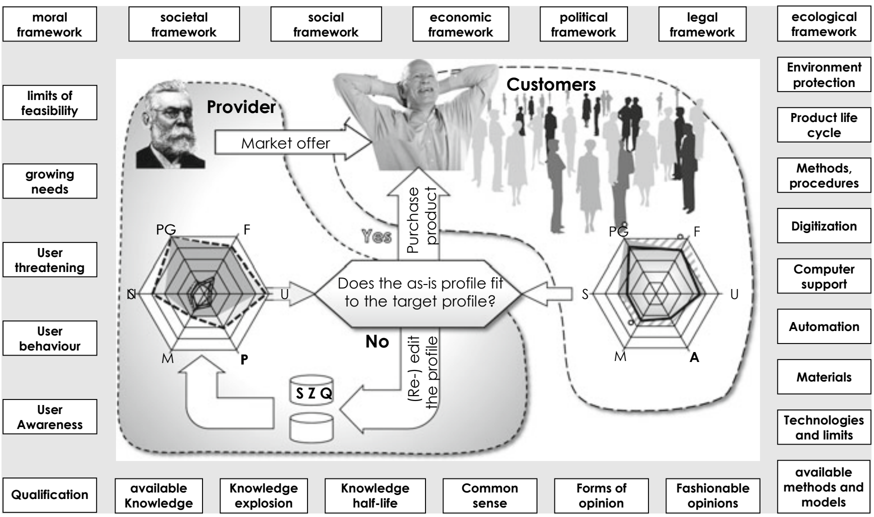

Fig. 3.21 Different influencing factors during product development in IDE

3.5 IDE in Comparison

On the basis of the evaluation scheme presented in [Vaki-2009], which bundles different questions in criteria groups, IDE is compared with some of the methods described in Chap. 1. These descriptions are compared on the other hand with (in anticipation of the following chapters) the descriptions of characteristics and properties of IDE. The criteria groups and the individual questions are:

- Basic concept: Does the method have an (exclusively) mathematical basis or was it also derived from empirical studies? Does the basic concept have a fixed structure (sequential, hierarchical, parallel or relational) or is it networked, object-oriented, disordered, multidimensional or chaotic? Does the method promote innovation across departmental boundaries, for example by supporting analogies? Can only simple products be developed or those of any complexity? How is complexity dealt with? Is the method a "toolbox" or an integrated concept?
- Integration capability: Is the method capable of bringing together several application disciplines (mechanical engineering, electrical engineering and electronics, software engineering and their combinations in mechatronics)? Can any products be developed with it? Are all attributes considered? Can economic influences as well as findings from other fields (e.g. biology, cognitive ergonomics, psychology and ergonomics) be incorporated? Does the method support people from different areas and with different knowledge profiles, working together or each working on their own? Does it support communication?
- Process model: Is the method based on a rigid process model that must be followed by the user and that is difficult to change? Does it offer a selection of suitable activities according to the actual situation, in order to allow an opportunistic and flexible, but nevertheless systematic approach? Does it support the parallelization of activities and, if so, to what extent?
- Adaptability and flexibility: Can the method be continuously adapted to changes in specifications (e.g. requirements and initial conditions) and the environment without losing consistency? Does it allow simple iterations, jumps and loops? Are current (interim) results continuously documented and evaluated in order to provide the product developer with continuous feedback on the appropriateness of the measures taken?
- Predictability: Does the method use the paradigm that a complete description and consideration of requirements and boundary conditions will lead to exactly one solution (the so-called funnel approach)? Or does it lead to a set of equivalent but not identical solutions from which the product developer can choose the most appropriate solution to his problem in due course, even if specifications or other conditions were changed during product development?

- Transferability: Transferability refers to the possibility of adequately teaching the method to people (learnability), to its applicability for the development of any products (general applicability) and to the adaptability of the method to any problems in industrial practice (practicability).

Since the individual criteria cannot be evaluated with a uniform evaluation standard, different levels of evaluation are used:

- A criterion is met (Y = Yes) or not (N = No). If this cannot be clearly described, the criterion is marked with I (=indifferent).
- The degree to which a criterion is fulfilled is rated H (=high), M (=medium) or L (=low).
- The excellence of fulfilment is assessed with five grades: very good (++), good (+), satisfactory (0), sufficient (−) and poor (−).
- If a criterion for a method does not apply or is not applicable, it is marked with an "X".

	TTS (Hubka, Eder)	VDI 2221 guideline	IPD (Olsson)	IPD (Ehrlenspiel)	DPD (Ottosson)	Systems Engineering	IDE
General applicability	++	++	++	++	++	++	++
Enabling innovation	+	+	+	+	++	+	++
Method compexity	L	M	L	L	M	M	M
Possible complexity of the product to be developped	H	H	H	H	H	H	H
Application of computer support (mainly CAx)	B	M	M	M	M	H	H
Integration of different application areas and specialist fields	B	+	+	+	+	+	++
Applicability for different types of products	+	++	++	++	++	++	++
Simultaneous consideration of different objectives	–	+	+	+	+	+	++
Multiple product attributes in parallel and equivalence	–	0	0	0	+	+	++
Using analogies to nature	N	N	N	N	N	N	N
Consideration of econmic influences and factors	–	0	0	0	+	+	++
Focussing on humans (human centricity)	–	0	0	+	+	+	++
Supporting communication	0	+	0	0	+	+	++
Supporting individual jobs	++	++	+	+	+	0	+
Supporting teamwork	0	+	++	++	++	++	++
Systematic, deterministic, and predefined procedures	Y	Y / N	N	N	N	J /N	N
Opportunistic and spontaneous activities and procedures	N	N	Y	Y	Y	J	Y
Same or similar activity pattern for different tasks	Y	N	I	Y	Y	J	Y
Parallelisation of activities	–	Y	++	+	++	+	++
Dynamic reactivity	–	0	0	0	++	k.A.	++
Continuous identification and evaluation of actual results	0	+	+	+	+	+	++
Continuous feedback	–	0	++	++	++	++	++
One single and predictable solution	Y	I	N	N	N	N	N
Several equivalent but not similar solutions	N	I	Y	Y	Y	J	Y
Learnability	+	++	+	+	+	+	+
Generality	++	++	++	++	++	++	++
Feasability	0	+	++	++	++	++	++

Fig. 3.22 Method comparison

Figure 3.22 shows the comparison of the General Process Model of Design according to Hubka (Sect. 1.1.1) with the VDI guidelines 2221 and 2222 (Sect. 1.1.2), Integrated Product Development according to Olsson (Sect. 1.2.1), Integrated Product Development according to Ehrlenspiel (Sect. 1.2.3), Dynamic Product Development according to Ottosson (Sect. 1.4), Systems Engineering [Daen-1999, Gaus-2013] and IDE.

The result of this comparison shows that IDE offers not only a good synthesis of existing methods, but above all a powerful alternative for the holistic development of arbitrary products from different disciplines through flexibility and dynamics of processing, focus on humans, diverse integration of topics and areas of the product lifecycle, interdisciplinarity as well as various forms of describing the behaviour of a product through attributes.

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References

[Aamo-2015] Aamodt, M.G.: Industrial/Organizational Psychology: An Applied Approach, 8th edn. Cengage Learning, Boston (2015)

[Beys-2020] Aachener Stiftung Kathy Beys: Lexikon der Nachhaltigkeit. http://www.nachhaltigkeit.info/artikel/definitionen_1382.htm. Visited 18 Jan 2020

[BrKn-1997] Breiing, A., Knosala, R.: Bewerten technischer Systeme: Theoretische und methodische Grundlagen bewertungstechnischer Entscheidungshilfen. Springer-Verlag, Berlin Heidelberg (1997)

[BoDe-2003] Boothroyd, G., Dewhurst, P.: Design for Assembly: A Designer's Handbook. Dewherst Inc., Wakefield (USA) (2003)

[Björ-2003] Björk, E.: Insider Action Research Applied on Development of Assistive Products. PhD thesis, Otto-von-Guericke-University, Magdeburg, Germany (2003)

[Burc-2001] Burchardt, C.: Ein erweitertes Konzept für die Integrierte Produktentwicklung. Dissertation Otto-von-Guericke-Universität Magdeburg (2000)

[Burc-2017] Burchardt, C.: Design thinking meets Integrated Design Engineering. In: Vajna, S. (ed.) 11th International Workshop on Integrated Design Engineering, Magdeburg (2017)

[Daen-1992] Daenzer, W. F.: Systems Engineering - Methodik und Praxis, Verlag Industrielle Organisation Zürich (1992)

[Daen-1999] Daenzer, W.F.: Systems Engineering—Methodik und Praxis, Verlag Industrielle Organisation Zürich (1999)

[DIN-40041] DIN 40041: Zuverlässigkeit elektrische Bauelemente. Stand: Dezember 1990, Beuth-Verlag, Berlin (1990)

[Dys-2010] "Frust ist ein großartiger Antrieb". Interview mit James Dyson in SPIEGEL Online vom 25. Mai 2010. http://www.spiegel.de/netzwelt/gadgets/erfinder-dyson-ueber-technikaerger-frust-ist-ein-grossartiger-antrieb-a-687513.html. Zugriff am 22 Mai 2013

[ECPD-1947] Engineers' Council for Professional Development: Canons of Ethics for Engineers, New York (1947)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung—Denkabläufe, Methodenseinsatz, Zusammenarbeit. 6., vollständig überarbeitete und erweiterte Auflage. Hanser (2017)

[Fair-2020] Homepage of the Dutch company Fairphone. http://www.fairphone.com, visited on 18 Jan 2020

[Frit-2020] Fritzsche, A.: Digital Sovereignty and Innovation—Setting the Foundations for a Never-Ending Project. Engineering and Technology. Valparaiso, Chile, Forum for Philosophy (2020)

[Garv-1988] Garvin, D.A.: Managing Quality: The Strategic and Competitive Edge. The Free Press, New York (1988)

[Gaus-2013] Gausemeier, J.: Systems Engineering in der industriellen Praxis. Hans Nixdorf Institut, Fraunhofer Institut IPT (beide Paderborn) und Unity GmbH Büren (2013)

[Hehe-2011] Hehenberger, P.: Computerunterstützte Fertigung—Eine kompakte Einführung. Springer, Heidelberg (2011)

[Hubk-1976] Hubka, V.: Theorie der Konstruktionsprozesse: Analyse der Konstruktionstätigkeit. Springer, Berlin, Heidelberg (1976)

[ISO 9241-210] ISO 9241-210:2010: Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems, 2010

[Meer-1994] Meerkamm, H.: Design for X—a core area of design methodology. J. Eng. Des. **5**(2), 165–181 (1994)

[Otto-1996] Ottosson, S.: Dynamic product development—findings from participating action research in a fast new product development process. J. Eng. Des. **7**(2), 151–169 (1996)

[Rutt-2012] Rutter, K.: Sustainable engineering. Vorlesungsreihe ENEL 301, University of Canterbury, Department of Electrical and Computer Engineering, Christchurch (NZ) (2012)

[SuRK-2020] Subrahmanian, E., Reich, Y., Krishnan, S.: We Are Not Users: Dialogues, Diversity, and Design. MIT Press, Cambridge (2020)

[Tjal-1979] Tjalve, E.: A Short Course in Industrial Design. Newnes-Butterworths, London (1979)

[VaKB-2011] Vajna, S., Kittel, K., Bercsey, T.: The autogenetic design theory—product development as an analogy to biological evolution. In: Birkhofer, H. (ed.) The future of design methodology. Springer, London (2011)

[VaKi-2009] Vajna, S., Kittel, K.: An approach to compare product development methods. Vortrag 5-313 in Leifer, L., Skogstad, Ph.: Proceedings of ICED 09 Stanford, The Design Society 2009 (auf CD, 12 Seiten) sowie Leifer, L., Skogstad, Ph.: Proceedings of ICED'09, vol. 5, Design Methods and Tools, Part 1, S. pp. 313–324 (2009)

[Webe-2005] Weber, C.: CPM/PDD—An extended theoretical approach to modelling products and product development processes. In: Bley, H., Jansen, H., Krause, F.-L., Shpitalni, M. (eds.): Proceedings of the 2nd German-Israeli Symposium on 2nd German-Israeli Symposium on Advances in Methods and Systems for Development of Products and Processes, Berlin 2005. S. pp. 159179. Fraunhofer-IRB-Verlag, Stuttgart (2005)

[Webe-2011] Weber, C.: Design theory and methodology—contributions to the computer support of product development/design processes. In: Birkhofer, H. (ed.) The Future of Design Methodology, pp. 91–104. Springer, London (2011)

[Webs-1983] Webster's New Universal Unabridged Dictionary: Simon and Schuster, 2nd edn. New York (1983)

[Zwic-1982] Zwicky, F.: Entdecken, Erfinden, Forschen im Morphologischen Weltbild. Droemer Knaur München (1982)

Chapter 4
Human Centricity in IDE

Jacqueline Urakami

Human factors are becoming increasingly important for the economy. Actual challenges of companies are changes in the age structure of the population, flexibility in work across the life span, shift in values and priorities such as work-family balance and the wish for self-realization and increased mobility. The central role of Human Centricity is summarized in Fig. 4.1. In the course of globalization, cut-throat competition occurs as more and more participants enter the market. The increasing individualization of products leads to fragmented markets in which only those companies can realize technical progress (upper part of Fig. 4.1) that works both in an effective and efficient way. Additionally, labour-intensive activities such as production are being relocated to so-called low-wage countries, while the tasks of product development remain within the provider in developed countries as a core competence and a competitive factor. This shift from physical work to mental work makes it essential to attract and to employ highly skilled and qualified workers. As result, the significance of the employee as knowledge worker continues to increase, thus moving him or her into the centre of entrepreneurial interest, where he or she is no longer perceived as a production factor, but is an essential success factor of the company [Grah-1998].

Human centricity increases satisfaction of employees, because they are accepted and respected in their importance. Focusing on customer needs and requests in a human-centric approach reinforces the development of products that are valued and appreciated by the customer. Because products and their appertaining processes are mastered, it is possible to react quickly to changing conditions without compromising quality. These effects not only result in competitive advantages for the provider, but also improve its internal and external profitability (lower part of Fig. 4.1).

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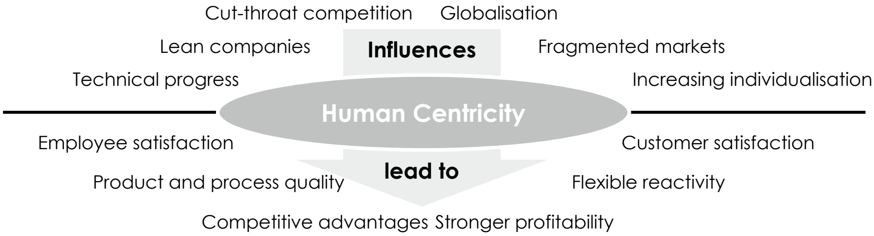

Fig. 4.1 Central role of human centricity (based on [Hofe-2010])

Therefore, it is not surprising that recent years have seen a refocus on people across various disciplines such as economics, architecture, engineering, and computer science. Human centricity is not just about providing efficient products, but should always ask the question whether a particular product improves the quality of life, creates new values and opens up opportunities for social participation. By applying human-centric criteria to all phases of the product life cycle and incorporating all humans involved in the product life cycle, the IDE perspective of human centricity goes beyond the mere formulation of requirements and recommendations for human-centred design. In addition, influences on people who do not come into direct contact with the product or who are not involved in the production process are also taken into account as an indirectly affected group of people here called persons concerned. In this way, not only the influence of a product on specific groups of people is taken into account, but also the extended influence of a product on society as a whole. That is why human centricity is the core philosophy of Integrated Design Engineering (IDE) and hence is the keystone for the interdisciplinary and holistic approach of IDE for the development of any kind of product or service.

Goal of this chapter is to introduce human centricity as the core concept of IDE focusing on humans involved in and affected by the product life cycle. First, a short history of the shift of values of work is given. Section 4.2 gives a brief introduction to stages of the product life cycle, its environments and human stakeholders. Section 4.3 describes the different roles human stakeholders fulfil in the product life cycle, highlighting different human effects throughout. Section 4.3.4 describes product requirements derived from humans involved in the product life cycle, and Sect. 4.4 highlights both benefits and effects of human centricity.

4.1 Shift in Values: A Short History of Human Centricity

The industrial revolution with its shift from manual labour to factory work and mass production can also be seen as a starting point for industrial engineering. The main focus of industrial engineers in the beginning of the nineteenth century was on improving efficiency and increasing the productivity of industrial employees. The American engineer Frederick W. Taylor introduced his principles of efficiency techniques in his book "The Principles of Scientific Management" [Tayl-1911].

Taylor was one of the first to introduce scientific methods to study work, to scientifically select and train employees, and to divide work between managers and workers; letting managers do the planning and workers perform the tasks. Even though Taylor's methods were very innovative and influential at that time, and are still employed in some settings nowadays, they have also been criticized of transferring control from workers to managers, to separate cognitive work (planning) and manual labour (doing). This resulted in boring, monotonous tasks that contributed to the demotivation of the employees [Hoxi-1915].

At the same time, the American psychologist and industrial engineer Lillian M. GILBRETH and her husband Frank B. Gilbreth, who worked his way up from mason to contractor and process consultant, proposed a concept which considered the psychological dimensions of work as important factors for workers' productivity and efficiency [Grah-1998]. The Gilbreths were among the first to realize that productivity is related to workers psychological factors such as fatigue and job satisfaction. Hugo MÜNSTERBERG, the founder of industrial and organizational psychology, described the effects of the working environment on the production of employees in his works "Beruf und Lernen" [Müns-1912] and "Psychologie und Arbeitseffizienz" [Müns-1913]. Münsterberg argued that methods of experimental psychology should be used for systematic work studies. Furthermore, he explained in his work how suitable workers can be selected on the basis of their personality traits and abilities for certain occupations in order to improve motivation and performance.

During World War 1, psychologists were involved in developing tests to place recruits within appropriate positions. Through this work, psychologist could make a valuable contribution to the society and gave the profession its social acceptance, resulting in the wide spread application of industrial psychology after the war.

The Hawthorn studies in the 1930s were another milestone in understanding the complexity of human factors at work. Researchers around Elton Mayo were originally examining the role of the work environment such as illumination on workers performance and surprisingly found that performance improved when changes were made but performance went back to the prior level after the study ended [RoDi-2003]. The researchers realized that other factors than the work environment must have played a role and concluded that both the attention employees received by the researchers and employees' desire to please the researchers resulted in higher productivity. The Hawthorn studies put the spotlight on the role of social relationships, interactions of managers and employees, and employees' attitudes as crucial factors for productivity, and inspired a new line of study, the Human Relations Movement. The Human Relations Movement focused on workers as social beings, emphasizing the importance of group work and communication needs. The Human Relations Movement gave industrial psychology a new direction by focusing on individual needs of employees in order to motivate them and to improve the working atmosphere.

Around this time, the factor "motivation" became the centre of interest and motivation theories by Abraham MASLOW and Frederick HERZBERG highlighted that a person's desire to realize their full potential and to reach a level of self-actualization needs to be fulfilled. In this humanistic perspective, productivity per se is not the ultimate goal in work design, but the fulfilment of both personal needs and well-being of the employee is emphasized. Herzberg proposed a two-factor theory of job satisfaction. In his theory, Herzberg [Herz-1968] describes motivators that have a positive effect on employees motivation (e.g., job recognition, promotion), but will not result in dissatisfaction when not fulfilled, and hygiene factors that will not motivate but prevent dissatisfaction (e.g., job security, payment). Herzberg's contribution is to place attention to the important role of job factors but neglects individual differences in regard to motivation or hygiene factors. Furthermore, it is still largely unclear whether happy employees are also more productive [Argy-1989]. Maslow [Masl-1943] introduced a hierarchy of needs with basic physiological needs at lower levels of the hierarchy and self-actualization at the top of the hierarchy. According to Maslow, people strive to attain self-actualization but can only reach it when needs at lower levels of the hierarchy of needs are fulfilled first. Although Maslow's theory has found great resonance especially in management theories, it is too simple to do justice to the complexity of human beings.

Since the 1970s, three schools have evolved taking a different perspective at the role of humans in work: (1) Sociotechnical system theory, (2) Job characteristics theory and (3) Action regulation Theory. Based on their work at the Tavistock Institute in London, Fred Emery and Eric Trist proposed a theoretical framework of sociotechnical systems that have as its goal the joint optimization of the technical system, such as procedures and related knowledge, and the humans working within [EmTr-1965]. Sociotechnical systems emphasize the role of teams or groups and promote partial autonomous work groups. Work design focuses on responsible autonomy, adaptability, whole and meaningful tasks. Goal of sociotechnical systems is to balance demands and capabilities of the technical system and humans working within the system.

The second school, the job characteristics theory by Greg R. Oldham and J. Richard Hackman describes how job characteristics such as skill variety, task identity, task significance and autonomy are linked to psychological states such as experienced meaningfulness of the work, experienced responsibility for outcome of work and knowledge of results of work activities [HaOl-1975, HaOl-2005]. The psychological states are linked to personal and work outcomes such as internal work motivation, job satisfaction, absenteeism, turnover and performance quality. The theory describes how work should be designed to fulfil needs of employees and to improve performance. The focus of this school is on designing jobs and tasks that match the needs of the workers for producing positive outcomes such as quality of work-life and performance.

The third school is based on the action-regulation theory by Winfried Hacker [Hack-1994]. According to Hacker [HaSa-2014], work should foster personal growth, unlock humans' potential and promote learning. Humans are seen as active agents who develop, select, pursue and revise goals. Work is defined as a mental and/or physical activity carried out in order to achieve a specific goal. The focus is on whole tasks that require decision-making and responsibility; stimulate learning and problem solving, offer autonomy and a sense of meaning, and provide social support through cooperation requirements. This school focuses on the personal growth of workers. Jobs should be designed in a way that the personality of a worker can unfold in order to unlock and empower human abilities.

4.2 The Importance of Humans in the Product Life Cycle

This view of human centricity in IDE is probably closest to the approach of sociotechnical systems, focusing on matching human capabilities and limitations with the demands of the task, environment and the technical system. Beyond that, the IDE framework of human centricity takes a holistic perspective considering all humans involved at different stages of the product life cycle. Humans are looked at as active agents, who strive to fulfil own needs and pursue own goals in the sense of the action regulation theory of HACKER [Hack-1994]. In the following, the product life cycle will be only shortly reintroduced here to highlight the role of human stakeholders (for a more detailed representation of the product life cycle of Chap. 2).

A product life cycle integrates life stages and stakeholders as well as influencing environments and contexts (Fig. 4.2).

The five life stages are planning, development, production, utilization and re-utilization of the product. If a product is completely created "from the scratch" (new product development), it goes through all five stages of its life cycle. Fewer stages will be passed if the product results from an adaptation or further development of an existing solution. After having finished the life cycle, the product re-enters a new product life cycle by being 100% reused or recycled into a new product.

Compared to other approaches such as user-centred design, human centricity not just evaluates the impact of the processes of generation, usage and re-utilization of a product only on users but considers other stakeholders that are directly or indirectly affected by the product life cycle as well. In consequence, human centricity in IDE

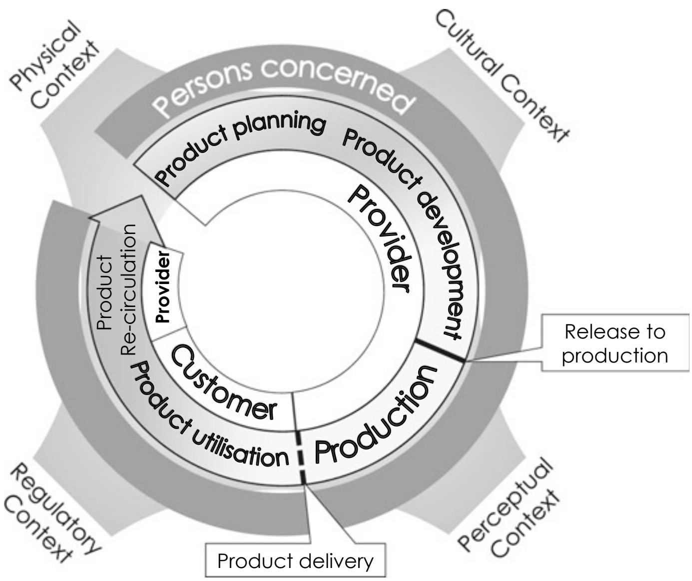

Fig. 4.2 Product life cycle with human stakeholders, product phases and influencing environments [UrVa-2018]

deals with three groups of stakeholders involved or affected by the product life cycle, which are providers, customers and persons concerned.

- Providers are all persons involved in the planning, development, production and re-utilization of a product. Thus, providers are persons who are working within the product life cycle such as persons that are directly involved in the creation, the production and the re-utilization of a product.
- Customers are persons who acquire a product and/or use a product.
- The third group, persons concerned, covers any person that might be directly or indirectly affected by activities or effects in context with the product across all the stages of the product life cycle. Persons concerned can be people who live at close proximity of a production site and are affected by noise or pollution that comes from it. Persons concerned are also persons who are indirectly affected by the utilization of a product, for example being bothered by compulsory listening to music or being exposed to exhaust fumes by cars. The group of persons concerned is not considered in most approaches to industrial design. By including persons concerned, the extended social relevance of human centricity is emphasized.

Furthermore, the product life cycle exists within an environment that is defined as having cultural, perceptual, regulatory and physical contexts.

- The cultural context emerges from cultural values, among these life style, habits, communication patterns, working culture or technological development of a culture. Cultural aspects affect the humans within the product life cycle, e.g., in the way of thinking [Nisb-2005], self-perception [MaKi-1991] and communication patterns, beliefs and value systems. As a consequence, products have to represent the cultural values of their targeted users. Products can also affect cultural elements, e.g., smart phones or text messaging have broadened the ways of communication and exchanging ideas.
- Perceptual context refers to how people perceive and comprehend the world around them. People from different cultural backgrounds perceive the world differently and process information in a different way (e.g., [Nisb-2005]). Providers and customers with different cultural backgrounds might differ in their perceptions and attitudes towards products. Cultural differences exist in regard to information processing, stereotyping and categorization when and how products are used.
- The physical context refers to the geographical location in which a product is developed and used. Products must be designed to function reliably in a particular climate or physical environment. The physical environment and the product influence each other in mutual interaction through the use of the product or its side effects, such as exhaust gases from vehicles that cause air pollution.
- The regulatory context covers laws, regulations, standards and guidelines. These govern the genesis, the application and the re-utilization of a product in its target environments on different levels of strictness. They provide a knowledge base for manifold best practices, thus offering guidance when developing, manufacturing and using solutions of any kind. On the one hand, they help to minimize aberrations, and on the other hand, they may hinder innovations or breakthroughs, e.g., self-driving cars may require new regulations and guidelines about manufacturing

issues as well as insurance policies or responsibilities in case of an accident and its possible consequences.

Human centricity in IDE takes people as a starting point and examines what is necessary for the different stakeholders in the product life cycle and why. Thus, human centricity is an ideal that may not be fully achieved, but which is approached as closely as possible by finding compromises and (preferably) synthesizing opposing positions and approaches in the development of work processes and products. People are not only seen as valuable resources, but well-being and personal development are important factors to consider. Building on existing skills, encouragement will be given to acquire new knowledge and skills that will benefit all stakeholders involved.

4.3 Humans Involved in the Product Life Cycle

This section describes in detail the role of stakeholders in the product life cycle such as provider, customer and persons concerned.

4.3.1 Provider

The term "provider" is here derived from the customer's point of view. The customer gets products that are provided by a more or less anonymous and not always transparent organization. Any institution or any person that works within the product life cycle, people who are involved in planning and realization of a product, its transition to the customer and the recycling or re-utilization of a product are called provider. Thus, providers are, for example, designers, entrepreneurs, researchers, product developers, producers, but also sales people, retailers, wholesalers, recyclers and disposers.

As described in Sect. 4.1, the IDE view of work and the role of people within organizations has changed from a passive view, testing and selecting people to place them at the right position within the organization, towards a more active view, seeing people as active agents who follow own goals, strive to fulfil needs and have individual attitudes and goals in life that needs to be met by the organization. Organizations have to be innovative to compete on a global market, and therefore, an organization's success greatly depends on the quality of its workforce. Already in 1997, Joachim SCHNEIDER (then board of directors of ABB Deutschland) asserted: "Our main assets are not machines or factories, but the quality of our heads". Employees need to be able to adjust to changing work environments and requirements and have to react to unforeseen disturbances and changing customer requests.

A successful provider needs motivated employees with professional and social competence, employees who can act independently and think holistically [Berl-1977, HaSa-2014].

- Professional competence: Skills and abilities, knowledge and expertise to fulfil the work assignment.
- Social competence: Ability to work in a team and to communicate appropriately in conflict situations.
- Taking responsibility: Acceptance of responsibility, goal-oriented behaviour and self-organization.
- Holistic thinking: The ability to look beyond one's area of responsibility, to understand and to handle the complex interrelationships to other disciplines and within the organization. Furthermore, being able to foresight consequences of one's own actions.

A central task in IDE is design, development and management[1] of the work tasks and work environments to motivate employees and support their continuous development. According to HACKER [Hack-1994], work is a special form of activity with the following characteristics:

- Goal orientation: Work activities are goal-oriented and involve conscious cognitive processes.
- Goal anticipation: Employees are able to envision goal achievement and are able to anticipate the state of goal achievement that has a positive effect on work motivation.
- Involving effort: Employees need effort to achieve the set goals that involves volition regulation, such as overcoming obstacles, and being persistent to attain goals despite arousing difficulties.
- Hierarchical structure: Activities (work tasks) have a hierarchical structure with goals and sub-goals.

Furthermore, basic processes of action regulation such as goal setting, orientation, planning, monitoring and feedback describe the underlying structure of work activities. A work task should contain all sequences of action regulation, starting with setting goals, orientation by finding tools and approaches to attain the goal, planning tasks and actions, monitor the progress of the performance and receiving feedback to be able to evaluate if the goal has been attained or not. Consequently, work design must reconcile objectives, decision-making, control of activities and social cooperation in order to avoid negative impacts such as mental ill health and performance degradation [RiRS-1983], Fig. 4.3.

Thus, job design has to meet the following criteria:

- Whole tasks: Tasks are comprehensive enabling employees to check the results of one's own work with the requirements. Employees thereby receive feedback on their own work progress from the activity itself.
- Diversity of requirements: Tasks contain goal setting, planning, execution and control activities. In addition, different cognitive as well as sensorimotor requirements exist.

[1]For the IDE management task mentioned here, see Sect. 15.7, Dynamic Process and Project Navigation.

Fig. 4.3 Basic processes of action regulation

- Cooperation requirements: The task makes it necessary to cooperate with co-workers. Thus, difficulties can be overcome together. Moreover, mutual support is a social resource to compensate stress.
- Autonomy: Employees have degrees of freedom in scheduling and making decisions. Autonomy strengthens self-esteem and the willingness to take responsibility. In addition, autonomy conveys the experience of having a meaningful task that matters.
- Opportunities for learning and personal growth: The necessity to solve problems requires that existing qualifications must be expanded or new qualifications have to be acquired in order to cope with task requirements.

Naturally, a provider cannot only concentrate on employees' well-being and personal growth, but, above all, has to be profitable. Requirements stemming from the human perspective as described above have to be matched with the demands of the technical system, such as hardware and software components and the interfaces of and between them as well as the environment. Goal is to match positive and negative outcomes of the complex compatibility relationship between human and technical systems to attain quality both of working life and system performance. A successful adjustment of technical and social systems produces positive results such as job satisfaction, well-being and motivation on the human side as well as productivity, product quality and performance for the company. If technical and social systems are poorly balanced, negative consequences such as stress, discomfort, dissatisfaction at work, demotivation on the human side and mistakes, loss of productivity, accidents and poor quality can be expected for the company [Karw-2006].

4.3.2 Customer

Products are made to satisfy the needs of customers. The customer can be a person or a group of persons that purchases and uses a product. Depending on who is the intended end-user of the purchased product, one can differentiate between three different groups, the buyer, the sponsor and/or patron, and the user. The following sub-chapters describe these groups of customers in detail.

4.3.2.1 Buyer

The buyer is a person or group of persons who purchases the product. If the product is intended for the buyer's own use, then the buyer is also the user of the product. However, the buyer might only acquire the product and pay for it, but does not use the product him/herself. In this case, buyer and user are different persons or groups of persons.

The divergence of needs between buyer and user can lead to conflict of interests. Buyers might be looking for low prices as well as simple and durable products with low maintenance that can be used over a long stretch of time by different users, whereas users are looking for efficiency, comfort and ease of use. As a consequence, possible conflicting interests of buyer and user of a product have to be clarified and to be taken into account from the very beginning of product development. For example, a health insurance company (the buyer) provides a wheelchair to a person with a disability and his attendant (the users). The health insurance company wants a cheap, durable and robust device that may be used by different parties. The person with a disability wants a customized chair that is both adjustable and comfortable, and aesthetically pleasant. The attendant wants an easily movable, not too heavy and ergonomically designed chair.

4.3.2.2 Sponsor and Patron

Sponsor and patron are special types of buyers. A sponsor is a person or organization that pays for or contributes to the purchase of a product. A sponsor may pay the product for a user out of various reasons such as increasing brand awareness and sales of a product, reposition his brand, block competition or because of social responsibility. Sponsors might link their own message to a product because it will align their brand to values and beliefs their customers are passionate about. Sponsoring can increase brand visibility, and it affects consumer perception.

A patron may provide financial, organizational, technical or ideological benefits to his customers to enable them to purchase a product. The reasons for patronage may range from philanthropy to promoting specific economic or political interests.

4.3.2.3 User

The user is the person the product is intended for. The user uses the product in order to perform a certain task, to satisfy individual needs or to pursue a specific goal[2]. The development of technologies should be motivated by user's needs.

[2] In this context, the user is not a person whose actions are determined by the respective product. On the contrary, the user acts, when dealing with the product, autonomously, on his own responsibility, self-determined, appropriately and independently (following [SuRK-2020] and [Frit-2020]).

Product development is a process in which the individual needs, abilities and limitations of the user and the resulting requirements (see Chap. 2) on the one hand and the affordances[3] (i.e.,) of the selected technologies on the other hand have to be matched.

First, a general need is to achieve and to ensure safety and health, usability, productivity, performance and human well-being. Products need to be safe to use, and users have to be protected from harm when using a product. Furthermore, users want products that support them in accomplishing a certain task in an efficient way, a product that is easy to use and improves their performance and productivity. Second, functional requirements and constraints resulting from human capabilities and limitations such as anthropometric and biomechanical factors, perception and cognition have to be matched.

- Physical: A product needs to take into account basic capabilities and limitations resulting from human anthropometry, biomechanics, kinematics and muscular strengths.
- Physiological: A product needs to consider capabilities and limitations resulting from the human sensory system, human perception and human psychophysics.
- Cognitive: A product needs to consider capabilities and limitations that are derived from how our cognitive system works such as processes of comprehension, understanding, memory, attention, reasoning, judgement and decision-making.

Functional requirements are derived from observations of how human interact with their environment. Thus, processes of perception, comprehension and respond mechanism have to be addressed in product development (see Fig. 4.4).

Perceive: First of all, the user must be able to perceive information provided by the product. The user has to be able to find controls, perceive displayed information, feedback and the system status. Basics of human sensation and perception such as minimal threshold for perceiving sensory input (the minimum magnitude of a stimulus that can be discriminated from no stimulus at all) and just noticeable difference (minimum stimulus magnitude to tell two stimuli apart) have to be respected in product design. This also includes compliance with ergonomic guidelines.

Comprehend: Secondly, the user must be able to receive the perceived information, process it, interpret and evaluate it. In short, the user has to understand how to use the product. Thus, users' capabilities and limitations of cognitive processes such as memory, attention, learning, problem solving, remembering and language have to be considered in product design and thus are mandatory in IDE. Because of memory capacity limitations, the user should not be required to hold information for too long in working memory. Furthermore, users' knowledge and experience have to be considered as well. Design criteria of cognitive ergonomics such

[3] Affordances describe the suitability of an environment to the observer. Because affordance depends on the observers' current needs and capability, the same environment provides different affordances to different people (according to [Gibs-1979]). With a closer focus on products, affordances are possible interactions between a user and a product, which result from performance, structure and shape of the product [Norm-2004].

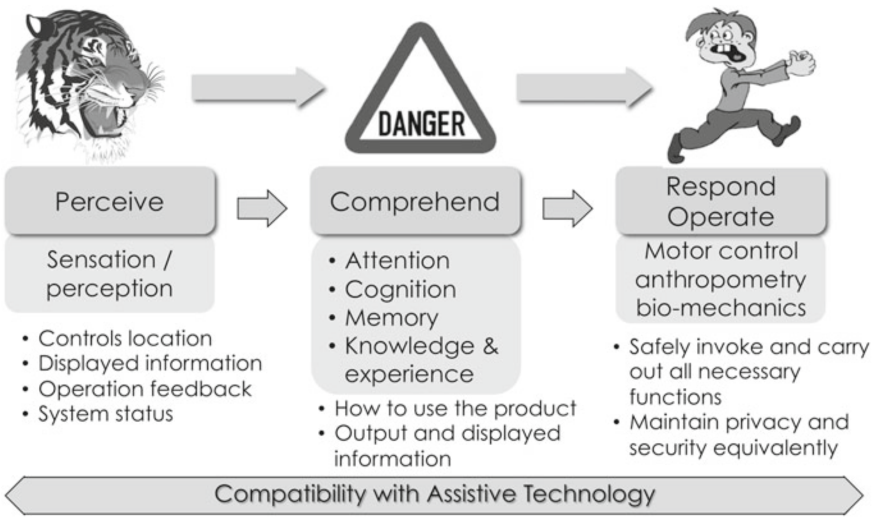

Fig. 4.4 Human interaction with environment (based on [UrVa-2018])

as compatibility, consistency, individualization, robustness (error tolerance), transparency, learnability, memorability, efficiency and satisfaction provide guidelines for the improvement of interfaces.

Respond/Operate: Third, the user has to respond appropriately to the information provided by the product. The user must be able to operate the product safely and to carry out all functions at the expected levels. Information from the product as well as from the user's body is integrated to generate a desired motion or action. The physical dimensions of the product have to be matched to the physical dimensions (anthropometry) of the user's body to design appropriate clearance, grips and positions of displays and controls. Capabilities and limitations of the user's motor control that is the coordination of body movements and muscle strength (biomechanics), precision of movements and time needed to carry out specific actions have to be considered in product design.

Capabilities and limitations across users can vary widely. To address a wide range of users with diverse capabilities and limitations, universal design criteria [StFM-1998] such as equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use have to be pertained. In practice, it is not possible to design a product everybody can use regardless of the respective available capabilities and limitations. Goal is to develop a product that is usable and attractive to the maximum possible number and diversity of users[4].

The requirements described above are basic requirements that a product has to fulfil. However, nowadays most customers take, e.g., functionality and usability of

[4]For issues of usability and ergonomics, see also Chap. 8.

a product for granted. To attract potential customers, products have, e.g., to inspire, enhance life, evoke emotions and dreams. This is especially true for matured products. According to NORMAN, products need to have an emotional appeal [Norm-2004]. Consumers do not just buy any product, they buy products that reflect their values and identity, products that entertain and provide valuable experiences. Many companies have realized that the future belongs to products that evoke an affective response such as pleasure, trust, excitement, or likeability. By describing products with attributes (especially with the first three, Product Gestalt, Functionality, and Usability, see Chap. 3), IDE indicates how product parameters, situations of use and user characteristics interact to generate specific affective responses.

From fundamental research, it is known that the human affective system and the cognitive system are partly unified and contribute to the control of thought and behaviour [Phel-2005]. The affective system is related to a group of structures in the brain called the limbic system. It reacts intuitively and quickly on sensory input, whereas the cognitive system, related to the cerebral cortex, is analytical, rational and slow. The affective system provides immediate information whether a situation is safe or dangerous, whether one likes or dislikes something, thus assisting the human in making quick and efficient judgements. Affective design can easily capture consumers' attention and guide consumers' behaviour. Therefore, a product needs to evoke an affective evaluation by the user (see Fig. 4.5). Product development has to take into account how the human affect system influences the processes of decision-making, judgement and attention. Moreover, emotional reactions such as pleasure of using a product and user satisfaction have to be taken into consideration as well.

The IDE approach of human centricity goes even beyond these development criteria and proposes that, above all, products should not only be useful, but also bring benefits of various kinds for users. This philosophy is similar to the goal of job design. It is not enough to protect working people or users from harm and

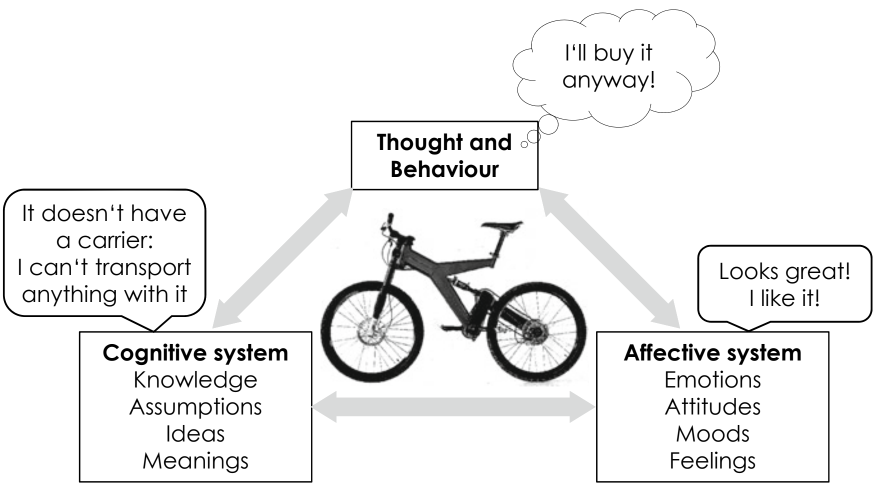

Fig. 4.5 Relationships between cognitive system, affective system, thought and behaviour

consider their different requirements, but the use of the product should enable humans to acquire new skills, to unlock abilities, to stipulate new experiences, to increase knowledge and, not to forget, to create pleasure and satisfaction.

Technology often aims to make people's lives easier and to relieve them of unpleasant tasks. This is by no means a bad thing, but if it comes together with a loss of skills, then a short-term work facilitation leads to a long-term loss of ability. The long-term goal of product development should therefore be to support and to promote the development of new skills and to provide new positive experiences. Recent years have seen a boom in the development of service robots. This development is seen to be critical by many based on the fear that, in the long term, robots will replace humans in many areas. However, there are a few robots such as Nao [Robo-2018] or Cozmo [Anki-2018] that also teach you programming. For example, Cozmo's Code Lab is built, so that even children can learn basics of programming in a fun and engaging way. This type of products is beneficial for users because they promote the development of new skills.

4.3.3 Persons Concerned

Persons working within the product life cycle and persons using products are focused on in various approaches both in product development and in industrial engineering. However, persons concerned are mainly overlooked so far. In the holistic framework of IDE also, such persons are considered, who are indirectly affected at all stages of the product life cycle. The goal is that any negative impact on third parties that are directly or indirectly affected at different stages of the product life cycle has to be avoided. This includes avoiding short-term and long-term negative effects on a person's health, protection from harm and maintaining psychological well-being.

Persons concerned can be exposed to negative effects at stages of the product life cycle such as

- Development and production: Persons living in physical proximity of a production site can be affected by negative outcomes of the manufacturing process such as environmental pollution, noise and traffic disturbances. Furthermore, a booming industry can tremendously change the living conditions, traffic situations and housing markets of larger regions as it is happening in the San Francisco Bay Area because of the surging demand for housing by employees of nearby companies such as Apple, Facebook and Google.
- Utilization: The use of a product can directly disturb or even harm persons in the same environment, such as negative effects of passive smoking or reduced air quality through high traffic volume. In recent years, lawmakers have become more sensitive to protect persons concerned from such negative effects issuing legislations that restrict smoking in public spaces or driving bans in highly polluted areas. However, general awareness of negative impacts of product utilization on public health is still low, and changes in legislations are often met with strong resistance.

- Re-circulation: The disassembling, re-assembling, recycling and disposition of a product can disturb persons and their respective environments. In recent years, awareness of responsible use of available resources has increased, and waste prevention, product reuse and recycling are receiving increasing attention (see Chap. 12). However, this awareness is not yet reflected in people's behaviour. According to Eurostat, approximately 480 kg waste per person was generated in 2016 in the EU, whereby Denmark, Malta, Cyprus, Germany and Luxembourg accounted for the highest amount of waste produced [Euro-2018]. Toxic waste of products is leaking into the environment, contaminating the world's oceans, causing flooding, transmitting diseases and in this way threatening the health and well-being of many people. The tremendous amount of plastic waste produced on a daily base cannot be recycled or reused. The World Bank Group has recently published reports about waste management showing that waste generation will increase drastically. The reports also highlight the necessity of waste management for developing sustainable, healthy and inclusive communities [Worl-2018].

While in more traditional product development approaches persons concerned are often overlooked by providers and users, IDE's holistic view on the product life cycle highlights the connections between all stakeholders involved and makes the interwoven relationships between them more apparent. IDE fosters providers as well as users to be more conscious about all stages of the product life cycle including to what happens to a product after its utilization and how a product impacts persons concerned.

4.3.4 Product Requirements Derived from Humans Involved in the Product Life Cycle

As described above, the three groups of humans are involved in the product life cycle are provider, customer and persons concerned. These three groups of humans have different demands and expectations towards a product. Table 4.1 summarizes requirements from human centricity within IDE for the three groups of humans. Higher-level requirements build on lower level of requirements. First of all, basic needs such as protection from harm and assuring safety have to be fulfilled. Second, in order to be able to carry out work tasks or to use a product, functional requirements that result from human capabilities and limitations have to be fulfilled. Third, to provide a positive experience and increase employee's motivation, effective requirements need to be fulfilled. Last, in line with the philosophy of seeing humans as active problem solvers who adjust the environment to their own needs, benefits such as personal growth, skill acquisition and new experiences should be the result of applying human centricity to the product life cycle. Furthermore, these criteria have also to guaranty that the quality of life and well-being of persons concerned is not affected under any circumstances.

Table 4.1 Human centricity criteria

	Provider	User	Persons concerned
Basic needs	Personal well-being, health and safety (Protection from harm, avoiding stress and fatigue)		
Functional requirements	Requirements and constraints resulting from human capabilities and limitations (e.g., physical, physiological, cognitive)		Does not apply
Affective requirements	Job satisfaction, psychological well-being, motivation	Satisfaction, positive physio-psychological stimulation, emotional experience	Does not apply
Benefits	Personal growth, acquiring new skills, knowledge, unlocking abilities, quality of life		Well-being, quality of life: not affected under any circumstances

In IDE, these demands are translated into a neutral description format using product attributes (see Chap. 3). To summarize, attributes describe both performance and capabilities of a product. The six product attributes product gestalt, functionality, usability, producibility/svailability, maintainability and sustainability derived from customers' demands describe what characteristics the product should have to fulfil the customers' demands to product performance, the so-called "target attribute profile". The respective fulfilment level is captured with the attributes safety, reliability and quality, the ideal and economic benefits with added value/profitability. The provider formulates, what he/she can offer, resulting in the "as-is" attribute profile. The "as-is" attribute profile can also be influenced by regulations and guidelines the provider has to maintain, or by conditions of the product environment. Taking into account the attributes derived from the persons concerned, attributes are further specified to describe the requirements of the target attribute profile and can thus go beyond the requirements formulated from customer expectations.

An assignment of product attributes and their descriptions to the three stakeholders is summarized in Table 4.2. Some attributes are relevant for more than one group of humans. However, each group formulates different demands on the attributes taken from their own point of view.

- **Provider**: First of all, the provider has to consider the *producibility*. The provider has to weight upon availability and costs of technologies, machinery, energy, raw materials, human resources, and is also responsible for providing an appropriate work environment and the design of work tasks. Furthermore, the provider is interested in *profitability*, balancing costs and profit. When it comes to *maintainability*, the provider has to foresee to what extent functional checks, repairs and other types of maintenance services have to be offered to guaranty the reliability and safety of the product (both attributes important from the customer's perspective). In the development stage of a product, the provider has to contemplate the *product gestalt*, because shape and general appearance of the product, as well as material and production costs are related to producibility as well as profitability.

Table 4.2 Attributes derived from the views of provider, customer and persons concerned

Derived from	Attribute	Description
Provider	Producibility	Includes available technologies, existing machinery, supplier environment, availability and capacity of people (and their skills), energy, raw materials, work environment, work task
	Profitability	Turnover, costs and profit
	Maintainability	Costs for providing maintenance service, necessity of repair, functional checks, etc.
	Product gestalt	Shape and appearance of a product, linked to material costs and producibility
Customer	Safety	Product does not harm the user
	Quality	Individual consumer demands are met
	Maintainability	Necessary effort (time and money) to keep a desirable performance level of the product
	Reliability	Product performance across its lifetime
	Functionality	What can the product do? Does the product increase effectiveness?
	Product gestalt	Is the product aesthetically appealing?
	Usability	How easy is it to use? Is it self-explaining? How much effort is required to learn how to use it?
	Availability	Is it easy to get?
	Added value	What do I get for my money?
	Sustainability	Are resources used in a responsible way? Is the negative impact on natural and social environment low?
Persons concerned	Safety	Does the usage and/or production of the product has any negative effects on persons concerned (e.g., air pollution, noise)?
	Sustainability	Is the social and natural environment of persons concerned affected by the production and/or usage of the product?

- **Customer**: A requirement that all customers demand from products is *safety*. Customers want products that are safe to use and do not inflict any harm. However, customers purchase products with different purposes in mind and out of different motivations. The attributes derived from the customer in Table 4.2 might not be relevant for each customer, but nonetheless need to be addressed to describe the target profile of a product to satisfy varying customer requirements as well as possible. Customers have individual demands on the *quality* of a product, expect a certain performance over the product's lifetime (*reliability*) and want a product that is easy to use (*usability*). Usability requirements can be directly derived from functional requirements such as perception, comprehension and response/operation as described in Sect. 4.3.2.3. Furthermore, customers expect that a product increases their effectiveness in accomplishing certain tasks, which reflects on the *functionality* of a product. On the other hand, as described in Sect. 4.3.2.3, functionality and usability alone might not satisfy customers; therefore, aesthetic appeal and affective evaluation by the customers have to be considered when developing the *product gestalt*. Other customers' demands concerns cost and effort required to maintain a desirable performance level of the product (*maintainability*), how easily the product can be acquired (*availability*), and if the costs for the product are being perceived worth-while (Added Value). Last, a demand that has gained significance in recent years especially among young customers is *sustainability*. Customers increasingly place importance on the environmental impact of a product, the responsible use of resources and work conditions under which a product has been developed and produced.

- **Persons concerned**: Additional requirements for the target profile of a product are derived from persons that might be indirectly affected by the product life cycle. Products not only have to ensure the safety of actual users, but also have to prevent any negative effects on persons concerned, e.g., through air pollution or noise. Thus, *safety* aspects of the product also need to address specific demands derived from persons concerned. Accordingly, it is necessary to ensure that the social and natural environment is not negatively affected by the production or usage of the product to prevent short- and long-term negative effects on persons concerned as described in Sect. 4.3.3. These requirements are complete aspects of the attribute *sustainability*.

4.4 Effects and Benefits of Human Centricity

The implementation of human centricity in work environments incorporates employee development, motivational leadership and the introduction of the continuous improvement process of products and development processes [Hofe-2010], of which the development of employees plays the essential role within IDE. A proper and confidence-building employee development is both desired by the employee himself (as intrinsic motivation) and demanded and promoted by the provider (as extrinsic motivation). It results in further development of the employee's competence profile, which fosters a responsible, integrated, interdisciplinary and holistic approach in IDE.

The competence profile of a product developer (as the core group within IDE) includes technical, social and personal competences as well as entrepreneurial skills [Hofe-2010, Berl-1977].

- The technical competence is based on the specialist knowledge, which includes all the knowledge, skills and abilities that the product developer needs to carry out his tasks.
- Social competence refers to all characteristics that make it possible and facilitate living and working together in groups and teams. This also includes appropriate communication behaviour and the ability to deal with conflicts without mutual personal damage.
- Personal competence manifests itself in the right inner attitude (e.g., ability to take responsibility, goal-oriented action, self-organization), independent and holistic

thinking (which manifests itself in a timely and complete assessment of the effects of one's own actions), the value system, a realistic self-assessment and motivation to solve problems.

- Entrepreneurial skills comprise the will, commitment and ability to directly contribute to the success of the (own) company, coupled with a realistic assessment of the opportunities and risks of the provider in its markets.
- In addition to the proven and known procedures of solution finding to develop successful products, further characteristics are needed. Among these are spontaneity (sudden action due to a flash of inspiration or an insight), intuition (direct contemplation without conscious process of insight) and creativity (ingenuity, creative power). Machines cannot yet reproduce these three typical human characteristics[5]. In product development in particular, the focus is on the human being as a creative test solver, because only with his multidimensional qualification of knowledge, experience, competence and skills he is able to acquire and generate knowledge, only he can filter existing data, information, can apply knowledge creatively and pass it on appropriately and according to the respective situation.

Working in the human-centred environment of IDE results in the following:

- Employees work in all decisive activities and phases both in homogeneous and interdisciplinary teams, which can plan, design and implement holistically in all phases of the product life, although special and clearly defined tasks can also be processed by a sub-team within the team or by individuals. IDE leads to the fact that a development based on partnership can take place not only in the own house, but as well with customers, partners and suppliers, or associations and authorities. This is the only way to achieve convincing and innovative products.
- Work tasks are designed with a strong participation of the employees, whereby the abilities, characteristics and inclinations of each employee are appropriately taken into account. This results in a higher personal responsibility with greater scope for decision-making in the sense of entrepreneurial action.
- Employees and managers work together in a spirit of partnership and multidisciplinarity, cultivating an open exchange of communication and information with rapid and brief feedback. Leadership takes place through delegation of responsibility and coaching, not primarily through management and control.
- In order to be able to develop solutions at any time that represent the current state of knowledge, there is a sufficient amount of time available for one's own further qualification (in the sense of lifelong learning). Much of this can be achieved through interdisciplinary project work [Krüg-2011].
- Since product developments today are carried out both in a company and in cross-border corporate networks, the different ethical and cultural values, and special features of the employees involved are incorporated into the work. Their mutual influence fosters an increasing quality of the results achieved.

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[5] And it is very doubtful whether this will ever be the case, even though, in the year 1999, Ray KURZWEIL expected this to happen in the years after 2020 due to the rapid development of computer technology and the increasing performance of algorithms [Kurz-1999].

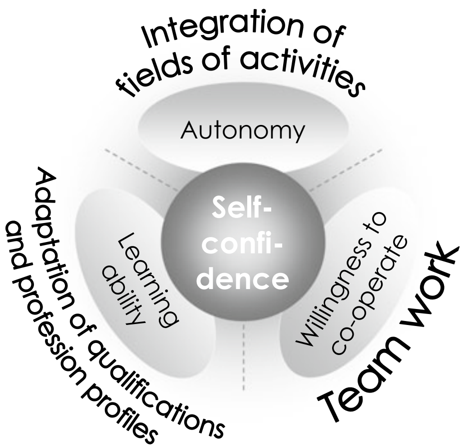

Fig. 4.6 Key qualifications within IDE

- Only such methods, procedures and tools are applied, in which human thinking and acting are adequately taken into account. To support this, systems and programs used should have highly user-friendly human-machine interfaces (e.g., dynamically adapted command interface, intuitive usage options, dynamic user guidance, etc.) that do not patronize the employee.

The integration of activity areas leads to increased autonomy. The continuous adaptation of qualifications generates improved learning abilities. The predominant teamwork fosters a continuous improvement both in social skills and in the ability to cooperate. All of these together lead to a high self-esteem, Fig. 4.6.

In such an environment, work is carried out according to the maxim of completing tasks correctly right away, instead of making costly improvements afterwards. IDE thus creates the working environment in which independently thinking, responsible and satisfied humans work.

References

[Anki-2018] Anki, C.: Home Robotics, Create with Cozmo. https://www.anki.com/en-us/cozmo/create-with-cozmo. Retrieved November 21st, 2018

[Argy-1989] Argyle, M.: Do happy workers work harder: the effect of job satisfaction on work performance. In: Veenhoven, R. (eds.) How Harmful is Happiness? Consequences of Enjoying Life or Not, pp. 94–105. Universitaire Pers Rotterdam, Rotterdam (1989)

[Berl-1977] Berliner, K.: Neue Wege zur Produktentwicklung - Untersuchung im Rahmenkonzept «Produktion 2000», Projektträgerschaft: Fertigungstechnik und Qualitätssicherung, Forschungszentrum Karlsruhe GmbH, Universität-GH Paderborn, Heinz Nixdorf Institut, Paderborn (1977)

[EmTr-1965] Emery, F.E., Trist, E.L.: The causal texture of organizational environment. Hum. Relat. **18**(1), 21–31 (1965)

[Euro-2018] Eurostats. Statistics Provided by the European Commission. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20180123–1. Retrieved September 20th, 2018

[Frit-2020] Fritzsche, A.: Digital Sovereignty and Innovation—Setting the Foundations for a Never-Ending Project. Forum for Philosophy, Engineering and Technology. Valparaiso, Chile (2020)

[Gibs-1979] Gibson, J.: The Ecological Approach to Visual Perception. Houghton Mifflin, Boston (1979)

[Grah-1998] Graham, L.D.: Managing on her Own: Dr. Lillian Gilbreth and Women's Work in the Interwar Era. Engineering & Management Press, Norcross, Georgia (1998)

[Hack-1994] Hacker, W.: Action regulation theory and occupational psychology: review of German empirical research since 1987. German J. Psychol. **18**(2), 91–120 (1994)

[HaOl-1975] Hackman, J.R., Oldham, G.R.: Development of job diagnostic survey. J. Appl. Psychol. **60**, 159–170 (1975)

[HaOl-2005] Hackman, J.R., Oldham, G.R.: How job characteristics theory happened. The Oxford Handbook of Management Theory: The Process of Theory Development, pp. 151–170 (2005)

[HaSa-2014] Hacker, W., Sachse, P.: Allgemeine Arbeitspsychologie [Work Psychologie]. Hogrefe, Göttingen (2014)

[Herz-1968] Herzberg, F.: One more time: how do you motivate employees? Harvard Bus. Rev. **46**(1), 53–62 (1968)

[Hofe-2010] Hofer, M.: Anwendungsgebiete von Coaching als Methode zur Förderung der Humanzentrierung in Unternehmen (Masterarbeit HS Mittweida 2010). http://www.alphalounge.org. Accessed on 25 May 2013

[Hoxi-1915] Hoxie, R.F.: Scientific management and labor. Google Digital Library. https://archive.org/details/scientificmanag01hoxigoog. Retrieved at September 19th, 2018

[Karw-2006] Karwowski, W.: The discipline of ergonomics and human factors. In: Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, 3rd edn, pp. 3–31. Wiley, Hoboken, NJ (2006)

[Krüg-2011] Krüger, A.: Anwendung der integrierten Produktentwicklung als Vorgehensmodell für die systematische Entwicklung von Sportgeräten. Dissertation Otto-von-Guericke-Universität Magdeburg (2011)

[Kurz-1999] Kurzweil, R.: Homo s@piens, Leben im 21. Jahrhundert: Was bleibt vom Menschen? Kiepenheuer & Witsch Köln (1999)

[MaKi-1991] Markus, H.R., Kitayama, S.: Culture and the self: implications for cognition, emotion, and motivation. Psychol. Rev. **98**(2), 224–253 (1991)

[Masl-1943] Maslow, A.: A Theory of Human Motivation. Psychol. Rev. **50**(4), 370–396 (1943)

[Müns-1912] Münsterberg, H.: Vocation and Learning, Band 4. Peoples University (1912)

[Müns-1913] Münsterberg, H.: Psychology and Industrial Efficiency. Houghton Mifflin (1913)

[Nisb-2005] Nisbett, R.E.: The Geography of Thought: How Asians and Westerners Think Differently… and Why. Nicholas Brealey Publishing, London (2005)

[Norm-2004] Norman, D.A.: Emotional Design: Why We Love (or Hate) Everyday Things. Basic Books, New York, NY (2004)

[Phel-2005] Phelps, E.A.: The interaction of emotion and cognition: insights from studies of the human Amygdala. In: Barrett, L.F., Niedenthal, P.M., Winkielman, P. (eds.) Emotion and Consciousness, pp. 51–66. Guilford Press, New York, NY (2005)

[Robo-2018] RobotLab, Nao Robot with Educator Pack. https://www.robotlab.com/store/nao-power-v6-educator-pack. Retrieved November 21st, 2018

[RiRS-1983] Richter, P., Richter, P.G., Schmidt, C.: Structure of activity and mental strain cognitive and psychophysiological aspects. German J. Psychol. **7**(3), 245–252 (1983)

[RoDi-2003] Roethlishberger, F.J., Dickson, W.J.: Management and the Worker. Psychology Press, Reprint (2003)

[StFM-1998] Story, M.F., Mueller, J., Mace, R.L.: The Universal Design File: Designing for People of All Ages and Abilities, Revised edn. North Carolina State University Raleigh, Center for Universal Design (1998)

[SuRK-2020] Subrahmanian, E., Reich, Y., Krishnan, S.: We Are Not Users: Dialogues, Diversity, and Design. Mit Press (2020)

[Tayl-1911] Taylor, F.W.: The Principles of Scientific Management. Harper and Brothers, New York (1911)

[UrVa-2018] Urakami, J., Vajna, S.: Human centricity in Integrated Design Engineering (paper 154). In: Marjanovic, D., Storga, M. (eds) Proceedings of DESIGN 2018, Zagreb (2018)

[Worl-2018] World Bank Group: What a Waste 2.0: A Global Snapshot on Solid Waste Management to 2050. https://openknowledge.worldbank.org/handle/10986/30317. Retrieved September 21st, 2018

Chapter 5
Sustainability and Sustainable Development

Hartwig Haase

If the survival of humanity on our planet is to be secured in the long term in an acceptable state, radical social changes are required, whereby it must be critically examined whether the radicalness and speed of these changes can even prevent a systemic collapse. These changes must be brought about both through political restrictions to comply with the planetary guide rails[1]—the tolerable limits to the carrying capacity of our planet—and through individual changes in behaviour, and also affect the properties of products and services.

Examples of political approaches are the energy turnaround with the coal phase-out and the transport turnaround with the promotion of e-mobility. Examples for behavioural changes would be sustainable nutritional patterns with regional/seasonal organic and vegan products or responsible mobility like the FlyingLess campaign[2].

This chapter begins with a description of the state of the world in order to understand the importance of sustainable action and the complex starting point. Here, the current megatrends of climate change and other acute problems of anthropogenic emissions, the scarcity of resources due to overuse of the regeneratively available supply, and the population development, which exacerbates both effects, are addressed.

Afterward the development of the concept of sustainability and sustainability research will be presented and the theoretical possibilities for sustainable design of human society derived from this will be discussed. Here, questions of definition and different views of sustainability are also presented, such as the interpretations of weak and strong sustainability. Possible starting points for sustainable development are

[1]These crash barriers include the integrity of the biosphere, ocean acidification, ozone loss in the stratosphere, and new substances and modified life forms (see also Fig. 5.8).

[2]https://academicflyingblog.wordpress.com/. Access: 01.02.2020.

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developed from the basic sustainability strategies efficiency, consistency, sufficiency and resilience, and the resulting implementation concepts are presented.

As it turns out, the current situation is so far advanced and dramatic that hoping for a "divine engineer" or a single patent remedy cannot be promising. We need new visionary and conceptual ideas for our future and immediate and consistent action to gain time for them. What needs to be done for this Herculean task from the author's point of view is summarized in the conclusion.

5.1 State of the World During the Anthropocene

> Two planets meet in space. One planet says to another: "You look like hell". He replies: "Yes, I am not well either. I have people". The first one: "I used to have that too. This will pass". (Planetary joke anonymous, among others in [Lesc-2017])

First of all, and if that is reassuring: It is not about the end of mankind as "threatened" in the planetary joke. Humanity will (somehow) survive. It is about the danger of collapse, a collapse of the anthropogenic systems, as shown in Fig. 5.1

In the first report to the Club of Rome "Limits to Growth" [Mead-1972], which was published as early as 1972 and examines the interaction of the five indicators industrial production, population (growth), food (production), resources (availability) and environmental pollution in a complex dynamic world model World-3, the scenario "Business-as-usual" predicts a collapse of the global human system with irreversible destruction of the environment in the first half of the twenty-first century [Mead-1972]. Exponential growth leads to an unstable—quasi high-energy—system state at a high level. Negative influences make the system, which is disturbed in its statics, susceptible to faults.

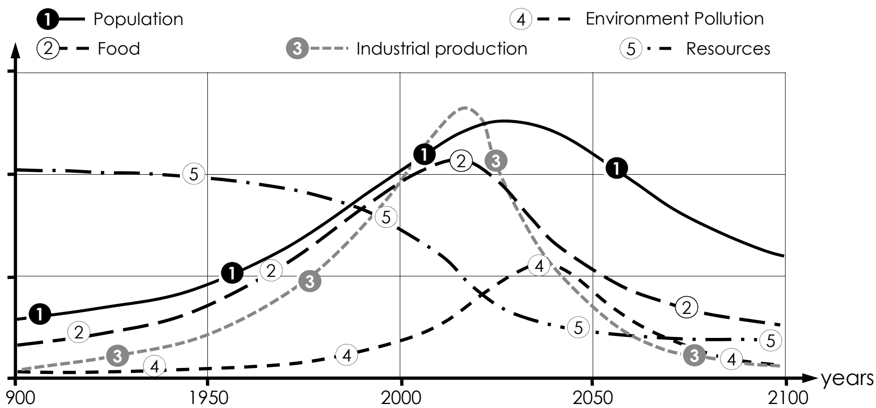

Fig. 5.1 The business as usual scenario of the World 3 model (after [Rand-2010])

The scarcity of non-renewable resources is leading to the collapse of food and industrial production, in particular, due to the declining fertility of agricultural land. Due to a lack of food and a reduction in health services, life expectancy is falling, the average mortality rate is rising and the population is falling significantly. Despite the critical assessment that the model is rather roughly based on the observation of continents and does not capture the influence of armed conflicts, the World 3 scenarios according to MEADOWS provide an accurate model of the future.

The aim of the authors was not to predict horror scenarios, but to avoid crises and to show ways to build a global community with humanistic values. The chances of achieving this goal decrease over time without initiating the necessary transformation.

> On the basis of this work, I come to the conclusion that, in view of the prevailing political, economic and cultural values, a collapse - an uncontrollable decline in the world population and industrial activity - can no longer be avoided. In other words: I am convinced that it is too late for sustainable development. [Mead-2000]

RADERMACHER [RaBe-2011] sees a probability of about 15% for an ecological collapse in a business-as-usual scenario, but with an increasing tendency if the remaining window of opportunity for peaceful transformation remains unused. With a probability of 40%, and eco-dictatorship scenario with neo-feudal structures can be expected, which regulates the environmental and remaining resource base at the expense of social balance, e.g. through military force and demarcation of the elites. The price for avoiding a systemic collapse would then be that 95% or more of the people would have to live in poverty without meat, petrol, and heated housing! A third transformative path towards a "Global Eco-social Market Economy" will be described later.

RANDERS, co-author of "Limits to Growth", is much more pessimistic: "My forecast for global developments up to the year 2052 is pessimistic, but not catastrophic. According to this study, climate catastrophes, natural damage, drastic and sometimes irreversible losses of biodiversity, as well as losses in living standards will be unavoidable even for the rich part of the world, since mankind will not be able to implement the known but necessary changes in time.

In simple terms, the current problems of human development on our planet can be summarized by the three megatrends climate change, resource scarcity, and population growth shown in Fig. 5.2. Man or the anthroposphere interacts with the geo-bio-sphere via input and output streams. Man uses them as the basis of his economic and social life. At the same time, however, as part of the biosphere, it is exposed to the effects of its actions (a kind of boomerang effect).

If both currents exceed the capacitive limits of the available and regenerative possibilities, the system is in danger of becoming unbalanced and tipping over. Tipping elements or tipping points are [3]seen, among other things, in the northern and southern ice sheets, in the current systems of the oceans and in ecosystems. According to MAXTON [Maxt-2018], it is too late to prevent a collapse entirely and

[3]http://www.pik-potsdam.de/services/infothek/kippelemente/hotspots_d.jpg, access 7.12.18.

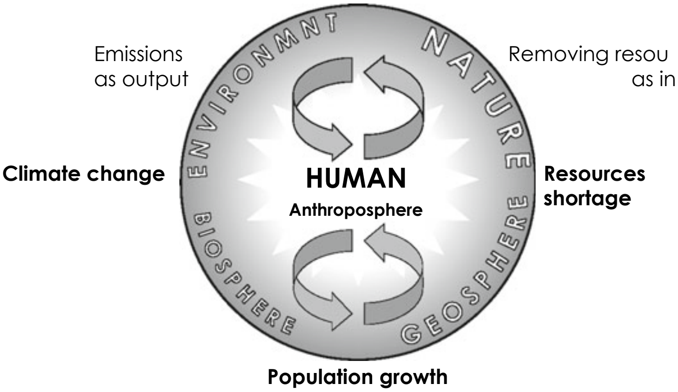

Fig. 5.2 Megatrends as a cause-effect complex

the task now is to steer the collapse in a controllable direction and reduce its long-term consequences.

5.1.1 Climate Change

Emissions as the output of the anthroposphere can enter the biosphere via the soil, water or air path. Examples include waste, liquid manure, greenhouse gases, particulate matter and many more. The effects of these emissions cause changes in the biosphere that can assume threatening dimensions for humans.

The world's population produces around 3.5 million tonnes of waste per day [Hoor-2013]. ECHEVERS even mentions about 130 million tons daily. The question of which fractions are included under the collective term waste plays a role here. About one-third of this waste volume comes from the USA. Every US citizen leaves behind a volume of waste at the end of his life "that can only be compressed to the size of the pyramid of Khufu with a lot of pressure." [Eche-2013]. This waste does not only consume (landfill) space. In this process, pollutants enter the leachate and are discharged into the groundwater. Fermentation processes in the deposits release methane, a greenhouse gas that is about 30 times more effective than CO_2. Approximately 70% of total methane emissions are of anthropogenic origin; in addition to landfills, the sources also include agricultural crop cultivation and animal husbandry (see also Table 5.1).

Plastic waste is discharged into the world's oceans via rivers (and back into the human food chain). Scientists estimate that one kilogram of plastic already comes on three kilograms of fish. In 2050 there will be more plastic than fish in the oceans [Elle-2016].

Table 5.1 Increase in greenhouse gases since the pre-industrial age according to [Maxt-2018]

Greenhouse gas	Damage potential	Concentration 18th century	Current concentration	Increase to (%)
Carbon dioxide CO_2		280 ppm	410 ppm	146
Methane CH_4	30 times CO_2	720 ppb	1850 ppb	260
Nitrous oxide N_2O	300 times CO_2	260 ppb	330 ppb	127

ppm—parts per million, parts per million; ppb—parts per trillion, parts per billion

However, the most urgent problem is climate change caused by an increasing concentration of greenhouse gases in the atmosphere. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has summarized scientific research on climate change and, in its first progress report in 1990, already identified the anthropogenic causes of climate change. The Fifth Assessment Report 2014 estimates that it is extremely likely (>95%) that human impacts are the main cause of the global warming observed since 1950 [IPCC-2014].

Despite many warnings and climate conferences (see Sect. 5.2), the share of greenhouse gases is rising steadily. While the CO_2 content of the earth's atmosphere has been below 300 ppm for at least 800,000 years, the symbolic 400 ppm CO_2 concentration mark has been permanently exceeded since 2016. In 2009 alone, caused by the financial and economic crisis, a decline in anthropogenic CO_2 emissions was recorded (Fig. 5.3).

Besides carbon dioxide, nitrous oxide (laughing gas) and methane are among the most important long-lived greenhouse gases. In order to make the various greenhouse

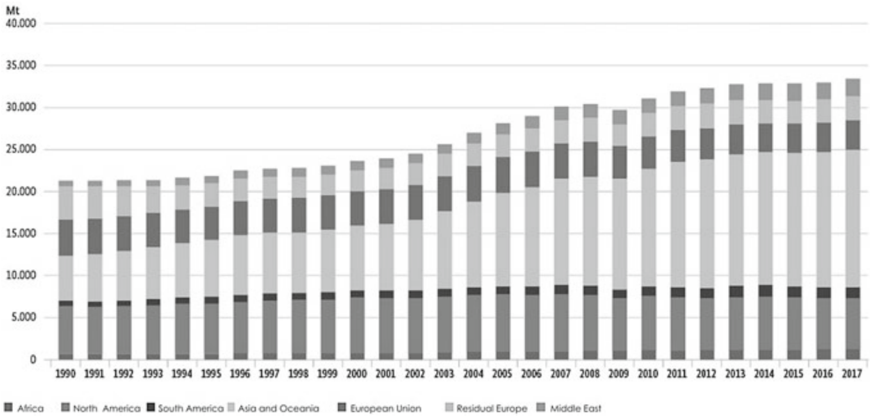

Fig. 5.3 Energy-related CO_2 emissions worldwide [BMWI-2018, according to BP Statistical Review of World Energy 2017]

gases comparable, they are converted into carbon dioxide equivalents in terms of their harmfulness to the climate (Table 5.1).

The average global temperature of the Earth[4]rose by 0.88 °C between the 30-year periods 1901–1930 and 1988–2018. A warming of 2° is seen as a critical limit, above which a further increase in warming would trigger a series of irreversible processes in the short term. Tipping points—tipping elements—are counted according to [Lent-2008]:

- Melting of the summer Arctic sea ice
- Melting of the Greenland ice sheet
- Melting of the West Antarctic ice sheet
- The Atlantic thermohaline circulation is weakening
- Change in El Niño-Southern Oscillation (ENSO)
- Collapse of the Indian summer monsoon
- Changes in the West African monsoon system with effects on the Sahara and Sahel (with possible greening of the Sahara as a positive tipping element)
- Deforestation of the tropical rainforest
- Boreal forest decline.

Already at a warming of 2°, Africa and the Mediterranean region will have 30% less water available, and 30% of animal and plant species are not expected to survive this increase (see Fig. 5.4).

Despite the inertia of the system and the slow impact of measures, scientists believe that this goal can be achieved if known technologies are used consistently.

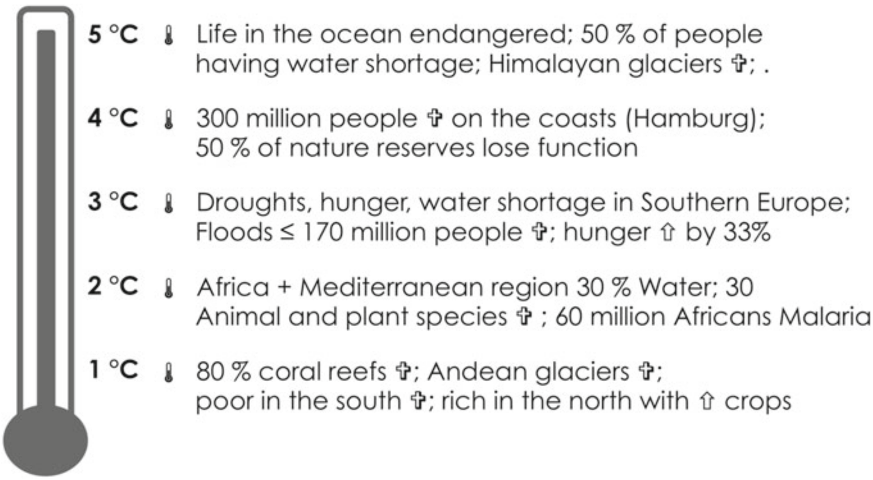

Fig. 5.4 The consequences of climate change (after [Alt-2008])

[4]https://data.giss.nasa.gov/gistemp/maps/, access 9.12.18.

However, in its special report published in October 2018, the IPCC urges the implementation of a 1.5-degree target, because even two degrees of global warming would have serious consequences for humans and the environment [IPCC-2018]. To achieve this, however, the world would have to reduce[5] net greenhouse gas emissions to zero between 2045 and 2060 at the latest. This time window has become very narrow due to long waiting, leaving little room for manoeuvre.

5.1.2 Overuse of Resources → Scarcity of Resources

The term "scarcity of resources" should be placed under cause-and-effect considerations. Scarce resources are not a "malicious revenge" of our earth, but the effect of overuse of resources by mankind. So humanity is enlightened, the knowledge is available. The instructions for the use of resources on our planet are available and translated into all languages. The collective will of humanity to comply with them is missing.

> The earth has enough for everyone's needs, but not enough for everyone's greed. (Mahatma Gandhi)

5.1.2.1 Fossil Fuels

When discussing finite resources, one speaks primarily about fossil fuels and here primarily about oil, which has been indispensable for unlimited mobility up to now. According to estimates by the ASPO (Association for the Study of Peak Oil and Gas), the peak for conventional oil production was already passed in 2005 [ASPO-2018], and since then attempts have been made to offset the world's growing energy needs with unconventional sources such as the deep sea, tar sands, and oil shale. However, it is assumed that this will not be sufficient to compensate for the loss of depleting conventional oil deposits, and even with unconventional resources and the addition of liquefied natural gas, the peak will be localized around 2015. This means that the relatively short oil age is already halfway through.

The International Energy Agency (IEA) and the Federal Institute for Geosciences and Natural Resources (BGR) estimate that there are still large available resources, especially for gas from unconventional deposits, but they themselves estimate that only part of these resources will be technically and economically usable [DeIW-2010]. In addition to the high environmental risks resulting from extraction (e.g. in fracking), the so-called harvest factor (EROI—energy return on investment) must be considered here. At the beginning of oil production, energy amounting to 1 barrel of oil had to be invested to produce 100 barrels of oil. This harvesting factor

[5] Essentially through the use of renewable energies, decarbonization of economic and private activities, capture of CO_2 at the gas source (Carbon Capture and Storage—CCS, Carbon Capture and Usage—CCU) and, in addition, artificial recovery of CO_2 from the earth's atmosphere (air capture process).

has decreased significantly even for conventional oil and, at a value below 8, is beginning to become ineffective for unconventional energy sources (tar sands, oil shale) [Bard-2013].

As a further possible important energy source, methane in the gas hydrate deposits of the permafrost soils of the tundra and on the seafloor, primarily on the continental slopes, should be discussed. These deposits would increase the fossil potential for climate change if used for technical purposes, but they also have a "natural" self-reinforcing effect if their stability on the seafloor is destroyed by sea-level rise (pressure increase) and ocean warming. A research project will attempt to replace the methane in the cage structure of the gas hydrates with CO_2 from sequestration. In this way, a valuable energy source could be extracted on the one hand and climate-damaging carbon dioxide could be deposited on the seabed on the other[6].

On the other hand, through technology development for conversion, storage and intelligent networking (smart grid) as well as infrastructure expansion, renewable energies are becoming increasingly competitive. If the external costs, including environmental costs, are added to the energy sources, fossil energy can soon be economically replaced by renewable energy (Fig. 5.5).

> The Stone Age didn't end because people had no more stones. (Ahmed al Jamani, former Saudi Arabian oil minister)

If fossil energies are subject to an emissions trading system (cap and trade), increasingly expensive emissions certificates in a scarce market could also accelerate this trend.

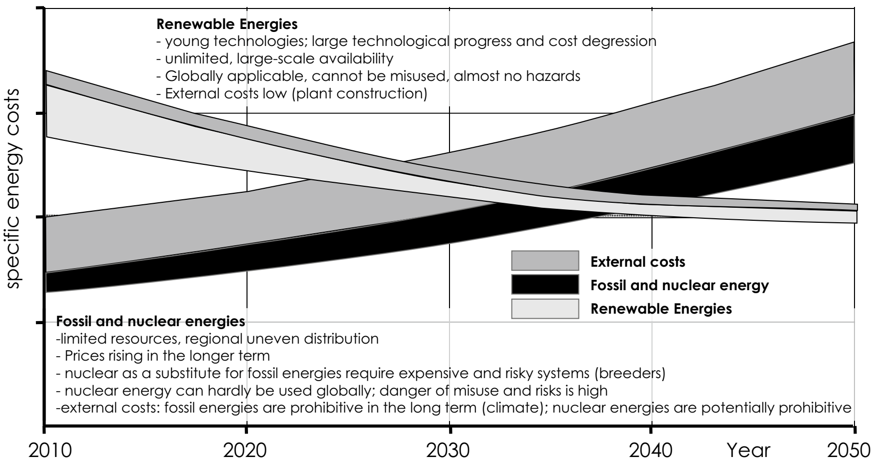

Fig. 5.5 Cost development of renewable and conventional energies [BMU-2004]

[6]See also GEOMAR—Helmholtz Centre for Ocean Research, Kiel: SUGAR Submarine Gas Hydrate Reservoirs. www.sugar-projekt.de/. Access 10.12.18.

5.1.2.2 Fresh Water and Drinking Water

Drinking water is probably the most important resource in the world. In contrast to salt water (1351 million km^3), fresh water takes up only 2.5% (35 million km^3) of the water on earth. Of these, 69.5% are not available and (still) bound in glaciers, snow, ice and permafrost [Blac-2009]. The problem here is not a dwindling total volume of about 12,500 km^3 in the atmosphere, which is exchanged about 36 times a year via evaporation and precipitation (with increasing intensity in the course of global warming). The unequal distribution of usable freshwater in surface waters and groundwater reservoirs worldwide is problematic. While in 2014 Colombia 3240 mm of precipitation was recorded, in the same year in Egypt it was only 51 mm [water column per m^2 (corresponds to l/m^2)]. The drinkable water is therefore not where mankind needs it. Even now, dry areas in India are regularly supplied by freight trains and in Spain by ship. According to UNICEF, there are still about 2.1 billion people worldwide without safe drinking water of safe quality and 4.4 billion without basic sanitation [Blac-2009 and current UNIC-2017]. The supply situation is becoming critical due to the rapid growth in demand resulting from the growing world population, but also due to increased demand in industrial and food production.

In addition, all too often there is careless and inefficient handling of drinking water. In the 1990s, the idea arose to ensure more economical and efficient use via the market in the course of privatization. However, water is not a commercial commodity like any other and, in the sense of services of general interest to secure public access to existential goods and services, is strongly politicized. Drinking water is a typical common resource and should be managed jointly (as a human right). However, resource protection requires a democratic and sustainable water policy. Especially in developing countries, corruption of governments is another problem.

Technical solutions and countermeasures are seen in desalination, which is technically unproblematic but energy-intensive (energy demand currently between 4 and 25 kWh/m^3 [Blac-2009]) or more climate-friendly simply in more efficient use of fresh water, especially in agriculture.

5.1.2.3 Phosphorus

As a non-renewable resource, phosphorus is a central component of human food and, after calcium, the most common mineral in the human body, where it serves as a building block for bones and teeth and as an energy supplier for cells (approx. 600–700 g in the body of a healthy adult). Plants can neither breathe nor grow without phosphorus. A large part of the phosphorus is washed into the sea via food residues or excretions. The peak phosphorus is expected to occur around 2030 [GPRI-2015] and the range of existing deposits is estimated to be 50–100 years. Guano as a fertilizer source has been almost completely exploited since the beginning of the twentieth century.

Especially in developing countries, where soils have been leached for a long time through monocultures, phosphorus deficiency is already becoming a serious problem. In addition to more effective use in agriculture (directing fertilizer precisely to phosphorus removal) and the natural cycle systems of organic farming, the recovery of phosphate from animal and human excreta (especially urine) is seen as a hope. In order to avoid potential risk to human health, the only possibility is seen here to be to incinerate sewage sludge and animal meal and to recover the phosphorus from the ashes [Schn-2008].

5.1.2.4 Sand

Even sand as a resource has become scarce due to the exponential increase in demand in the construction sector (infrastructure, housing, prestige). Grains of sand are defined by geologists according to size and have a diameter of 0.0625 to two millimeters. Worldwide, between 40 and 50 billion tonnes of sand are currently consumed annually. That is twice as much as the rivers of the whole world are flowing towards the sea every year[7].

However, only grains of sand with corners and edges that can get caught and stick is suitable for concrete production in the construction industry. Sufficiently available desert sand is sanded round by the wind and is therefore largely useless. Salty sea sand has to be washed at great expense before it can be used.

5.1.2.5 Soil Degradation and Desertification

> The forests go before men, the deserts follow them. (Chateaubriand in [Grun-2007])

Soil degradation is the deterioration of soil quality up to the complete loss of soil fertility. The process leads via states of desertification to desertification.

The causes are manifold:

- Drifts and erosion with the destruction of the vegetation cover (deforestation, slash-and-burn or overgrazing, farming on slopes)
- Destruction of soil structure and fertility through the cultivation of monocultures, missing or incorrect supply of organic fertilizer, salinization through insufficient drainage, compaction by machines and large livestock populations
- Pollution through urban inputs (waste, pollutants) or intensive inorganic fertilization in agriculture.

[7] According to [GEAS-2014], almost 30 billion tons of building sand were used for the production of concrete in 2012. The material would be sufficient to build a wall around the equator 27 m high and 27 m wide.

The main cause is seen as intensive industrial agriculture, which tends to be trapped in a complete package of coordinated crop protection products and genetically modified hybrid seeds, as well as digital precision farming, which makes farmers dependent on the stock markets and food speculation in their input from corporations and in their output. In addition to urbanization, soil sealing and artificial "light pollution", the use of pesticides is also a major cause of the alarming decline in insects[8].

Time and again one hears the argument that higher yields are needed to supply the growing world population, which can only be achieved through industrial agriculture. On closer inspection, however, this part of agriculture mainly serves the production of animal feed for the meat needs of the northern industrialized countries.

Almost 2.5 billion people worldwide currently live mainly from agriculture. More than 40% of the world's population—especially in developing countries—still live in a subsistence economy. A study by the Research Institute of Organic Agriculture (FiBL) has shown that organic farming, together with a sustainable food system (avoidance of food waste, less animal products, less concentrated feed) can feed a world population of over 9 billion people in 2050 [Mull-2017]. The issue of nutrition and the effects of animal products—especially beef—on the climate are other important problems, see [Loew-2011].

The goal of obtaining higher yields from the soil (and into the coffers) in the short term shows as a negative side effect a decreasing CO_2 absorption capacity and an alarming loss of soil fertility in the long term.

> Ten million hectares of fertile land are lost worldwide every year. between 1950 and 1990, a third of all fertile land worldwide… [Loew-2011]

Soil and the form of land use also have a complex relationship with the carbon balance and climate change. According to the World Agriculture Report [WeAg-2009], about 50% of the total land area of the earth has been converted into pasture and arable land, destroying[9] more than half of the world's forests and causing storage losses and carbon dioxide emissions.

Worldwide system comparisons show that organic farming systems can bind about 500 kg more C per hectare per year than current comparable systems [KuLa-2015]. The potential for carbon storage in the humus of agricultural soils is estimated at 0.4–1.2 giga-tons (Gt) carbon (C) per year. Carbon sequestration via organic farming can thus be seen as a reduction strategy of agriculture.

The amount of carbon globally bound in soils (2500 Gt) exceeds the amount of C contained in the atmosphere (760 Gt) by a factor of 3.3, the amount of C bound in the biotic pool (560 Gt) by a factor of 4.5 [Lal-2004] (see also Fig. 5.6, differing amounts due to different sources).

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[8]For a more in-depth look at this problem, we recommend Rachel Carson's book "Der mumme Frühling" (The Silent Spring) from 1962 (!).

[9]For a more in-depth look at the problem, we recommend the book "Wälder, die wir töten" by Emanuelle Grundman 2007 [Grun-2007].

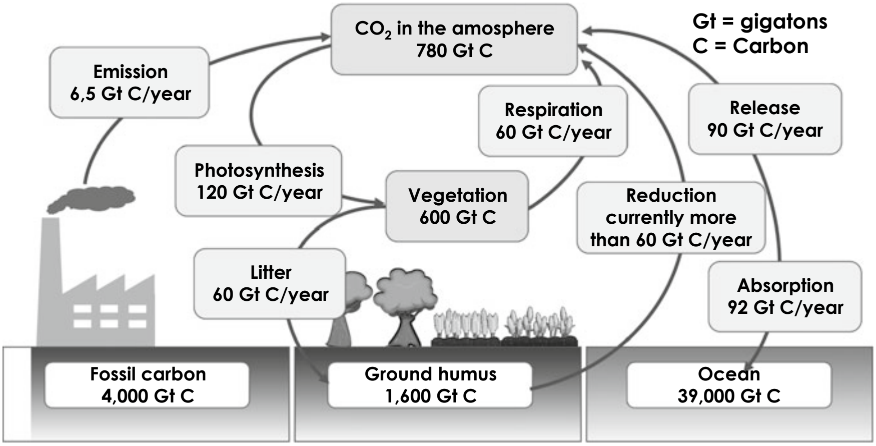

Fig. 5.6 The role of soil in the carbon balance [FiBL-2013]

> We feel in many areas that simple cause-and-effect considerations do not do justice to our living environment. It is therefore more timely and necessary than ever to understand soil as a complex organism rather than a simple chemical-mechanical model. (Thomas Fisel, THE BIOLAND FOUNDATION [Bern-2012])

5.1.2.6 Biodiversity

Biodiversity refers to three interrelated areas of ecosystem diversity, species diversity and genetic diversity within species. Scientific estimates of the global total number of all species are between 5 and 20 million. Around 12,000–25,000 species can be newly researched and described each year. The long-term average is just over 13,000, and even today the extinction rate is expected to be 3–130 species per day, which is a factor of 100–1000 higher than the naturally tolerable level. Climate change will significantly intensify this process [WWF-2018].

The resource function of biodiversity becomes clearer when nature is viewed as a company that provides the service products demanded by humans. This approach is described by the concept of ecosystem services associated with direct or indirect benefits to humans. These include basic services (soil formation, photosynthesis), supply services (food, drinking water), regulatory services (CO_2 storage, water purification) and cultural services (recreation). Ecosystem services that have only recently begun to receive greater attention include pollination by bees and other insects, on which 30% of global agricultural yields depend. Other important ecosystem services include natural pest control, the provision of medically effective plant substances and the production of fertile soil [BioÖ-2016].

5.1.2.7 Summary Resources

The areas mentioned here show only a selection of the currently critically viewed resources, which can be expanded at will. Besides rare earth, other finite resources are nickel (range 44 years), cadmium (34 years), copper (31 years), zinc (22 years) and lead (20 years) [TASI-2010].

The Great Acceleration is the umbrella term for many global trends, all of which follow exponential progressions, such as population growth, atmospheric CO_2 concentration, biodiversity loss, soil degradation, water consumption, number of McDonalds restaurants … and all of which are due to anthropocene influence [BPB-2018].

In the Planetary Boundaries [Rock-2009], Rockström gives a summary of the ecological limits of the Earth (see Fig. 5.7, after [Stef-2015]). Several of the nine planetary boundaries recorded there have already left the safe space of action for mankind. The dimension “introduction of novel substances” could not be assessed so far due to the lack of a definition for a control variable or a limit. For the two dimensions “functional diversity” and “aerosol content of the atmosphere”, the exposure limits were (only) exceeded regionally.

> The scarcest resource we have left is not oil or coal, but the time to replace oil or coal with renewable energies. [Alt-2008]

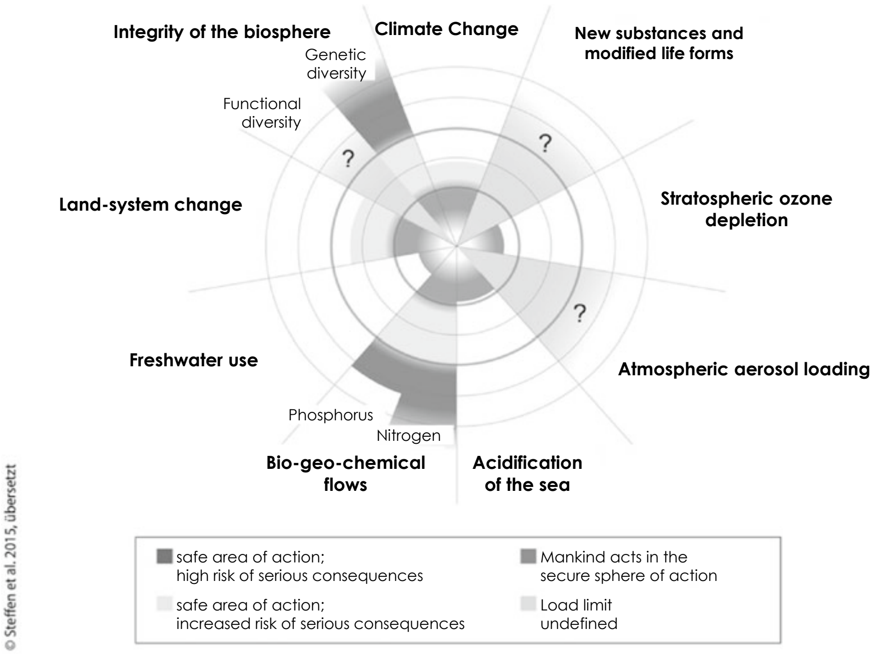

Fig. 5.7 Overview of the planetary guard rails [Stef-2015]

Human rights and democracy can be seen as further—currently threateningly claimed—humanistic guard rails, which cover the often neglected social dimension of sustainability, as well as basic humanistic values such as justice, trust, compassion and dignity.

> It is easier to fight for democracy while it still exists. After that, it becomes much more difficult. [Welz-2017]

5.1.3 Population Growth

> If we don't curb population growth, we won't have to worry about nature conservation anymore. (Shrija Mathema, employee in the DSW project "Bhujung"/Nepal)

The world population is currently growing by 157 people per minute; 226,184 per day, 82,557,224 per year. The number of 7621 million people living in the world at the time of access is expected to increase to 9852 million people by 2050 and to peak at around 11 billion in 2100 [DeSW-2018]. The above-mentioned problems of emissions and resource consumption are thus aggravated every day.

The strong growth has another "side effect": more than 25% of the population is under 15 years old, and almost half of the world population is under 20 years old. Today, more than one billion people worldwide are between 15 and 24 years old. FUSSLER calls this demographic phenomenon the "global teenager" [Fuss-1999]. Today, children and young people worldwide are generally better educated than in the past. Although secondary education opportunities—especially for girls—are still poor in many countries, almost all children at least attend school. According to the UNESCO World Education Report, by 2015 the global connection rate in primary education will be 83%, in lower secondary education 69% and in upper secondary education 45% [UNES-2017].

But better access to education and information also leads to increased risks of frustration and dissatisfaction. Futurist Peter SCHWARTZ compares the teenage generation in Asia, Africa, Latin America with European and North American movements in the 1950s and 1960s and expects them to influence world culture in a similar way as they did then. "Her energy and hormone balance create the familiar mixture of curiosity, vitality and rebellion" [Fuss-1999]. A state that can also be described as "rich north" versus "hungry south", or "grey panthers against Asian tigers".

5.2 Sustainable Development—History and Characteristics of a Concept

Long before the Saxon mining chief Hans Carl von CARLOWITZ (1645–1714), who is often referred to as the "forefather of sustainability", the indigenous peoples with their indigenous way of life showed in a much more comprehensive way life in harmony with and within the natural boundaries, at least as long as they traditionally lived in mostly small communities and settlements. However, one should not indulge in very social-romantic ideas here either. With increasing success, advanced civilizations such as the Maya also plundered the available natural resources excessively and at the same time divided society into a rich elite and poor masses. Combined with mismanagement, which destroyed the nutrient content of their soils, this inevitably led to the collapse and decline of society even then. Does this look familiar to us now?

The result: The (local) system collapsed, the elites were eliminated by the dissatisfied masses, and thus valuable knowledge was also destroyed. The rest moved on and sought areas with new resources[10] [Diam-2005]. But where does humanity move to if this procedure is repeated globally?

CARLOWITZ is credited with the first mention of the term "sustainable" in his Sylvicultura oeconomica [Carl-1713], when he was searching for an additional synonym for durable, perpetual, continuous, caring and perpetual. Actually, however, his considerations only served the economic aspect of sustainability, since the wood required for mining and smelting was to be secured in the long term. The result is ecologically critical and has given us monocultures that are foreign to nature.

After all, CARLOWITZ coined a term for a hitherto unnamed concept that was initially only used in forestry texts. It was only in the nineteenth century that the term "sustainable" was translated into French (soutenir) and English. In the middle of the twentieth century, the terms sustainable were first used outside of forestry by the environmental movement[11] and in the context of growth criticism, here also in the 1972 report "The Limits to Growth":

> We are searching for a model output that represents a world system that is: (1) sustainable without sudden and uncontrollable collapse; and (2) capable of satisfying the basic material requirements of all of its people. [Mead-1972]

A selection of important milestones, based on the Limits-to-Growth report to the Club of Rome in 1972 described at the beginning, is shown in the timeline in Fig. 5.8 and is explained below.

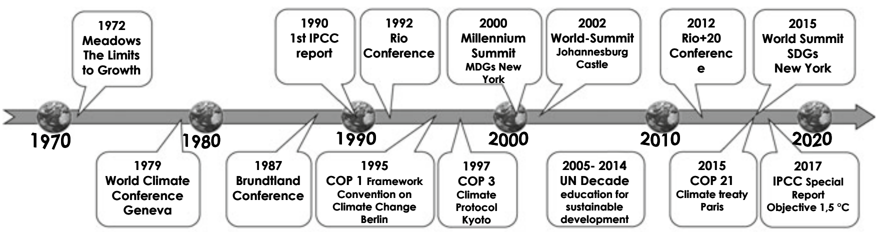

Fig. 5.8 Timeline of selected events in environmental policy and sustainable development

[10]Certainly the interrelationships were and are much more complex than those presented here.

[11]The Nature and Biodiversity Conservation Union NABU was founded on 1 February 1899 under the name "Bund für Vogelschutz (BfV)".

As early as February 1979, experts discussed the connection between climate anomalies and anthropogenic influence at the first World Climate Conference (WCC1) in Geneva, organized by the World Meteorological Organisation (WMO), and drew the attention of the international community of states to the dangers of global climate change due to the increase in the carbon dioxide content of the atmosphere. A rise in sea level of up to five meters was predicted as a result of the melting of ice seas and glaciers, and it was recommended that the consumption of fossil fuels be rapidly reduced and large-scale deforestation stopped.

The establishment of a Commission on Environment and Development under the chairmanship of the former Norwegian Prime Minister Gro Harlem BRUNDTLAND BY resolution of the UN General Assembly in 1983 and the subsequent report of the Commission "Our Common Future" [Brun-1987] published in 1987 can be seen as the beginning of a worldwide discourse on the concept of "sustainable development" and as a milestone in global environmental policy.

The report and the definition fixed there have been translated into many languages. It is one of the most frequently quoted environmental policy works.

> Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
>
> Two keywords are important:
>
> - The concept of 'needs', especially the basic needs of the world's poorest people, which should be the overriding priority;
> - the notion of constraints imposed by the state of technology and social organization on the ability of the environment to meet present and future needs. [Brun-1987].

In this context, intra-generational justice demands a fair balance between the interests of people in industrialized and developing countries and intergenerational justice demands that future generations are not impaired in their satisfaction of needs[12] by the way of life of the current generation.

At the United Nations Conference on Environment and Development (UNCED, also Rio Conference or Earth Summit) in Rio de Janeiro in 1992, the Brundtland Report was to be translated into international action through Agenda 21. Follow-up conferences were the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg and the United Nations Conference on Sustainable Development (UNCSD, Rio + 20 Conference), which took place again in Rio de Janeiro in 2012.

The 1992 Rio Conference also signed the United Nations Framework Convention on Climate Change (UNFCCC), whose 197 Parties have met since 1995 (Berlin) at the annual UN Climate Change Conferences (COP—Conference of the Parties) to decide on measures to curb global warming. Important results were the Kyoto Protocol 1997 (COP 3 in Kyoto), which set quantitative reduction targets for greenhouse gas emissions, especially for industrialized countries, and the Paris Convention 2015 (COP21), which for the first time obliges all signatory states to set and review

[12]See Maslow's pyramid of needs [Masl-1977] (see also Sect. 4.1), which ranks basic human needs in a hierarchy of level 1: physiological needs, security needs, social needs, appreciation and self-realization.

their own reduction targets through a new climate agreement that is binding under international law. One of the most important innovations of the Paris Accord is the inclusion of a specific target to limit the rise in the global average temperature to well below two degrees Celsius compared to the pre-industrial age.

In parallel, the Intergovernmental Panel on Climate Change (IPCC) was founded in November 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Section 5.1.1 has already dealt with the five status reports published to date by the IPCC. At this point, the IPCC Special Report of 2018 should be emphasized once again, which emphasizes the importance of a 1.5° target [IPCC-2018].

Further milestones of a global sustainable development are as follows:

- The Millennium Development Goals (MDGs) of the United Nations, which were derived from the Millennium Declaration signed at the 55th General Assembly of the United Nations (Millennium Summit) in New York in 2000
- The 17 Sustainable Development Goals (SDGs), whose development was decided upon at the Rio + 20 Conference in 2012 and adopted at the United Nations General Assembly in 2015 (World Summit on Sustainable Development, also known as the UN Sustainability Summit) as the core of Agenda 2030.

The implementation of the Millennium Development Goals has been successful to a certain extent, for example reducing poverty in some areas of the world and improving educational opportunities. However, there were also criticisms that were taken into account in the further development of the SDGs. While the quantitative goals and deadlines were primarily related to the countries of the Global South, which had little involvement in the selection of goals, there were no measurable goals for countries of the Global North, so that their production and consumption patterns played practically no role in the achievement of the goals. Thus, the MDGs tended to follow a more narrow understanding of development and did not pursue a comprehensive sustainability approach. While the Millennium Declaration still mentioned key factors influencing development such as peace, the environment and human rights, these were largely ignored in the MDGs themselves and their indicators [NABU-2018].

In the SDGs, the goals were formulated for all countries. They are to be implemented, adapted according to the state of development. However, the high hopes placed in the SDGs are also to be critically questioned and in part contradictory.

> Taking into account all experience to date, the implementation of Agenda 2030 is a practically insoluble task. (Franz Josef Radermacher in [DieW-2018])

The two major goals of humanity "preservation of the natural foundations of life" and "economic development for all people" can only be achieved simultaneously by putting national interests on the backburner and renouncing growth (at least in the industrialized countries). According to RADERMACHER, international agreements are also usually characterized by three properties. "They're not binding, nobody's in charge, and there's no budget." [TheW-2018].

But SDGs structure the international discourse and give the world a common position and vision. However, it is also clear that there are no simple approaches to achieving the sustainability goals and that there are still extremely difficult hurdles to overcome and complex tasks to be performed. No matter how differently the objectives are interpreted and to what extent they can be implemented, the target would be desirable:

> It's about nothing less than saving the world. [TheW-2018]

5.3 Sustainability Dimensions—Ecology, Economy, Social

The starting point for the development of the concept was the action programme for sustainable development (Agenda 21), which was adopted at the Rio Conference in 1992 and reflected the recognition that global environmental protection is only possible if policymakers take account of both economic and social aspects.

The idea of the three-pillar-model—economy, ecology and social issues are seen as equally important and simultaneous goals of sustainable development—originated around 1994, following the Brundtland Report. It is attributed to the Enquete Commission of the German Bundestag "Protection of Humanity and the Environment" [EnKo-1998] and was finally laid down EU-wide in the Treaty of Amsterdam in 1997. The main contents of the three dimensions of sustainability are described in brief below and illustrated by indicators:

- Ecological sustainability—no overexploitation of nature: Conservation of natural resources with resistant, vital ecosystems; only using natural resources to the extent that they can regenerate.
  (Environmental) indicators according to [OECD-2003]: environmental pressures, environmental status (quality) and societal responses.
- Economic sustainability—the permanent maintenance of economic achievements: Maximum economic return while securing the required input resources in the long term; design of an economic system that remains functional in the long term for future generations.
  Indicators: high employment, price stability, labour productivity and external balance.
- Social sustainability—a peaceful and just coexistence: securing a dignified existence by satisfying basic material and immaterial needs; democratic structures and fair distribution of income to limit and peacefully resolve social tensions and conflicts.
  Indicators: Poverty reduction, health, equal opportunities, education, participation [ÖkoI-1999].

At the time of its creation, the three-pillar-model, quasi as an "introductory thesis", at least achieved an upgrading of environmental protection, since this was now taken up as a priority alongside economic and social goals. It became acceptable above all for the economy with the idea of achieving suitable win–win–win situations. In any case, it has had a discouraging effect and has fired many discussions between the actors in politics, society and business and initiated further approaches.

The three-pillar-model was instrumentalized neoliberally under the term "weak sustainability" in the interest of radical market circles [Schr-2015]. The basic idea of intergenerational equality of people was increasingly sacrificed by market economy and technology-optimistic actors to the fundamental primacy of market mechanisms and the demand for fair but free trade.

The capital stock model developed by the World Bank in 1994 assumes that all objects, institutions and structures are uniformly measurable in monetary terms. It divides all production factors (resources) of an economy into three different capital stocks: environment, economy and society. In order to enable the inherent potential to satisfy material and immaterial needs and thus to achieve social welfare in a sustainable manner, the sum of the capital stocks, the sustainability capital, must be preserved. Sustainability in the sense of the capital stock model is given if it is possible to live in the long run from the interest and not from the capital itself, whereby it is disputed whether the capital stock must be kept constant (or increasing) as a sum or separately for each individual capital stock.

Supporters of "strong sustainability" consider environmental or natural capital as the foundation of economic activity to be sacrosanct. Here, the stocks of the individual natural resources must be kept at least constant in the long term. Substitution by other types of capital is considered inadmissible. Only the new growth of a natural resource may be consumed, non-renewable resources should not be touched [Brun-2010].

While "strong sustainability" is eco-centric and growth-critical and requires that none of the three capital stocks must decline over a longer period of time, "weak sustainability" is growth-oriented and anthropocentric and only imposes this condition for the entire sustainability capital as the sum of the capital stocks. For example, the environmental capital stock may be reduced as long as more economic or social capital is created as compensation.

In [Ott-2005] OTT TAKES A very differentiated and critical look at "weak sustainability". The concept of "weak sustainability" is implicitly based on a "grand narrative" of the emancipation of human beings from their attachment to a superior, resistant and hostile nature. There are no limits to inventiveness, shortages are eliminated by technical innovations. And even a world in which nature would have been largely substituted would be a "good" world for humans [Ott-2005].

To justify rational selection at the concept level, Ott recommends the "false-negative/false-positive" criterion known from risk assessment, which is used to examine which of two possible errors is morally more acceptable or produces the "most justifiable" result and which must be applied here above all from the point of view of intergenerational responsibility (see Table 5.2).

One acts under the assumption that "Hypothesis 1 is true" and does everything right if this hypothesis proves true, but risks irreparable damage if one is wrong. If one acts under the assumption "hypothesis 1 is wrong", nature is protected, if necessary, which one could do without from an anthropocentric point of view. However, you do not risk massive damage to the system if you do not receive any benefits [Ott-2005].

Table 5.2 Payoff matrix for the ethical evaluation of possible errors

Possibilities/reality	Hypothesis 1 is true[a]: Extensive substitution of natural capital is possible	Hypothesis 1 is wrong[b]: Extensive substitution of natural capital is not possible
Development confirmed Hypothesis 1	No error	False negatives: Even nature that is "dispensable" when necessary is protected = "useless" effort
Development refuted Hypothesis 1	False positive: Destruction of the life bases for future generations	No error

[a]Corresponds to the principle of "weak sustainability"
[b]Corresponds to the principle of "strong sustainability"

The discourse and the above-mentioned criticism led to further conceptual models for sustainability. The integrating sustainability triangle (also known as Gibb's triangle) attempts to eliminate the clear separation between the three pillars and thus allows overlapping topics to be assigned. For example, health is more likely to be assigned to the social pillar but is also an important economic factor for workers (occupational health and safety). Other models usually give priority to the natural foundations as the basis for all other dimensions (e.g. priority model), link the dimensions to Maslow's pyramid of needs (Pyramid Model Green Journalism [GrJo-2019]) or define the limits to non-sustainable development via a development corridor within ecological guard rails (guard rail model).

The head of the Stockholm Resilience Centre, Johan Rockström, links the seventeen Sustainable Development Goals with the planetary guard rails (Planetary Boundaries, see Fig. 7) in the so-called "Wedding Cake" model (see Fig. 5.9). The economy is an integrative part of society with the four non-negotiable planetary boundaries of drinking water (SDG 6), climate (SDG 13), biodiversity (SDG 15) and oceans (SDG 14) as a basis.

5.4 Sustainability Strategies

Various strategies are mentioned for ensuring sustainable development on our planet, mostly efficiency, sufficiency and consistency, here extended by resilience.

5.4.1 Efficiency—Resource Productivity, Output-Oriented

While effectiveness ("doing the right things") is a measure of the achievement of objectives and the associated effectiveness and quality and does not focus on the

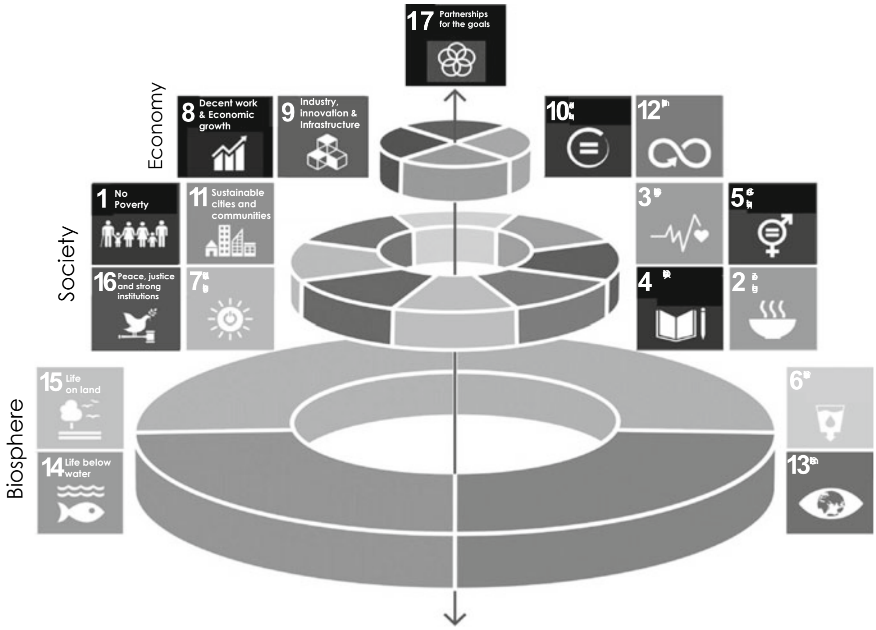

Fig. 5.9 The "Wedding Cake" model according to Johan Rockström and Pavan Sukhdev as a link between the 17 Sustainable Development Goals and the planetary guard rails (Planetary Boundaries). Stockholm Resilience Centre (designed by Azote) [Rock-2016]

effort required to achieve them, efficiency ("doing things right") measures the ratio of benefits to the effort required to achieve a specific result. Efficiency is thus a yardstick for resource economy. Since even the wrong things can be done efficiently, efficiency should be considered a sub-goal of effectiveness.

With a global "Factor 4 Strategy" (double prosperity with half the consumption of nature) [WeLo-1997], an efficiency revolution is to make sustainable development possible and avoid the threatening resource shortage of the future. The use of market-based instruments (e.g. emissions trading, eco-taxes) is intended to quadruple resource productivity. The concept is in line with the market, builds intensively on known and existing economic strategies and does not require major individual and social changes in behaviour. It was also referred to as "dematerialization" or "R.I.O. Resource Input Optimization" was disseminated and since then seems to have become a universal tool for sustainable development.

> When the only tool you have is a hammer, everything looks like a nail. [Mead-2000]

In [Schm-2007] it is calculated that a factor of 2 would be sufficient to "preserve" the existing global economic situation with dwindling resources, a factor of 4 would be necessary to create a fairer distribution in the world at present. However, taking population growth into account, at least a factor 10 is already required in the industrialized countries in order to be able to continue economic activity and relative prosperity on our planet with the future population in a reasonably equitable manner and also to grant a certain degree of (development) freedom to emerging and developing countries. It is assumed, however, that the calculatory concept could be implemented without "side effects".

> You can never solve problems with the same mindset that created them. (Albert Einstein)

A factor of 10 alone (including population growth) makes it clear that such efficiency increases can never be achieved by individual measures and that products or services must be considered in a complex way and, above all, taking into account their entire life cycle, including product design, production process, use and disposal.

Moreover, it has been shown that rebound or boomerang effects completely consume the specific efficiency gains achieved through technical progress to a large extent and often in absolute terms. Resource-efficient (dematerialized) production lowers production costs and leads to extra profits, which are used by producers for reinvestment and/or reduce prices, thus increasing the supply of goods and services that can be demanded by more consumers even if income remains the same.

Examples repeatedly mentioned are televisions and cars. Although the energy consumption in relation to the screen area has fallen significantly for modern LED monitors compared to old CRT TVs, the absolute consumption is increasing due to larger screen areas and the tendency to use second or third devices in different rooms. Lower car prices lead to the purchase of larger models (or, to quote the former German foreign minister Sigmar Gabriel, "too much Viagra in chrome on our roads") and fuel economy leads to more kilometres driven. An indirect rebound effect can occur if the money saved by buying cheaper products is used for the (further) holiday flight.

In [Neir-1997] NEIRYNCK warns against overestimating the enormous power of technical systems resulting from "technical evolution". "Without a relationship to a social project… the technical illusion … produces solutions whose effectiveness destroys all criticism.

> Technology without ethics is a mental ruin.
>
> The goal of biological evolution is the adaptation of the body to the environment; the goal of technical evolution is the adaptation of the environment to the body. [Neir-1997]

In both cases, this is done to ensure the survival of the species. Selection is used to decide between successful and unsuccessful attempts at adaptation. The challenge is to stop these trials in time "if the first results do not meet our expectations". This also includes the timely recognition of an impending failure.

This Section is not intended to discredit efficiency as a sustainability strategy. All too often, it is seen and focused on all too often, especially from economic and political circles, as "sole blessing". Together with the following strategies, efficiency should, therefore, take its place in a holistic view.

5.4.2 *Sufficiency—Reducing Resource Consumption, Input-Oriented*

The term sufficiency (from the Latin sufficere = to suffice, to be sufficient) stands for "the right measure" or "enough is enough" [Baue-2008]. Often this definition of contentment is only seen as the restrictive, the renunciation or even a new asceticism as in Schmidbauer's work:

> Basically every purchase must become a specific ethical issue; every consumer product is a piece in the mosaic of the Moloch of pollution. [Schm-1997]

But the strategy can also be interpreted and used much more comprehensively than this aggressive attitude would suggest. Sufficiency is the insight into the wisdom of the ancient sentence "From nothing too much"[13], "which has been regarded since antiquity and up to the present day as the right measure, as a good life (see Sect. 5.5.4), as the art of living" [Linz-2004].

At the same time, sufficiency creates a reduction in environmentally harmful behaviour in order to use resources differently and consume less of them than before. Thus, sufficiency is also a dematerialization strategy, but in a much broader sense than efficiency, as it is based on the absolute use of resources on the input side. With the change in the prevailing patterns of consumption and the move away from "too much", the aspects of self-limitation and thus self-determination, deceleration of life and de-commercialization can also be seen. Many examples show that sufficiency strategies and the behavioural changes associated with them need not be translated as "renunciation". Predominant "normality" can be broken up with reflected action and changed with personal advantage. If processes and existing structures are critically questioned, this automatically results in opportunities and incentives for action.

Also, the mental overload resulting from more and more products, their handling and care and the overloaded living spaces bring new trends such as "Small is beautiful" [Schu-2013] or minimalism into fashion.[14]

> Sovereign is not who has much, but who needs little. Whoever is in danger of sinking into a material diversity of options does not renounce through reduction, but frees himself from superfluous things. [Paec-2012]

Changing forms of use and consumer demands, in turn, influence product design and the range of services offered (see Chap. 12).

Sufficiency primarily and sometimes also exclusively addresses the individual person and thus brings with it the danger of overstraining the individual [Linz-2004]. However, it can also be embedded in community concepts such as the Transition Town Movement [Hopk-2014] or have a group dynamic effect on civil society organizations (see also Section on resilience) and can in principle also become a political and economic strategy if a society promotes the prosperity of its citizens without having to grow for it [Sten-2011].

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[13] Inscription of a temple in Delphi, about 500 years before Christ.

[14] Petra Pinzler also recommended "More and more is not enough! From growth mania to gross national happiness" 2011.

5.4.3 *Consistency—Use Resources Without Destroying, Cycle-Oriented*

The term consistency in the context of sustainability describes the compatibility of nature and technology and thus the "adaptation of human production and consumption processes to the natural processes of organization and effect" [Baue-2008]. Alternatively, the terms eco-effectiveness or "industrial ecology" are used.

Consistency thus learns from nature, adapts natural cycles, and tries, "as far as this is possible from an anthropogenic point of view, to take this as a model for the design of the technosphere" [Baue-2008]. This means that materials that are created in the production process and do not correspond to the purpose of production do not become waste, but remain resources in the sense of a cycle economy or the cradle-to-cradle approach of BRAUNGART [Brau-2003] and are used again and again, if necessary in other production processes. To achieve this, substances that cannot be returned to the household in an environmentally friendly way must be replaced in the products by materials that can be recycled as biological or technological raw materials after use.

As in nature[15], consistency does not aim at dematerialization. The aim of this strategy is "to integrate materials and energies into the natural material cycle (production waste can be composted, use of renewable energy sources) or into the technical material cycle (recycling without loss of quality)" [Sten-2011]. If industrial and natural material cycles cannot be harmoniously and complementarily designed, they must be separated and non-biodegradable products must be kept away from ecological material cycles (see also Chap. 12).

Since consumption patterns and production processes are also to be converted to a sustainable concept in the sense of a "third industrial revolution" at the same time, a future-oriented innovation policy with high investments in R&D is necessary to support this goal. Consistency strategies thus seem to promise a solution to ecological problems while at the same time maintaining or even increasing material prosperity without restrictions or losses.

> We see a world of opportunity, not of limitations. [Brau-2003]

For an industrial society in search of a solution, consistency thus becomes a source of hope. As a rule, the existing capital stock and know-how do not have to be completely replaced; known technologies can be modified (see also [Baue-2008]).

This unbroken trust in technology often results in a devaluation of the concept of sufficiency among advocates of consistency, while all serious advocates of sufficiency recognize the fundamental importance of consistency strategies [Linz-2004].

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[15] Plants and animals do not "work" eco-efficiently. In ecosystems, there is rather "overproduction" to ensure the existence of the species (turtles, sturgeon, etc.). However, they do not cause any environmental damage, but the surplus amount they produce is part of the biological material cycle (food for other individuals) according to [Sten-2011].

5.4.4 Resilience—System Resilience, Stability-Oriented

The term resilience describes the ability of a system to absorb and compensate for disturbances and changes in order to maintain essentially the same function, structure, identity and feedback. In [Walk-2004], four crucial aspects of resilience are listed, the first three of which can apply to both the overall system and its subsystems.

- Latitude: Maximum amount by which a system can change before it loses its ability to recover.
- Resistance: the ease or difficulty of changing the system; how "resistant" it is to change.
- Precariousness: proximity of the current state of the system to a limit or threshold.
- Panarchy: Due to interactions across scales, the resilience of a system on a given focus scale depends on the influences of states and dynamics on scales above and below. For example, external repressive policies, invasions, market changes or global climate change may trigger local surprises and regime change.

The relation to sustainable development becomes apparent when one looks at the development of industrial production according to PAECH [Schu-2013].

By efficiently breaking down production into a chain of many specialized individual processes and companies, spatial and functional differentiation leads to "the responsibility for the overall process being distributed over so many competencies that it is, so to speak, erased." The actor of a complex process chain who concentrates on his partial aspect loses sight of the consequences for the overall process. PAECH calls this "moral indifference" and also refers to the effect on the relationship between producer and consumer. Since consumers basically consume things that they have not produced themselves, the consequences of production remain hidden in principle. "Thus the essential principle of modern, functionally differentiated societies creates the pathological conditions under which individual economic decisions are almost perfectly shielded from feedback and thus moral inhibitions."

> Responsibility, the basic element of moral behaviour, arises from the closeness of the other. Proximity means responsibility and responsibility is proximity. [Baum-2002]

For resilience, systems and regions must be able to supply themselves with basic goods at least to a certain extent, even if disturbances to the superordinate overall system should occur (subsistence farming) [Kopa-2015]. A great danger is also seen in the fact that basic skills can be unlearned—sometimes forever—by the separate and highly technical division of labour and are no longer available in a crisis situation.

A practical example of this is the Transition Town Movement with its "vision of local resilience" [Hopk-2014]. The idea is to take the basic needs of life back into one's own hands, and thus to bring decision-making power back to a close, local level. The resilient system/community is characterized by as many elements as possible that function side by side, overlapping but independent of other parts of the system, instead of many interconnected and interdependent elements[16]. HOPKINS sees social capital (social networks and vibrant, trusting communities), innovation (learning from each other and room for experimentation), overlap (a mess is better than a perfectly rationalized system with no reserves), short feedback loops (short distances for cause-and-effect experiences, proximity, see above) and environmental responsibility (resilient communities consider the impact of their activities on the ecosystem) as the foundations of a resilient community.

The "resilient communities" can be conceived and organized according to neighbourhood, district, or town size, and due to the complexity of regional or local conditions, they also have a large number of different approaches and solution variants. They can, therefore, also be used as blueprints for new local economic systems and serve as real laboratories for testing them, including failure (see also Sect. 5.5.4). Instruments for a resilient regional design would be for example, regional economic plans, local currencies, internal investment, cooperatives, subsistence and prosumers[17].

5.4.5 Summary

Depending on the interests and social background of the actors, there are different preferences for the sustainability strategies described: efficiency, sufficiency, consistency, and resilience. In the different camps, the range of approaches extends from reduction to rejection on the one hand and cooperation approaches for the strategies on the other.

With the I = PAT formula the mutual dependencies according to [Ehrl-1990] can be described as follows:

(Environmental) Impact $= f$ (population, wealth, technology) or

Environmental impact $= f$ (population, wealth, technology),

with strategies of efficiency and consistency targeting technology and sufficiency targeting the provision of consumer goods to individuals. In [Hube-1999] global aspects are also mentioned: While in developing countries the "enough is enough" of sufficiency tends to be related to population growth and other aspects of sufficiency tend to be ignored in the context of catching up on consumption, at least the NGOs of the industrialized North are more inclined to influence the factor of the level of consumption demand.

In business and politics, there is currently a clear preference for the efficiency strategy. The consistency is seen together with the efficiency of the implementation

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[16] Hopkins cites the world record attempt at "Domino Day" as an illustrative example. A single domino that accidentally falls over prematurely would destroy the work of many months. Therefore, gaps are inserted at regular intervals. If one stone falls now, not the whole system is affected [Hopk-2014].

[17] Prosumer, in English prosumers, modern term for self-catering, but also extended when consumers contribute to product design with their knowledge or, for example, operate solar systems.

and directional development of the approach of an industrial ecology [Baue-2008]. In [Hube-1999] this interplay of eco-efficiency and consistency is called "metabolic nature integration". Since efficiency and consistency are compatible with further economic growth pursued by policymakers, these two strategies are given priority by the World Bank, the European Commission and the German government [Sten-2011].

Technical developments to implement efficiency and consistency are time, material, energy and cost-intensive. This is particularly true of the long-term goal of consistency. For this reason, efficiency approaches to reduce or slow down ecological interventions that are to be implemented in the short term are sometimes also seen as a means of providing the time "that the consistency strategy needs to develop them" [Sten-2011]. However, consistency and efficiency strategies do not provide a solution for every ecological problem and, for example, "cannot address the serious ecological consequences of a global herd of several billion animals and overfishing of the oceans" [Sten-2011].

Linz sees a different order here: sufficiency before efficiency before consistency. He argues that the fastest way to significantly reduce consumption levels is from one day to the next. Sociologists, on the other hand, warn that behavioural changes in particular—if they are not administratively ordered and implemented—are difficult to accelerate and take time, perhaps much more than technological developments do. Since the long-term goal of consistency is still a long way off, not only efficiency but also sufficiency is needed to bridge the time until the required technology for the consistency strategy is ready to function. At the same time, sufficiency, implemented primarily in the rich industrialized countries, contributes to global resource justice: "The affluent scarcely one-third of the world population will no longer be able to use more than half of the environmental goods". [Linz-2004]

> Ecological sustainability as the preservation of the natural foundations of life cannot be achieved in the decisive decades ahead with resource efficiency and the prospect of consistency strategies alone. Both will only achieve the intended effect in combination with sufficiency. Social sustainability as the peaceful coexistence of a growing humanity will not come about without more balanced development opportunities between the poor and the wealthy and between the nations in which they live. This includes a lower use of resources by the industrialized countries. [Linz-2004]

As in many areas of sustainability, not one single path leads to the goal for everyone. "Only the holistic consideration of all conceivable implementation strategies can have a target-oriented effect" [Baue-2008].

5.5 Sustainability—Implementation Concepts

The insight that the radical market approach cannot function (for much longer) in a finite world has led to the development of various concepts that pursue political, scientific, entrepreneurial and civil society approaches, and which are based to varying degrees on the sustainability strategies presented. In the overview, however, focuses on concepts that are partly limited to economic criticism and that need to be conceptually expanded for global solutions, see Sect. 5.5.1 (Table 5.3).

The following classification is an attempt to structure different approaches. A clear separation between the different approaches from a system and actor perspective is not seen and does not seem to make sense in terms of a holistic solution.

Table 5.3 Overview of alternative economic and social concepts according to [LebM-2012]

	Goal/vision	Representative	Perspective	Approach
Green economy	A green transformation of the economy leads to sustainable development	UNEP, OECD	Nationally and internationally	Political
Europe 2020	Decoupling is possible through smart, sustainable and inclusive growth	European Commission, European Council	European Union	Political
Enquete Commission for Growth, Prosperity and Quality of Life	Concrete political recommendations create more prosperity and quality of life in Germany	17 members of the German Bundestag; 17 external experts	Germany in the international context	Parliamentary discussion
Blue economy	The innovative use of waste and resources leads to a prospering Zero Emission Economy	Gunter Pauli, Blue Economy Institut, Blue Economy Alliance	International	Scientific, entrepreneurial
Cradle to Cradle	Closed material cycles make "intelligent waste" possible	Michael Braungart, William McDonough	International	Scientific, entrepreneurial
Factor X	More prosperity from less nature by increasing resource productivity—by a factor X	Friedrich Schmidt-Bleek, Ernst Ulrich von Weizsäcker, Factor X Institute	At the level of products, services, companies, national	Scientific entrepreneurial, political
Steady-state economy	Economic development at an optimal physical level	Herman E. Daly	Global	Scientific

(continued)

Table 5.3 (continued)

	Goal/vision	Representative	Perspective	Approach
Degrowth	Shrinking the economy for greater social justice, environmental sustainability and well-being	Many activists and science-learners	Local to global	Scientific, civil society
Postal growth sgesellschaft	An economy that leads to a high quality of life within ecological limits even without growth	Tim Jackson, Niko Paech, Peter Victor	National	Scientific, civil society
Buen Vivir	Development model that leads to a good life	Alberto Costa, Eduardo Gudynas	South America, especially Ecuador and Bolivia	Scientific, political, civil society
Public interest economy	An economy based on principles of general interest	Christian Felber, 500 pioneer companies	National	Civil society, entrepreneurial
Solidarity economy	Living the diversity of grassroots democratic and needs-oriented economic forms	Many actors	Mostly local	Civil society, self-organized
Transition movement	Building local resilient and self-sufficient communities together	Rob Hopkins, Naresh Giangran-de, Louise Rooney	Local, regional	Civil society

5.5.1 System Repair and Expansion, Eco-social Market Economy, Global Marshall Plan

The collapse of the party-communist systems of the Eastern bloc was attributed to the victory of the free market economy and not to the weaknesses of dilapidated state mismanagement of an ideology-driven party dictatorship. With this mantra, market-fundamental positions of neoliberalism with strong tendencies towards deregulation and privatization subsequently prevailed, also with the argument that global markets with their laws do not allow for regulatory regulation.

> Neoliberalism, as it is propagated today, is nothing more than a reverse communism. Communism replaces the market with politics, neoliberalism replaces politics with the market.
>
> An unleashed, irrational market and an uncontrolled globalization harm people not only materially, but also psychologically, character-wise, since this system is based on extreme individualism and brutal and suicidal competition, which promotes the negative in people. Solidarity, community, family, long-term working relationships and the moral foundations of society are dissolving, the increase in authoritarian measures is the necessary consequence. (Gerald Mader: The total market, quote from [RaRW-2011])

In [RaRW-2011], the philosophy of the "free" market is called the "DNA of the current Western economic system", which has taken on the character of a substitute religion "as if it had scientific irrevocability"[18]. The effects of globalization left primarily to the market are shown on the one hand in extremely high returns and a massive private accumulation and concentration of capital, and on the other hand in the exploitation of natural (and social) resources along the lines of "privatization of profits and socialization of losses". This development also led to the recent crisis of the world financial and economic system, which then had to be stabilized with public funds (whereby the private banking system could again benefit).

The free market guarantees efficiency but has no ethical and moral goals for the state and society. Only by means of rules (global guard rails) can these goals and thus the effectiveness of the system be determined. Töpfer demands a "social and ecological qualification of the market economy" [RaRW-2011]. In addition to or rather above the restrictions of the market, the second system of sustainability restrictions in the form of global governance—a world government of the interior—with minimum social and ecological standards is required [Rade-2014].

> What we need today is a Global Marshall Plan to save the environment and give billions of dispossessed people the opportunity to really participate in the economy. Remember that the right thing remains right even if no one does the right thing. And the wrong remains wrong, even if everyone does it. (Al Gore, [Gore-2009])

If a transformation of the economy from market radical to eco-social does not succeed, RADERMACHER predicts the following with regard to the three dimensions of sustainability (see also the forecast for future development in Sect. 5.1): A collapse of the ecological dimension would lead with a probability of about 15% to a "global Easter Island", a collapse. The loss of the social dimension means a return to (new) feudal structures, also known as Brazilianisation or eco-dictatorship (about 40%). A collapse of the economic "market dimension" (about 10%) would lead to a "new" communism, a planned economy, but a reasonably socially just distribution of the remaining resources at a low level [RaRW-2011]. This leaves the choice between three less desirable alternatives!

On the homepage of the Global Marshall Plan Initiative for a World in Balance, five building blocks are named [GloM-2019], which will be used and supplemented

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[18] Mont Pelerin Society—influential group of economists in governmental and scientific circles with the aim of spreading radical market thinking as an ideology See also Randers, Maxton: One percent is enough [RaMa-2016].

in a different order below. The steps build on each other, are mutually dependent, and thus form a holistic solution concept.

The first step is to determine the goal (quasi the guideline for effectiveness) of development and the necessary social transformation through the sustainability definition of the Brundtland Report. This would be on the one hand the securing of basic needs and a fair distribution (intra-generational justice, especially social, economic) and on the other hand the securing of the future of humanity and thus the preservation of resources and intergenerational justice (especially ecological and economic justice). More specifically, these goals are anchored in the Sustainable Development Goals (SDGs) 2015–2030, which are to be implemented as part of the transformation process.

The second is to establish a globally applicable framework that can provide the guidelines for implementing these goals. At present, globally active companies (for example, from the financial sector) do not find any regulatory framework. Here, global governance, a world domestic policy with a holistic set of rules ("World Basic Code" with binding social, ecological and cultural standards) must be established. The Global Marshall Plan Initiative calls for this: "Functioning global governance structures need reforms of existing institutions and regulatory frameworks (such as the United Nations, the World Trade Organization and the world financial sector) and their coherent linkage to a functioning whole." The "enforcement of a balanced distribution of property and assets and transparency of ownership" is also necessary.

Third, within this normative framework, the efficient use of existing resources and opportunities can be further regulated through the market and its mechanisms (for example, through an eco-social market economy or green economy). The Global Marshall Plan Initiative calls for: "A sustainable world economy with reformed priorities and role allocation". The regulatory framework (under second) must support this process and correct the current market failure for a sustainable economy, e.g. by internalizing external costs [RaMa-2016]. Through "Green Growth", eco-innovations (resource efficiency) and better management of natural capital should open up new markets and make environmentally sustainable growth possible. A consistently enforced "cap and trade" approach to emissions trading can serve as an example here. The "cap" regulates the political boundaries, the guide rails of the market (achievement of objectives, effectiveness). Efficiency is guaranteed via the "trade", the market.

> In the view of WBGU,[19] CO_2 pricing is the most important political measure for decarbonisation and a necessary component of a regulatory framework for the transformation to a climate-friendly society. [WBGU-2011]

Furthermore, tax reform is needed to complement and integrate emissions trading, which uses emissions and the consumption of raw materials as a reference rather than income, and achieves "fair taxation of all, especially global, value-added processes, especially in the financial sector".

[19]German Advisory Council on Global Change.

> If now the state economic framework conditions are still right and the company's earnings are not taxed, but rather the use of resources and energy, then the resource efficiency that is urgently needed to maintain our prosperity will come about almost automatically. [Stah-2000]

The Global Marshall Plan Initiative suggests the following: "Possible financing mechanisms are a Terra Levy on world trade, a levy on world financial transactions, trade in equal per capita CO_2 emission rights, a kerosene tax or special drawing rights with the International Monetary Fund (IMF)."

Fourth, the financing of the concept must be guaranteed. To this end, the above-mentioned tax reform can be designed not only as a regulatory instrument for dealing with global common goods but also as a means of financing them. In addition to implementing the SDGs, the financing also serves to finance the development cooperation and partnerships required for this purpose. The funds are to be used nationally to fulfil the Paris Climate Change Agreement to comply with, or better still to fall below, the 2 °C limits, but also to co-finance globally the climate financial compensation agreed in Paris. According to [Ekar-2018], compliance with this target is binding under international law.

The Global Marshall Plan Initiative calls for at least 0.7% of the gross national income of the industrialized countries to be invested in development cooperation and estimates that additional funds of around US$ 150 billion per year would be required for this purpose. However, it would be wrong to speak of development aid here. De facto, it is a matter of making good the (neo)colonialist damage caused by the industrialized countries in the developing countries, at the expense of which the recovery of the industrialized countries has partly taken place (quasi as loan repayments). The industrialized countries were also responsible for the climate damage, the repair of which or the effects of which could be financially compensated.

> An effective use of funds for self-determined development paths is perhaps the most difficult aspect of a Global Marshall Plan. The promotion of good governance, subsidiarity, regionality, education, the fight against corruption and coordinated and grass-roots forms of resource use are considered crucial for self-directed development. Concrete examples are microfinance, renewable energies and cooperation with local development workers. (Global Marshall Plan Initiative)

5.5.2 System Criticism and Change. Steady State Economy and Degrowth

The concepts of an eco-social market economy, a green economy, or green capitalism discussed in Sect. 5.5.1 correct the system distortions and "repair" the existing economic system for the new global challenges. Economic growth is still considered necessary for the prosperity and progress of society but is to be decoupled from environmental impacts, primarily through resource efficiency and innovation. RADERMACHER also does not see growth as such in a negative light. However, it puts into perspective that it remains necessary for the global south to fight poverty and that the global North could be freed from the pressure for growth if necessary [RaRW-2011]. All approaches move within the neoliberal economic logic, do not question existing modes of consumption and production [LebM-2012], and largely ignore sufficiency strategies or regard them as subordinate. This topic is discussed in detail in the final report of the Enquete Commission “Growth, Prosperity, Quality of Life” 2013 [EnKo-2013].

> Right now we take from the future, sell it in the present and call it GDP. We might as well have an economy based on healing the future rather than stealing from it. (Paul Hawkins in [Hopk-2014])

The protagonists of the degrowth movement and post-growth (or steady-state) economy consider the old system to be unsustainable and purposeful, no longer in line with future requirements and consider how a system must be designed so that planetary boundaries are respected and humanistic requirements can be met in a fair manner and brought back into focus. This is a change of sight: One does not adapt the system to the requirements but redesigns it according to the requirements. This creates new degrees of freedom for system design, but also higher risks of failure since empirical experience is largely not yet available.

Here, on the one hand, one can primarily see growth criticism—what happens if it is not possible to decouple growth and environmental consumption?—and on the other hand, general criticism of capitalism and thus the search for alternative forms of economy and society. The concepts, which are also subsumed under the term “degrowth”, are diverse, in some cases located in both areas of criticism, and extend to approaches that conceptually dispense with the market and the state (see also 5.5.4).

Both areas of criticism can be described in their context by a conditional statement: IF “capitalism is forced to grow” AND “growth ultimately leads to collapse”, then “replace capitalism with an alternative system”. In order to act according to this algorithm of a conditional statement, the two conditions must first be checked for truth (true or false).

According to Marx, capital is a “value that strives to increase its value”. By reinvesting the added value, capital is reproduced, and through this accumulation, growth is generated, measured by the changed gross domestic product (GDP). Growth is achieved by increasing labour productivity, technical innovation and “widening the field of operations”. In a loop of competition and reinvestment to remain competitive and expansion, not only are existing resources depleted, but there are fewer and fewer still un-commercialized areas of life that can be developed for further growth [Andr-2016].

Is capitalism conceivable without growth if this structure of effects cannot be broken through? Here the degrowth theorists are in disagreement: Steady-state economists (for example Herman E. Daly) acknowledge the second condition (growth criticism) as true, but see the possibility of zero growth at an optimal, sustainable level of consumption and population, or even demand negative growth until a stationary economy is reached. According to Daly economic growth has already become uneconomical and no longer creates prosperity but rather reduces the capital stock [LebM-2012]. The (capitalist) economy will not die of the cancer of “Growthmania” but of old age [Daly-1974].

> Those who believe that exponential growth can continue indefinitely in a limited world are either madmen or economists. (Kenneth Boulding, economist, in [Maxt-2018])

In the argument, “DALY … above all to the laws of thermodynamics, according to which mankind has a limited budget of energy with low entropy at its disposal with which it can operate and live. If too much of this energy is used for economic activities, the complex life-sustaining ecological systems begin to fail. This is the basis of his criticism of orthodox economic theory and its logic of growth. It violates the second law of thermodynamics: “An economy simply cannot grow infinitely with a limited supply of energy and resources [Aach-2018] (on the subject of entropy see also [Ulgi-2016]).

Continuous, infinite growth, as it is regarded as legitimate in market economies to guarantee prosperity through the “interest-based compulsion to generate a surplus” [Paec-2012], is not known by nature.

> Growth is followed by decline - a perfectly normal story. [Mead-2000]

In nature, processes tend to run in cyclical cycles of growth, death, decomposition, etc., and consumption is geared to the available resources. Resource-inappropriate growth in nature can best be compared to cancer cells that grow at the expense of the (limited) resources of the host and ultimately perish with it. In social processes, too, the concept of history was occupied by theories of time until the eighteenth century, with rise and fall alternating: “Growth is an economic topos of the twentieth century”. According to PRIDDAT, “even Smith, Malthus, Ricardo to Marx were still convinced of an absolute historical limit to these processes of increase (Ricardo’s borderlands, Marx’s crisis, etc.)” [Prid-2017].

As in nature, there are also cycles of growth, decline and regeneration (Pulsing Paradigm) in society. But these social cycles are long-wave and difficult to recognize because we are firstly part of the system and second we are used to shorter cycles from nature (for example seasons).

> Sustainability in this sense is rather the ability to adapt to the resource oscillations. [Ulgi-2016]

Degrowth and post-growth economics not only provide criticism of the existing, but also develop concepts for an economic and social transformation without growth dependency. The post-growth economy attempts to eliminate growth drivers, which can be achieved structurally by shortening or unbundling complex production chains with a reduction in the degree of external supply and culturally through sufficiency approaches.

Three parallel supply systems are combined for the structural transformation. According to the motto “as regional as possible, as global as necessary”, these are after [Paec-2012]:

- De-monetisation subsistence approaches with intensified use through community use, an extension of the useful life through care, maintenance and repair as well as own production, also to increase resilience.In the process, objects from industrial production based on the division of labour are partially substituted and used longer and more intensively due to subsistence inputs. The subsistence inputs are market-free goods, such as own time, craft skills and social relations.
- An economy of proximity with local or regional supply, which creates transparency and trust between market participants via short production chains at a sufficiently short distance, allows identification with the region through the loss of anonymity and the creation of mutual empathy and relativizes yield claims by controlling use and congruence of interests between investor and consumer. The regional economic system is supported by interest-free, regional complementary currencies (see also [Ditt-2016]).
- Services resulting from the global division of labour, whereby industrial production would have to focus on the preservation, conversion and upgrading of existing product stocks (renovation, optimization, intensification of use) in addition to the new production of durable, repair-friendly products. In this way, the skills of subsistence could be supplemented and the new production of goods minimized.

The degrowth drafts and the post-growth economy thus focus not on “less”, but above all on “different”. From the perspective of a “good life”, one could also define “better” with this. Concepts such as sharing, caring, commons or commons, conviviality, minimalism, eco-communities, and cooperatives combine the well-tried with the developed and newly developed or to be developed further.

> Since available time cannot be increased from an individual point of view, there is a threat of escalation: a scarce, un-reproducible quantity of time must be distributed among an ever increasing number of objects of consumption. Under the regime of time scarcity, the growth of individual possibilities has a devastating price, namely superficiality - and this does not make anyone happy, but encourages burnout. [Paec-2012]

The necessary, monetarily remunerated working time is reduced in a shrinking capitalist economy (for example, after the Steady-State Economy) by the lower production level of a stationary economy or in a post-growth economy by the division of human activities into different creative areas. While in the industrial production sector, manpower can be saved through digitalization and artificial intelligence, less specialized economic concepts of subsistence or regional supply, based on the division of labour, are deliberately not designed for efficiency and require more working time per product unit. In sum, this creates relief and space for family and commitment on the one hand, but also requires alternative concepts for practical implementation on the other.

> In the work-fixed societies of the Global North, family and community life, as well as political commitment, suffer from the fact that people do not have enough leisure time for social activities. [Scho-2016]

The diminishing “wage labour” share can be divided among those who are able to work over annual or lifetime working hours. A share of unpaid social work not included in GDP (e.g. home care) can also be integrated as paid work according to different approaches [RaMa-2016]. These concepts can be flanked by an unconditional basic income either for those in need [RaMa-2016]) or, where appropriate, coupled with social work or recognition of unpaid work, as well as a maximum income, for example through progressive taxation, to avoid major material inequalities [Alex-2016].

5.5.3 Actor's View of the Company/Business: "Better Business, Better World"

For the sake of completeness, this heading should also often mention highly specialized companies that see their business field in the solution of mostly individual problems of sustainability and try to solve them by technical means or other innovations. Examples include developments that use principles of innovation, efficiency and substitution, such as renewable energies, alternative drives, technology development for the capture, storage and utilization of carbon dioxide (Carbon Capture and Storage—CCS, Carbon Capture and Usage—CCU and Climate Engineering, artificial recovery of CO_2 from the earth's atmosphere, air capture processes). For explanations and further examples see [Fran-2013] and [BUND-2002].

The focus here should be on companies that pursue a sustainable concept as an integral part of their corporate goal and/or see it as a means of standing out from their competitors in global competition or "making a positive contribution to achieving SDGs" [TheW-2018]. This approach is often subsumed under Green New Deal, Green Economy and the range of implementation extends from Green Washing to Green Start Ups, which have deliberately not included growth targets in their business concept. Sustainability in companies is recorded in management strategies such as Corporate Social Responsibility (CSR) or Corporate Sustainability (sustainability management in companies). This approach can also be seen in the continuation and modernization of the tradition of the "Honourable Merchant".

The starting position in which the economy currently finds itself between short-term profit orientation and long-term livelihood security is well described in the book "Global Impact": "In the current globalized economy based on the division of labour, smaller and smaller competitive differences become more and more decisive over time" [RaOS-2009]. Business enterprises optimize global production "by exploiting all the strengths and weaknesses of all the countries in the world". In this context, countries are in competition with each other to "increasingly satisfy the wishes of the economy" in order to generate or maintain value-added and jobs regionally. Increasing lobbying attempts to assert particular interests, for example by companies and associations paying law firms to draft national laws and international agreements. Avoiding systemic damage is not the focus of their efforts [RaOS-2009].

This results in a kind of aggravated "economic prisoner dilemma" for the companies: If they act sustainably in order to contribute to the long-term preservation of the economic base, there is not only the fear that others will not participate and that their own share alone will not be sufficient. Even if one's own efforts contribute to success, there is a danger that one will not be able to play along in this future due to competitive disadvantages. As long as sustainable action in the market does not also offer economic advantages in competition, the problem from this point of view is not a globalized economy, but the lack of a political global framework for economic activity.

As a result of [WEF-2019], however, environmental risks are the primary threat to the global economy. These risks include extreme weather, failure of climate protection and adaptation measures, natural disasters, data fraud or theft, cyber attacks, weapons of mass destruction and water shortages. If these are classified according to the criterion of "probability", they include the risks of extreme weather, failure of climate protection and adaptation measures, natural disasters, data fraud or theft and cyber attacks. If one classifies them and according to the criterion of "impact", then they are weapons of mass destruction, failure of climate protection and adaptation measures, natural disasters and water scarcity.

High environmental standards are not a problem for a global economy if they are competition-neutral and affect everyone equally [RaOS-2009]. In the meantime, the business community itself is increasingly demanding this political framework. "Instead of allowing further professional exploitation of systemic weaknesses", a turnaround in the economy will be necessary. "Common interests are more intelligent than particular interests" [RaOS-2009] if a basis of long-term economic activity is to be maintained. On the other hand, sustainability is no longer seen as a mere image and marketing task, which is usually still burdened with additional costs but is increasingly recognized by many companies as a competitive factor (beyond an image advantage) with many win–win approaches and integrated into their core business.

> The motivation of companies to act sustainably has broadened: energy-saving processes, the efficient use of resources or the sustainable use of waste in the industrial cycle have long since ceased to be based solely on ethical and moral considerations and have become a strategic, economic, even monetary argument. (Klaus Töpfer, Preface [Leup-2012])

The increasing importance of sustainability in companies is driven by win–win aspects, such as training and further education, occupational health and safety, energy consumption, and less often by external motives such as the preservation of biodiversity and global poverty reduction. According to a KPMG study from 2017, "Climate protection measures", "Decent work and economic growth" and "Health and well-being" are the highest priorities for companies [KPMG-2017].

Table 5.4 provides an overview of the tasks and possible measures of sustainability management in the company. Sustainability management is not seen here as a final state to be controlled, but as a "goal-oriented learning and design process" that requires many small pragmatic steps and must be decided on situation-specifically for each company [BUND-2002].

For larger companies, the standards of the Global Reporting Initiative (GRI) continue to form the framework for reporting (63%). Integrated reports (sustainability

Table 5.4 Sustainability management in companies [BUND-2002]

	Market (effectiveness)		Organization (efficiency)		Personnel (commitment)		Sustainability report
	Paragraph	Procurement	Production	Administration	Motivation	Qualification	
Economy	Increase in turnover and gross profit	Reduction of procurement costs for raw materials, personnel and capital	Rationalization of production processes	Rationalization of the administration processes	Transition to flexible working hours and performance-related pay	Development of junior staff and effective qualification measures	Benchmarking and controlling
Ecology	Resource-saving and multifunctional product design	Resource-saving procurement and transport of raw materials and products	Resource-saving production process	Conservation of resources through paperless office and office sharing	Rewarding ecological behaviour by means of job tickets and the like	Ecological education/transparency and quality management	Life cycle assessment and eco-audit
Social issues	Socio-ethical added value of the products and sponsoring	Social impacts of procurement and fair prices	Team-oriented process design	Home/part-Time Office and workplaces suitable for the disabled	work-life balance and flexible monetary/non-monetary social benefits	Team development/gender training and promotion of social commitment	Social balance sheet and social-audit
	Eco-social marketing		Eco-social process optimization		Eco-social human resources management		

is part of the annual report) continue to be considered the exception rather than the rule but are showing an upward trend. Two-thirds of the 250 largest companies worldwide and almost half of all companies analyzed (45%) have their data externally verified. Some 40% of the world's largest companies already include the Sustainable Development Goals in their reporting [KPMG-2017]. In Germany as well as in the European region, reporting obligations for larger companies have been in place since 2017.

The implementation of SDGs is of course also interesting from a business perspective. Especially in four major areas: Food and agriculture, cities, energy and materials as well as health and welfare are expected to have a large market potential.

> Achieving the Global Goals creates at least US$12 trillion in opportunities. [BSDC-2017]

Companies that want to take full advantage of this market potential should position themselves in a good time and present themselves in an ecologically and socially sustainable manner. Then the probability is high that "first movers will also get the biggest piece of the cake. So saving the world should also be economically rewarding." [TheW-2018].

5.5.4 Actor's Perspective ME: "We'll Get Started" Civil Society Approaches

> "The culture of EVERYTHING ALWAYS consumes the future of those who have the misfortune to be born later than you." "I myself am the problem that must be solved if our world is to be sustainable." [Welz-2013]

Thus, the responsibility for effects caused by each individual's actions on our planet is transferred (not only, but also) to the individual in a very personal way. It is not necessary to wait until necessary measures are ordered by the legislator and political decisions are taken by our governments. Each individual can take responsibility through his or her daily activities. Which impacts are caused in which areas of life can easily be determined by the ecological footprints already described? However, the current existential problems of the climate crisis represent a completely new situation for humanity. The drastic changes required (for example, the energy and transport transition) include dimensions that have not been seen before on this scale. Historical experience is difficult to use or translate into usefulness. Practical experience does not exist or is only just being made on a "laboratory scale".

> More sustainability in climate protection has so far failed less because of knowledge than because of outdated ideas of normality, habits, convenience, repression and emotional difficulties with highly complex and multi-causal damage relationships. [Ekar-2017]

Even if people still deny climate change as a whole or the man-made exacerbation of the climate crisis, no one can now claim to be insufficiently informed or at least to have the chance to be so. But why is the gap between knowledge and action[20] apparently so difficult to bridge? The hurdles mentioned in EKARDT's quotation also form the starting points for possible changes, which must be understood as ongoing and time-consuming processes that can be advantageously supported (or hindered) by political measures. Possible starting points for determining how personal and social changes are determined and can ultimately succeed are described in [Ekar-2017]. In addition to knowledge in conjunction with better information offers and research support, a necessary change in values and a change in the ideas of normality and self-interest calculations are described as "construction sites".

Values are understood here to be social or cultural values: "something that has become socio-cultural and exists independently of individual persons" [WBGU-2011]. A change in values is not about black-and-white decisions (to have or to be), but about shifts in emphasis between the striving to satisfy material needs, which often goes well beyond the satisfaction of basic needs (see Maslow's Pyramid of Needs, Sect. 5.2), and post-material needs, such as self-realization, the expression of intellectual, creative and aesthetic needs, opportunities for participation in state and society, and the appreciation of freedom of opinion and tolerance [WBGU-2011].

In the global North (according to FROMM "in the West"), attempts are being made to compensate for the inner emptiness through possession, "wanting to have"[21], through compulsive consumption, which FROMM describes as a symptom of the "pathology of normality" [From-2005], as a general illness, which is only not felt as such since everyone suffers from the same illness:

> If having is the basis of my sense of identity, because 'I am what I am habe', then the desire to own must lead to the desire to have much, more, most. [From-1976]

However, over the past 25 years, scientists (e.g. Ronald INGLEHART) have noted a global shift in emphasis towards post-material values (expansion of choice and individual autonomy of action), particularly in prosperous and 'secure' societies, in connection with an increasing degree of saturation of material well-being [WBGU-2011].

Ideas of normality tend to be in the unconscious or semi-conscious mental area and (like values) show a high degree of persistence. If normality is to be changed, the first step is to question previous habits and then to experimentally try out the resulting possibilities, which are often amazingly simple and meaningful, through alternative life practices. In order to be successful here, it is helpful to look for allies, to be role model for each other, to work together and exchange ideas. This is particularly important, since "the establishment of new concepts of normality amounts to a denunciation of conformity with the previous environment" [Ekar-2017].

In the case of self-interest calculations, a middle way between birth-related self-interest (economic liberalism, Thomas HOBBES) and socially induced and thus

[20] A phenomenon known as "cognitive dissonance": people act against their own knowledge and convictions.

[21] The so-called "Habenwollen", see also the book by Wolfgang Ullrich: "Habenwollen: How does consumer culture work?" [Ullr-2008].

socially influenceable self-interest (anti-authoritarian-educational optimism, Jean-Jacques Rousseau) could be found [Ekar-2017]. In this context, self-interest not only pursues the economic interests that are often in the foreground, whereby alternative views of benefit can be strengthened by, among other things, changing values and changing ideas of normality. Again, personal reflection helps to decide what is seen as self-interest and how important this is. At this point, information and education are needed to understand and make clear to young people in particular that tackling long-term goals (e.g. climate change) and distant problems (e.g. intra-generational justice, poverty) can also support personal self-interest [Ekar-2017].

According to Ekardt, the collective good character of sustainable problems requires "political-legal and thus for all valid rules" in order to give motivation and legitimacy to the actions of the individual. For political changes, politicians in turn need democratic legitimacy, which is not only established every four years through elections but also through social pressure, through discourse in civil society, i.e. by each individual, including the esteemed reader.

In order to change values and ideas of normality, the existing, normal, everyday practiced, and tested must be questioned as to their meaningfulness and individual significance. The answers to these questions can be surprising and thus of course also vary widely.

The variety of different designs (see examples in [Jens-2011] and [Welz-2014]) is immensely important especially for exploring and entering new territory, because not every design can automatically lead to the goal and failure is inherent in the principle of search (the classic trial and error principle). In order to speak with Welzer, "thinking for oneself" is essential [Welz-2014]. Often as a result of the reluctance to let consumerism dictate too much and in search of one's own values, of a self-determined life, new things are tried out or tried and tested for suitability and modified for one's own needs (example urban gardening). Since it is difficult to go it alone against the culture of the "all-time", like-minded people come together in "Resilience groups of the avant-garde" [Welz-2014] and rehearse there today a different life for tomorrow: "We'll start already". Social media makes it easy to communicate, network and seek allies.

Sufficiency strategies are often the basis, the degrowth movement with a common good economy or a solidarity economy and the post growth economy are "soulmates" of this movement. Transition Town, RepairCafé and others are real laboratories for testing alternative life and social designs and provide blueprints for imitators and for further developments.

Which attitudes, which views have to change in principle in order for sustainability to succeed? At present, at least the global North is highly technical and tends to distance itself from nature. See the approach of weak sustainability (replacement of natural capital is possible) to ideas of radical mechanization of man (flexible adaptation of the "deficiency human being" to market requirements by technical means, genetic engineering, chip-equipped trans-humanoids). Can all individual, economic and social goals and wishes be fulfilled under only two questions: What is technically possible? And how much money does it cost? And when "nature" becomes scarce, an attempt is made to "price it in" and make the best use of it in a market economy. Was there something else? Oh yes, human rights and morality! There are commissions for this as well as fair trade and animal welfare labels.

> One of the great tasks is to abolish the separation between nature and man. [Acos-2017]

In the 17 Sustainable Development Goals (SDGs), too, one looks at the system "from the outside", is an analyst, sets goals, manages transformation at best, observes developments and controls the achievement of goals. What is missing and what is needed is an 18th—a very personal—sustainability target, preferably with highly individual characteristics. To do this, everyone has to start with themselves, take personal responsibility in a double sense and see themselves as part of nature, of the system.

> The dichotomous separation between man and nature must be challenged. The human being is an integral part of the networked system. We cannot talk about the transformation of the system as if the system were somewhere - We are the system. [Bru2-2018]

Depending on one's own point of view, either "above" or "in the midst" of nature, the individual approach to the ecosystem and the respect that is shown for it also results in a better understanding of it.

> Look around you and you will see creatures that behave as if the world belongs to them, and others that behave as if they belong to the world. [Quin-1994]

While time is becoming increasingly scarce and many of the aspects described here have been known for a long time, "the sustainability and climate discourse focus on efficiency and eco-efficiency efforts, while the issue of sufficiency is repeatedly pushed into the background" [Bruh-2018].

> Let us dare to approach the painful questions that focus on the real causes! What is the good life? What do we really need and which values are important to us? And how do we finally manage to live according to our deeper insights and convictions in order to preserve the living space and civilisation of the earth? [Bruh-2018]

5.5.5 Compensation, Offsetting, Gain Time

With his book "Der Milliarden-Joker" (the Billion Joker) [Rade-2018], on which this chapter is primarily based, Radermacher presents an opportunity to create short-term climate relief through voluntary compensation of CO_2 emissions and thus gain time for further necessary medium and long-term measures.

5.5.5.1 Time Emergency

The expectations of the governments of our planet to solve sustainability problems (climate crisis, injustice, etc.) by a worldwide common political approach are exaggerated and have unfortunately also proven to be unrealistic. The political capacity

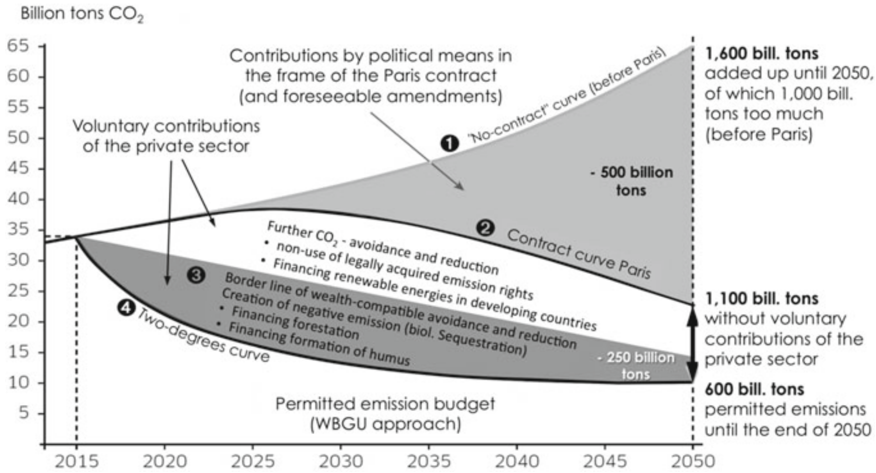

Fig. 5.10 Contributions required to achieve the 2-target after the Paris Agreement [Rade-2018]

manifested in the Paris Climate Agreement is not sufficient to bring the temperature increase caused by the climate crisis below 2 °C or even below that of the Earth's surface towards 1.5 °C.

The existing voluntary, governmental commitments to reduce CO_2 (Nationally Determined Contributions—NDC) under the Paris Climate Treaty may be sufficient to limit global warming to around 3 °C in relation to the pre-industrial age and would already have to be improved for this purpose (curve (2) in Fig. 5.10). In addition, implementation is highly uncertain, as there are no sanctions for non-compliance and the USA will withdraw from the treaty when it comes into effect in 2020.

However, even these necessary changes cannot be implemented in the short term by avoiding and reducing emissions without economic conflicts, especially in the developed industrialized countries. What is needed is time to implement political agreements, to convert the economy to climate "friendly", to make innovations, e.g. the methanol strategy [Rade-2018], applicable on a large-scale and to give room to the development of sufficient lifestyles. And this time corridor for changes in the economy, in lifestyles, for innovations in energy supply, for the development of synthetic fuels must be created in the short term—i.e. now!

In order to achieve the 2 °C target (curve (4) in Fig. 5.10) and close the so-called "Paris gap", reductions of a further approx. 500 billion t CO_2 are required, of which about half can be achieved by biological sequencing, the other half by avoidance and reduction strategies (curve (3) in Fig. 5.10). Both areas can be tackled in the short term and lead to a relief of the climate crisis if the money necessary for implementation is made available (e.g. through voluntary "lost" investments).

5.5.5.2 Prevention and Mitigation Strategies

Modern technologies, especially innovations in the energy and building sectors, can help to decouple economic growth from environmental degradation and avoid CO_2 emissions. These innovations will have the greatest effect not where the technical level is already far advanced, but where the potentials for improvements using small funds are still greatest, where existing funds can be used efficiently: in the developing countries. Good examples of this are climate protection projects in Africa, Asia and Latin America, which replace fossil energy conversion with renewable energy supply systems: Provision of efficient cooking facilities, decentralized electricity generation from wind and water power or solar energy, cooking with biogas from agricultural waste, promotion of environmental education, etc.

Just as with the creation and causation of environmental problems, the solution must also be thought of globally. Compensation payments for (as yet) unavoidable CO_2 emissions can help to solve social problems of distributive justice via co-benefits and contribute to technology transfer if measures can be implemented with as little corruption and wear and tear as possible, i.e. with low transaction losses, in the countries of the global south. To this end, projects should be validated by independent auditors and checked for additionality and savings. The most stringent standard available is the Gold Standard under the Clean Development Mechanism (CDM Gold Standard). Through the CDM, savings of CO_2 emissions through projects in developing and emerging countries are internationally recognized (according to the Kyoto Protocol) and support climate-friendly development [Atmo-2019].

Another possibility is the retirement of CO_2 certificates from the European Union Emissions Trading System(EU ETS). If certificates are bought and not used (decommissioned), the politically controlled cap is undercut, the number on the market is reduced, the certificates become expensive, and the market pressure in the trade increases, and with it the incentives to save CO_2.

5.5.5.3 Negative Emissions

While technical sequestration processes (such as Carbon Capture and Storage—CCS) are used to capture CO_2 emissions, for example from fossil combustion processes, and prevent them from being released into the atmosphere, biological sequestration can be used to extract existing CO_2 quantities from the atmosphere and bind them.

An essential biological sequestration measure is the planting of trees (and other woody plants). A beech tree, for example, can bind 12.5 kg CO_2 per year after the first few years through its growth. Here, too, this can be implemented much more cheaply in developing countries, while at the same time creating win–win situations through additional jobs and supporting sustainable, climate-friendly development in non-industrialized countries (see here the Plant-for-the-Planet children and youth initiative). If the afforestation of degraded areas at the edge of tropical rainforests is pursued, this can additionally prevent drying out and preserve the threatened microclimate of the rainforests (one of the tipping points as per Sect. 5.1.1). This measure also includes the prevention of clearing and paid protection of rainforests [Rade-2018].

Other measures include humus formation through organic farming (see Sect. 5.1.2 Soil degradation), the preservation and promotion of moors and wetlands, the renaturation of degraded soils using biochar[22], and methane management in rice cultivation [Rade-2018].

5.5.5.4 The Polluter Pays Principle—The Top Emitters

As described at the beginning of this Section, politics alone cannot reduce global warming to a hopefully tolerable level. Financial resources are required which are to be used as "lost contributions" for short-term compensation measures. The argument of the polluter pays principle comes into play here: Those who bear the main responsibility for global warming and CO_2 emissions should also make a significant contribution to tackling the problem.

Radermacher identifies this group of "top emitters" among people with an "elaborate lifestyle and a wide range of activities", which can be found in all parts of the world, but in very different concentrations. The richest 10% of the world's population is responsible for about half of the CO_2 emissions. The top emitters and the companies and organizers associated with them are not only the main causes of the problem, they are also the ones who have the necessary means and who benefit most from avoiding a collapse, thus securing their "lifestyle and property titles" [Rade-2018]. It is therefore expected that these top emitters, with reasonable insight, will voluntarily make these "lost investments" and take a climate-neutral or climate-positive stance[23]. Politicians can recognize, support and encourage this and should at least recognize compensation payments as operating expenses.

Politics and public administration should also set a good example in this respect. The municipalities, cities, federal states, and the federal government are responsible for the "grey emissions" of public infrastructure with their properties and their activities. In the personal CO_2 footprint according to the Federal Environment Agency, this amounts to 0.73 tCO_2 per inhabitant and year. After all, the German government has set the goal of a climate-neutral federal administration in the German sustainability strategy, and the federal states of North Rhine-Westphalia and Hesse are striving for climate neutrality under the maxim "avoid, reduce, compensate".

> The Federal Environment Ministry and the Federal Development Ministry have set themselves the goal of becoming climate neutral by the end of 2020. Both ministries use EMAS (Eco-Management and Audit Scheme) to manage the process. [BuRe-2018]

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[22]The origins of bio- or vegetable coal can be found among the indigenous people of the Amazon region hundreds or thousands of years ago. The coal is produced by heating organic materials and mixed into fertile soil—terra preta.

[23]Among the DAX-30 companies, Allianz and Deutsche Bank have announced that they will make their business activities climate-neutral [Rade-2018].

5.5.5.5 Personal Responsibility—Simply | Do It Yourself

The market is formed directly (Business-to-Consumer B2C) or indirectly (Business-to-Business B2B) by a sum of individuals in their function as consumers. The effects of satisfying consumer "needs" can thus be individually assessed. This means that every citizen is once again addressed personally. With an average German CO_2 balance of 11.6 tCO_2 per person and year [UBA-2019], it is frighteningly cheap to compensate for climate neutrality. At "atmosfair" or "klimaohnegrenzen" (climate without borders) one can currently be climate-neutral for about 260 €/person and year! This corresponds to about 22–23 € per tCO_2 per year. Both organizations base their calculations on compensation measures in the form of projects registered according to the CDM Gold Standard and thus on the best ranking [Atmo-2019]. The children and youth initiative Plant-for-the-Planet and many other initiatives can also be used, depending on different individual interests.

The emission certificates in the EU emissions trading system—although their price has almost tripled since the beginning of last year—stood at around EUR 20 in September 2018. However, it is expected that after the reform of emissions trading, which is to come into force in 2019, prices will rise to an average of €35 to €40 per tonne by 2023, which would also result in new economic conditions for coal-fired power plants. If Radermacher's goal of saving 500 billion tons of CO_2 to close the "Paris gap" is to be achieved, the "certificate market must be dramatically expanded" [Rade-2018]. Many more projects need to be initiated and Africa in particular could (and should) be supported by new meaningful jobs.

Compensation is also critically and often condescendingly referred to as selling indulgences (and then used as personal justification for not participating and saving the money). However, the plan to gain a better conscience through compensation requires at least responsible consideration when considering whether to take a flight, for example! Thus this "indulgence trade" does not result from belief in personal advantage (salvation of the soul) but from knowledge of social responsibility. A study that proves that especially people who are already sensitized compensate their CO_2 emissions, in this case mainly flights, is used as an argument that compensation is not used to carelessly pollute their environment with CO_2.

> There was general agreement that people who offset climate-damaging emissions from their consumption behaviour tend to adopt a more sustainable lifestyle in other ways. This means that compensation payments are by no means seen as a free purchase or carte blanche, but as an additional opportunity for climate-protecting action. [UBA-2014]

Conversely, however, this also means that people who are not sensitized, the "environmental sinners", are not, or less so, thinking about compensation! Is it then possible to persuade the top emitters or a sufficient number of them to "voluntarily" make the required contribution beyond symbolic contributions for marketing purposes? Are "lost investments" to be expected voluntarily and outside of market constraints if, on the other hand, every tax loophole is exploited and cheap software tricks are used instead of existing but more expensive innovation? Will the top emitters show insight into the necessity? Even if it is only in the hope of securing their property and lifestyle, it would be desirable! Or are they more likely to follow the path of Donald Trump's renationalisation and protectionism?

5.5.6 Implementation Concepts—Summary

To summarize the previous chapters, a pictorial comparison from the field of medicine is permitted:

The patient No. 1 is our earth, which must be certified as a metabolic disease. The pathological deviations from normal, tolerable metabolic processes result, on the one hand, from an excess of emissions, in this case mainly greenhouse gases, which is manifested by fever symptoms (global warming).

If the normal temperature is exceeded by one degree in humans, they already feel uncomfortable. A critical condition with necessary observation is seen from two degrees and from three degrees temperature increase it becomes life-threatening without medical treatment. However, fever also has a positive function in the human body, because an increase in temperature weakens or eliminates invaders such as viruses, bacteria and other parasites. On the other hand, deficiency symptoms, which our earth shows, can be recognized by a lack of, an overexploitation of resources. The symptoms here include loss of biodiversity and soil degradation.

Patient No. 2 is the "super-organism of mankind" as RADERMACHER calls it [RaBe-2011]. Here the diagnosis is behavioural disorder and addiction symptoms. The behavioural disorders manifest themselves, on the one hand, in parasitism towards patient No. 1, who fights back with fever, and, on the other hand, in signs of indirect cannibalism towards his fellow human beings and fellow men. The addiction phenomenon is expressed in its dependence on consumption and growth constraints.

The previous sections describe the symptoms and different therapeutic approaches. The strategy of sufficiency and the ICH concept (see Sect. 5.5.4) are primarily aimed at curing the behavioural disorder in patient 2 (therapy: return to "human scale" and harmony with nature) and could thus also indirectly, but in the long term (in homeopathic doses) save patient 1.

Efficiency and consistency as well as the concepts of system repair (eco-social market economy) and economy using these strategies, on the other hand, primarily treat the metabolic problems of patient 1 (therapy: efficient, market-regulated use of finite resources and economies in cycles), are to be assessed rather as conventional healing methods and leave the complicated patient 2 largely "alone".

The concept of post-growth economics takes into account the diagnosis of patient 1 but tries to treat his disease simultaneously with the disease of patient 2 (radical restructuring of economy and society), which, however, requires a long rehabilitation process.

The concept of compensation could reduce the fever to a tolerable level in the short term or delay a further increase in order to create sufficient time for the healing of the basic problems/illnesses. This "pill" would have to be prescribed to patient 2 and may cause conflicts with his behavioural disorder.

While medicine here serves only—roughly simplified—for comparison purposes, the different disciplines of the cited literature show the extreme interdisciplinary requirements that arise when dealing with and solving sustainable problems.

From childhood on, and unfortunately all too often continued in the course of studies, however, we are taught and learned in subjects and drawers, which—in contrast to the complex reality outside—creates in our minds thinking in disciplines, industries and resources within the framework of an artificial classification universe. On the contrary, reality, the world outside, is a highly interconnected structure of effects with interactions between the elements that vary in strength.

> Once the static of a system is fundamentally disturbed, the negative factors add up. [Mead-2000]

Particularly at the present time, when the level of development is at a turning point when even small influences can have a major impact (see the tipping points already mentioned several times) and when the complexity of the world is increasing, experience and knowledge of complex systems are absolutely essential. Unfortunately, it is becoming more and more difficult and hardly affordable for individuals to grasp the problems in their causal structure, to bring the interactions in the structures into context, and to work out possible solutions. In addition, complex problems in a fast-moving age with an ever decreasing ability to concentrate on one problem are difficult to communicate to all population groups. This educational vacuum or deficit is currently being penetrated by nationalist charlatans with one-dimensional enemy images and simple sham solutions, collecting disoriented people and giving them new, but unfortunately false hopes.

Theorem 1 Sustainability requires interdisciplinary cooperation and networked thinking for complex systems in a global context.

In the energy turnaround—a partial aspect on the way to sustainability—fossil energy sources cannot be replaced by a universal energy conversion method, but rather a mix of different renewable energy sources, efficient use and energy saving by doing without, e.g. energy-intensive mobility, is required. To achieve a sustainable state of our world—as described above using the example of the energy system transformation—the possibilities and measures are manifold. Some actors are already on their way with different ideas and different approaches will also be required for this task! There's no silver lining. All possibilities must be used!

The sufficiency strategy, the testing of alternative approaches and lifestyles in small, decentralized groups and clearly structured regions, can show a way to a "compatible, humane level" in harmony with natural possibilities. Here a slow-growing or better spreading, trying out and gaining experience is possible. Also included is the failure of individual attempts without causing much damage.

> The growing number of people who dare to start with contradictions represents a greater potential for change than a few who behave in a fundamentally different way. More people can identify with contradictions, ambivalences and beginnings than with fundamentalists. (Micha Hilgers, in [Linz-2004])

The strategies of efficiency and consistency can be used for the long-term transformation of industrial production in an eco-social market economy, a steady-state, or even a post-growth economy. In the case of efficiency, rebound effects must be prevented in order not to eat up the resource productivity that can be increased through innovation. Building consistent cycles also require technical developments and takes time. Economic restructuring can only be thought of globally and requires global governance that sets the planetary guard rails.

The (immediate) compensation of climate emissions through voluntary and administrative "lost" financing subsidies attack the most urgent problem of the climate crisis in order to gain the necessary time for social transformation. The compensation measures as well as avoidance and mitigation approaches must be thought of globally in order to use the available financial resources well where the greatest effects can be achieved and at the same time create co-benefits for the holistic implementation of Sustainable Development Goals. This requires differentiated, internationally coordinated cooperation.

Theorem 2 There is no general concept to solve the problem and no experience with it. The problem is existential. It is not helpful to fight each other. Many things must be tried out in parallel, as interlocked as possible and as immediately as possible.

> It is about a new social contract for a climate-friendly and sustainable world economic order. Its central idea is that individuals and civil societies, states and the international community, as well as business and science, assume collective responsibility for preventing dangerous climate change and for averting other threats to humanity as part of the Earth System. The social contract combines a culture of mindfulness (out of ecological responsibility) with a culture of participation (as democratic responsibility) and a culture of commitment to future generations (responsibility for the future). [WBGU-2011]

In the current capitalist economic and social system, a mixture of market, competition and growth (belief) is the fuel that drives the Titanic. The presence of icebergs is well known and experience teaches that only a small part of the problems are visible. It was overslept, exploring the terrain far enough ahead (or warnings were ignored) and now the course must be drastically corrected to avoid collisions. Attention: Their high inertia and long "braking distances" make manoeuvring even more difficult!

But perhaps the salvation lies not in the large, innovative, technically "unsinkable" promise of a "titanic" Noah's Ark, but in small, flexible, agile units that adapt to the natural swell and do not try to fight it? If humans see themselves as outsiders, as the rulers of the environment (problems) and not as part of nature, changes will be difficult to implement.

> It is rather a matter of completely rethinking the whole system of human development. … If mankind wants to solve its environmental problems and build a better world it will have to question almost everything that has seemed normal to it so far. [Maxt-2018]

Therefore, it is not very helpful to prove only possible errors of reasoning in other concepts. The different concepts should be better examined for interlocking possibilities, chronological sequence and common potentials.

Theorem 3 Question everything! Humility, not cockiness! Seeing man as part of nature!

Each individual needs more attention and mindfulness towards the convenient, simple solutions but also towards themselves. Intellectuals such as ILLIC, who sees individual autonomy lost through industrialization, or KNOFLACHER, who demonstrates with his walking gear how much space we give to the car (on the planet and in our heads) [Knof-2009], provoke consciously and stimulate reflection on inhuman "normalities". Only by taking a closer look, reflecting critically and "thinking for yourself" can it be recognized what is valuable, useful and worth preserving in the light of all its effects. And, of course, what is important to you is what is "human scale".

While on the one hand existing things have to be questioned in the way described above, alternative, new ideas are needed to solve the problems at hand. The German magazine for future and politics taz. Futurzwei entitled "Whoever has no visions should go to the doctor" in reversal of a quotation from Helmut Schmidt.

> The real challenge of the twenty-first century is … to continue to think and build on the civilizing project of modernity. A radical modernisation project, the reintroduction of FUTURE into politics.
>
> The future of today is no more: less inequality, more humanity, fairer distribution, a pacified natural relationship. It is: a consumer hell on a global scale.
>
> The fact that this cannot go well creates the diffuse but pressing basic feeling. The more neurotically politicians cling to the (old) recipes, the clearer it becomes why the mental budget of the republic is currently vibrating. It remains unclear, however, who can ultimately build the political sounding board for these vibrations. (H. Welzer in [tazF-2018])

Theorem 4 We need provocations to recognize what is bad about the old, as well as visions to think new.

No one has to wait for the visions of the politicians but can instead become active themselves. RANDERS formulated this appeal as follows:

> But what can and should each and every one of us do in this matter? I believe that everyone should publicly declare themselves in favour of reducing emissions, point out that climate change is a serious problem and that countermeasures must be taken as soon as possible, that

a solution is technically possible and relatively cheap, and that they themselves are prepared to bear their share of the costs if the majority decides to do so. If, in addition, you prove in your daily life how easy it is to reduce greenhouse gas emissions through your personal lifestyle, then I believe you have done more than your duty. For you have contributed to the political decision-making necessary to initiate and support a clear and targeted step towards a climate-friendly future. But as you know from my forecast, this step will unfortunately probably not be taken on a large-scale until much later, in the 2030s. [Rand-2012]

Theorem 5 Begin! Preferably with yourself! Seek allies!

All … data is publicly available and widely known. The almost unbelievable fact is, however, that no serious efforts have yet been made to avert the fate that has been announced to us. While in private life only a madman would remain inactive in the threat to his entire existence, those responsible for the public good do practically nothing, and those who have entrusted themselves to them let them go. [From-1976]

To put the quote from Erich FROMM into concrete terms: It is not only the data (raw material, e.g. temperature measurements) that are known and information derived from them (structured data, e.g. time series, courses, temperature rise, if necessary with regional reference). The necessary empirical knowledge (information with interrelationships, cause-effect relationships, for example, the hypothesis of global warming and statistically reliable verification of this hypothesis) is also available to mankind. There is knowledge of who the main polluters, the top emitters, are—people with an elaborate lifestyle and the value-added and service processes required for this lifestyle (fossil energy industry, industrial agriculture, etc.). However, the ecological footprint also reveals starting points for change and where the most important adjustment screws, the big points, lie (flying, meat, heating, hyper-consumption).

From the footprints result starting points and options for action for each individual, depending on his or her individual knowledge, abilities and skills as well as possibilities for action. The prerequisites (satisfied basic needs, freedom of decision, attitudes, empathy, etc.) and the skills learned from them form the basis for action. With the appropriate motivation, this leads to a change in behaviour and sustainable action. Through active participation, not only less bad (reduced footprint) can be achieved, but also a positive effect through so-called handprints. The possibilities and fields of action are manifold:

- **Individual** behavioural change in consumption, housing, nutrition and mobility,
- Generate **social** pressure and give politicians legitimacy, incentives and compulsion to act,
- Become **active** in civil society or political organizations, planting trees and helping others to take positive action,
- **Joint** testing of alternative economic and living forms in "real laboratories",
- **Professional** influence on the sustainable design of processes, products and services.

The hope for political change or the self-awareness of the major global players in the economy to voluntarily conserve resources and protect the climate tends to lead to personal passivity—and contains a huge potential for frustration.

Each individual can alternatively and actively act in the immediate vicinity, seek allies and jointly engage in empowerment (inciting the (re-)acquisition of self-determination over the circumstances of their own lives). Such an approach is doubly profitable. It increases personal competence, creates social community and helps the climate and humanity for the future. Lack of time is not an argument here, because not starting does not bring improvement.

> To make a difference, you don't need a majority. 80% of changes are made by very few people. Find a few and make them powerful. [Mead-2000]

References

[Aach-2018] Aachen Foundation Kathy Beys: Encyclopaedia of Sustainability. https://www.nachhaltigkeit.info/artikel/steady_state_economy_1848.htm. Accessed 29 Dec 2018

[Acos-2017] Acosta, A.: Buen Vivir. The Right to a Good Life. oekom, Munich (2015)

[Andr-2016] Andreucci, D., McDonough, T.: capitalism. In: D'Alisa, G., Demaria, F., Kallis, G. (eds.) DEGROWTH. Manual for a new era. oekom, Munich (2016)

[Alex-2016] Alexander, S.: Basic and maximum income. In: D'Alisa, G., Demaria, F., Kallis, G. (eds.) DEGROWTH. Manual for a new era. oekom, Munich (2016)

[Alt-2008] Alt, F.: Sunny prospects. How Climate Protection Becomes a Win-Win Situation for All. Gütersloh Publishing House (2008)

[ASPO-2018] http://aspo-deutschland.blogspot.com/p/peak-oil.html. Access 9 Dec 2018

[Atmo-2019] https://www.atmosfair.de/de/standards/zulassung_und_standards/. Access 12 Feb 2019

[Bard-2013] Bardi, U.: The Plundered Planet. oekom Verlag (2013)

[Baue-2008] Bauer, J.: Industrial ecology. Theoretical approach to a concept of sustainable production methods. Dissertation, University of Stuttgart. https://elib.uni-stuttgart.de/bitstream/11682/5515/1/Dissertation_Bauer_.pdf (2008). Access 20 Feb 2019

[Baum-2002] Baumann, Z.: Dialectics of order. Modernity and the Holocaust. Europäische Verlagsanstalt, Hamburg (2002)

[Bern-2012] Berner, A., Böhm, H., Brandhuber, R., Braun, J., Brede, U., Colling-von-Roesgen, J.L., Demmel, M., Dierauer, H., Doppler, G., Ewald, B., Fisel, T.: Basic principles of soil fertility-develop the relationship to the soil. Research Institute of Organic Agriculture (FiBL), Bio Austria, Bioland Beratung GmbH, Bio Suisse and IBLA Luxembourg. http://orgprints.org/21814/ (2012). Access 02 Feb 2020

[BioÖ-2016] Useful Diversity: Biodiversity as a Resource. 12.07.2016. https://biooekonomie.de/nuetzliche-vielfalt-biodiversitaet-als-ressource-0. Access 13 Dec 2018

[Blac-2009] Black, M., King, J.: The Water Atlas. EVA European Publishing House, Hamburg (2009)

[BMU-2004] BMU: RENEWABLE ENERGIES Innovations for the Future. https://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/broschuere_ee_innov_zukunft.pdf (2004). Access 10 Dec 2018

[BMWI-2018] https://www.bmwi.de/Redaktion/DE/Infografiken/Energie/Energiedaten/Energie-und-Umwelt/energiedaten-energie-umwelt-17.html. Access 21 Jan 2019

[BPB-2018] Dossier anthropocene. The Great Acceleration. http://www.bpb.de/gesellschaft/umwelt/anthropozaen/216918/die-grosse-beschleunigung-the-great-acceleration. Access 13 Dec 2018

[Brau-2003] Braungart, M., McDonough, W.: Simply Producing Intelligently. Berlin Paperback Publisher, Berlin (2003)

[Bruh-2018] Bruhn, T.: Through mindfulness to a climate-friendly life. IASS Blog 2018. https://www.iass-potsdam.de/de/blog/2018/30/durch-achtsamkeit-zum-klimavertraeglichen-leben. Access 05 Feb 2019

[Bru2-2018] Bruhn, T.: Towards a mindset for the anthropocene. Facilitating Sustainability Through "Inner" Transformation? Lecture on the 5th ÖSHT, Magdeburg. 01.06.2018

[Brun-1987] Brundtland Commission. In: V. Hauff (ed.) Our Common Future. Oxford University Press (1987)

[Brun-2010] Brunner, A., Kägi, E., Renner, E.: The Capital Stock Model as a Basic Concept for Sustainable Development. https://digitalcollection.zhaw.ch/bitstream/11475/120/1/1033991198.pdf (2010). Accessed 28 Dec 2018

[BSDC-2017] Business and Sustainable Development Commission. Better Business better world. London 2017. http://report.businesscommission.org/uploads/BetterBiz-BetterWorld_170215_012417.pdf, Accessed on 20 February 2019

[BUND-2002] BUND and UnternehmensGrün (ed.): Zukunftsfähige Unternehmen. oekom Verlag, Munich (2002)

[BuRe-2018] Federal Government of Germany: German Sustainability Strategy. Update. https://www.bundesregierung.de/resource/blob/975292/1559082/a9795692a667605f652981aa9b6cab51/deutsche-nachhaltigkeitsstrategie-aktualisierung-2018-download-bpa-data.pdf (2018). Access 11 Feb 2019

[Carl-1713] von Carlowitz, H.C.: Sylvicultura Oeconomica or Household message and Natural instruction for the Wild Tree Breeding. Reprint of the 2nd resection. Leipzig, Braun, 1732. Remagen-Oberwinter: Boilers (1. 1713)

[Daly-1974] Daly, H.E.: Steady-state economics versus Growthmania: a critique of the orthodox conceptions of growth, wants, scarcity, and efficiency. Policy Sci. **5**(2), 149–167 (1974)

[Diam-2005] Diamond, J.: Collapse. Why Societies Survive or Perish. S. Fischer Verlag, Frankfurt am Main (2005)

[DieW-2018] https://www.die-wirtschaft.at/die-wirtschaft/agenda-2030-klappt-die-rettung-der-welt-162675. Accessed on 23 Dec 2018

[Ditt-2016] Dittmer, K.: Alternative currencies (regional money). In: D'Alisa, G., Demaria, F., Kallis, G. (eds.) DEGROWTH. Manual for a new era. oekom, Munich (2016)

[DeIW-2010] DIW: Unconventional gas resources unexpectedly large. Berlin. https://www.diw.de/documents/publikationen/73/diw_01.c.357509.de/10-24-3.pdf (2010). Access 9 Dec 2018

[DeSW-2018] German Foundation for World Population: DSW Data Report. https://www.dsw.org/wp-content/uploads/2018/08/DSW-Datenreport-2018_final.pdf (2018). Accessed 18 Dec 2018

[Eche-2013] Peter Echevers, H.: Tendencies 3000—quo imus? LULU Press Enterprises (2013)

[Ehrl-1990] Ehrlich, P.R., Ehrlich, A.H.: The Population Explosion. Simon and Schuster, New York (1990)

[Ekar-2017] Ekardt, F.: We can Change: Social Change Beyond Criticism of Capitalism and Revolution. oekomon Verlag, Munich (2017)

[Ekar-2018] Ekardt, F.: Paris Agreement, Human Rights and Climate Complaints. https://www.sfv.de/pdf/ParisSFV7.pdf (2018). Access 19 Jan 2019

[Elle-2016] EllenMacArthurFoundation: The New Plastics Economy: Rethinking the Future of Plastics. https://www.ellenmacarthurfoundation.org/publications/the-new-plastics-economy-rethinking-the-future-of-plastics (2016). Access on 7 Dec 2018

[EnKo-1998] Enquete Commission: Protection of Humanity and the Environment—Objectives and Framework Conditions for Sustainable Development. Final Report. http://dip21.bundestag.de/dip21/btd/13/112/1311200.pdf (1998). Accessed 27 Dec 2018

[EnKo-2013] Final Report of the Enquete Commission: Growth, Prosperity, Quality of Life. http://www.bpb.de/system/files/dokument_pdf/schlussbericht_Enquete-Kommission_WWL.pdf (2013). Accessed 21 Jan 2019

[FiBL-2013] Forschungsinstitut für biologischen Landbau (FiBL) (eds.): Principles of soil fertility. https://shop.fibl.org/chde/mwdownloads/download/link/id/552/ (2013). Accessed on 05 February 2019

[Fran-2013] Franken, M.: Report from the future. Heinrich Böll Foundation (ed.). oekomon Verlag, Munich (2013)

[From-1976] Fromm, E: To Have or To Be. German Paperback Publisher, Munich (1976)

[From-2005] Fromm, E.: The Pathology of Normality: On the Science of Man. Ustein Paperback, Berlin (2005)

[Fuss-1999] Fussler, C.: Eco-Innovation. S. Hirzel Publishing House, Stuttgart, Leipzig (1999)

[GEAS-2014] UNEP Global Environmental Alert Service: Sand, Rarer than One Thinks. http://na.unep.net/geas/archive/pdfs/GEAS_Mar2014_Sand_Mining.pdf (2014). Accesses on 2 February 2020

[GloM-2019] https://www.globalmarshallplan.org/in-5-minuten/. Access 18 Dec 2019

[Gore-2009] Gore, A.: We have a choice. A Plan to Solve the Climate Crisis. Riemann Publishing, Munich (2009)

[GPRI-2015] Global Phosphorus Research Initiative: GPRI Submission to the EU Public Consultation on the Raw Materials Initiative. http://phosphorusfutures.net/wp-content/uploads/2015/02/GPRI_submission_EU_CriticalRawMaterials.pdf. Accessed on 11 December 2018

[GrJo-2019] https://gruener-journalismus.de/schwerpunkte/nachhaltigkeit/. Accessed on 01 Jan 2019

[Grun-2007] Grundmann, E.: Forests we kill. About Forest Destruction, Climate Change and Human Reason. Riemann Publishing House, Munich (2007)

[Hoor-2013] Hoornweg, D., Bhada-Tata, P., Kennedy, C.: Waste production must peak this century. In: Nature, vol. 502, S. 615. https://www.iswa.org/fileadmin/galleries/News/NATURE_Comment_waste.pdf (2013). Accessed on 31 Oct 2013

[Hopk-2014] Hopkins, R.: Simple. Now. Do it! How We Take Our Future into Our Own Hands. oekom, Munich (2014)

[Hube-1999] Huber, J. Industrial ecology—consistency, efficiency and sufficiency in cycle analysis. Lecture script of the "Global Change" VDW Annual Conference, Berlin, 28–29 October 1999. Berlin. http://www.rla-texte.de/texte/16%20Lehre%20Regional%C3%B6konomie/Huber%20industrial%20umweltkonsistenz.pdf (1999). Access 06 Jan 2019

[IPCC-2014] Intergovernmental Panel on Climate Change: Climate Change 2014: Synthesis Report. Summary for Policymakers. https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf. Accessed on 9 December 2018

[IPCC-2018] Intergovernmental Panel on Climate Change: Global Warming of 1.5 °C. Summary for Policymakers. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf (2018). Accessed on 20 February 2019

[Jens-2011] Jensen, A.: We Increase the Gross National Happiness: Of People Who Manage Differently and Live Better. Publisher Herder GmbH (2011)

[Knof-2009] Knoflacher, H.: Standing Vehicles: Traffic Jams are Not a Traffic Problem. Böhlau Publishing House, Vienna (2009)

[Kopa-2015] Kopatz, M.: Economic Development 4.0. In: Human Economy 06/2015. https://humane-wirtschaft.de/2015_06/HW_2015_06_S04-06.pdf. Accessed 05 Jan 2019

[KPMG-2017] KPMG. The Roadhead. The KPMG Survey of Corporate Responsibility Reporting. https://assets.kpmg/content/dam/kpmg/at/pdf/studien/KPMG_Survey_of_Corporate_Responsibility_Reporting_2017.pdf/jcr:content/renditions/original (2017)

[KuLa-2015] Cultivated land cooperative. Circular 5. https://kulturland.de/download/circulars/circular_no.5.pdf (2015). Access 05 Feb 2019

[Lal-2004] Lal, R.: Soil carbon sequestration impacts on global climate change and food security. Science **304**, 1623–1627 (2004)

[LebM-2012] Lebensministerium (ed.): Growth in Change: Alternative Economic and Social Concepts. Vienna. https://www.nachhaltigkeit.info/media/1384510357phppDcfjA.pdf?sid=qllae5it2mrut0lobaiua572b1 (2012). Access 11 Jan 2019

[Lent-2008] Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., Schellnhuber, H.J.: Tipping elements in the earth's climate system. PNAS **105**(6), 1786–1793 (2008); published ahead of print February 7, 2008

[Lesc-2017] Lesch, H.: Humanity is abolishing itself. The Earth in the Grip of the Anthropocene. KOMPLETT Media, Munich/Grünwald (2017)

[Leup-2012] Leuphana Universität Lüneburg and Centre for Sustainability Management. Corporate Sustainability Barometer. http://www2.leuphana.de/csm/CorporateSustainabilityBarometer2012.pdf (2012). Accessed on 2 February 2019

[Linz-2004] Linz, M.: Neither lack nor excess: On sufficiency and sufficiency research. Wupper Papers 145th Wuppertal Institute. https://www.econstor.eu/bitstream/10419/21832/3/WP145.pdf (2004). Access on 05 January 2019

[Loew-2011] Löwenstein, Felix zu: Food Crash. Wir werden uns ökologisch ernähren oder gar nicht mehr. Pattloch Verlag München (2011)

[Masl-1977] Maslow, A.: Motivation and Personality. Walter-Verlag, AG, Olten (1977)

[Maxt-2018] Maxton, G.: CHANGE! Why We Need a Radical Change. Complete Media, Munich/Grünwald (2018)

[Mead-1972] Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W. III: The Limits to Growth. Universe Books (1972)

[Mead-2000] Meadows, D.: Growth is followed by decline. In: Aachen Foundation Kathy Beys (Hrsg) Perspectives Opportunities Sustainability. Aachen. https://www.aachener-stiftung.de/fileadmin/ASKB/Media/forum_2000_01-1.pdf (2000). Access 21 Jan 2019

[Mull-2017] Muller, A., Schader, C., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Klocke, K., Leiber, F., Stolze, M., Niggli, U.: Strategies for feeding the world more sustainably with organic agriculture. Nat Commun **8**, 1290. https://doi.org/10.1038/s41467-017-01410-w (2017)

[NABU-2018] https://www.nabu.de/umwelt-und-ressourcen/gesellschaft-und-politik/deutschland/sdgs/20925.html. Access 13 Dec 2018

[Neir-1997] Neirynck, J.: The Divine Engineer—The Evolution of Technology. Publisher: Expert (1997)

[OECD-2003] Organisation for Economic Co-operation and Development. OECD Environmental Indicators. Development, Measurement and Use. Reference Paper. Paris. https://www.oecd.org/env/indicators-modelling-outlooks/24993546.pdf (2003). Accessed on 27 November 2018

[ÖkoI-1999] Öko-Institut (ed.): Henseling, C., Eberle, U., Grießhammer, R.: Soziale und wirtschaftlichen Nachhaltigkeitsindikatoren. Freiburg 1999. https://www.oeko.de/oekodoc/79/1999-007-de.pdf. Access 27 Dec 2018

[Ott-2005] Ott, K. In: Mappus, S. (eds.) Earth 2.0 Technological Innovations as an Opportunity for Sustainable Development. Jumper, Berlin, Heidelberg (2005)

[Paec-2012] Paech, N.: Liberation from abundance. On the Way to the Post Growth Economy. oekom, Munich (2012)

[Prid-2017] Priddat: Growth Narratives. https://www.econstor.eu/bitstream/10419/173381/1/1011580438.pdf (2017). Access 14 Jan 2019

[Quin-1994] Quinn, D.: Ishmael, 6th edn. Goldmann Publishing House, Munich (1994)

[RaBe-2011] Radermacher, F.J., Beyers, B.: World with a future. The Ecosocial Perspective. Murmann Publishing House, Hamburg (2011)

[Rade-2014] Radermacher, F.J.: Sustainability. In: Vajna, S. (eds.) Integrated Design Engineering. An Interdisciplinary Model for Holistic Product Development. Springer, Berlin, Heidelberg (2014)

[Rade-2018] Radermacher, F.J.: The billion dollar joker. How Germany and Europe can Revolutionise Global Climate Protection. Murmann Publishers, Hamburg (2018)

[RaMa-2016] Randers, J., Maxton, G.: One Percent is Enough. oekom, Munich (2016)

[Rand-2010] Randers, J.: Climate Post COP15 in a Limits to Growth Perspective. Peder Sather Symposium, Berkeley. https://slideplayer.com/slide/7761336/ (2010). Accessed on 10 December 2018

[Rand-2012] Randers, J.: 2052—The New Report to the Club of Rome. oekom, Munich (2012)

[RaOS-2009] Radermacher, F.J., Obermüller, M., Spiegel, P.: Global impact. The New Path to Global Responsibility. Carl Hanser, Munich (2009)

[RaRW-2011] Radermacher, Franz Josef, Riegler, Josef: Weiger. Ecosocial Market Economy. oekom Munich, Hubert (2011)

[Rock-2009] Rockström, J. et al.: Planetary boundaries: exploring the safe operating space for humanity. In: Ecology and Society. Band 14, Nr. 2, 2009

[Rock-2016] https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html. Accessed on 20 February 2019

[Schm-1997] Schmidbauer, W.: The new ethics of consumer renunciation. In: Schenk, H. (eds.) On the Simple Life. Search for Happiness Between Abundance and Asceticism. C.H. Beck, Munich, pp. 259–262 (1997)

[Schm-2007] Schmidt-Bleek, F.: Are we using the earth properly? The achievements of nature and the work of man. In: Wiegandt, K. (ed.) Forum for Responsibility. Fischer Paperback, Frankfurt am Main (2007)

[Schn-2015] Schnug, E., Ekardt, F., Haneklaus, S., Schick, J.: Phosphorus, agriculture and sustainable development. In: Ecology and Agriculture 3/2008. https://www.researchgate.net/profile/Ewald_Schnug/publication/283411473_Phosphor_Landwirtschaft_und_nachhaltige_Entwicklung/links/58ad3c80a6fdccac900b19ce/Phosphor-Landwirtschaft-und-nachhaltige-Entwicklung.pdf. Access 11 Dec 2018

[Scho-2016] Schor, J.B.: Redistribution of work. In: D'Alisa, G., Demaria, F., Kallis, G. (eds.) DEGROWTH. Manual for a new era. oekom, Munich (2016)

[Schr-2015] Schreiner, P.: "Sustainability"—neoliberally instrumentalized and diluted. In: Spotlight WiSo. 9 April 2015. https://www.blickpunkt-wiso.de/post/435/pdf/. Access 28 Dec 2018

[Schu-2013] Schumacher, E.F.: Small is beautiful. The Return to Human Scale. oekom Verlag, Munich (2013)

[Stah-2000] Stahel, W.: Use rather than own. In: Aachen Foundation Kathy Beys (Hrsg.) Perspectives Opportunities Sustainability. Aachen. https://www.aachener-stiftung.de/fileadmin/ASKB/Media/forum_2000_01-1.pdf (2000). Access 21 Jan 2019

[Stef-2015] Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S.: Planetary boundaries: guiding human development on a changing planet. In: Science (online first). https://science.sciencemag.org/content/347/6223/1259855/tab-pdf (2015). Accessed on 14 May 2019

[Sten-2011] Stengel, O.: Sufficiency—The Consumer Society in the Ecological Crisis. oekom Verlag, Munich (2011)

[TASI-2010] Franke-Wöller, C.: Recycling versus incineration. In: Waste Between Market and Environmental Protection. LOGISCH Publishing House, Magdeburg (2010)

[tazF-2018] Welzer, Harald: There's something in the air. In: taz.FUTURZWEI Nr. 4/2018 taz Berlin

[TheW-2018] https://www.die-wirtschaft.at/die-wirtschaft/agenda-2030-klappt-die-rettung-der-welt-162675. Access 23 Dec 2018

[UBA-2014] German Federal Environment Agency (Umweltbundesamt): Voluntary compensation payments and sustainable lifestyles: Do they go together? Documentation of the UBA conference on 10 November 2014 in Berlin. Texte 24/2015 https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_24_2015_freiwillige_kompensationszahlungen.pdf, Accessed on 12 December 2019

[UBA-2019] Federal Environment Agency: Climate neutral: The CO balance in view. http://www.uba.co2-rechner.de/de_DE/. Access 20 Feb 2019

[Ulgi-2016] Ulgiati, S.: Entropy. In: D'Alisa, G., Demaria, F., Kallis, G. (eds.) DEGROWTH. Manual for a new era. oekom, Munich (2016)

[Ullr-2008] Ullrich, W.: Want to Have: How Does Consumer Culture Work? S. Fischer Publishing House (2016)

[UNES-2017] UNESCO: World Education Report 2017–2018. https://www.unesco.de/sites/default/files/2018-01/UNESCO_Weltbildungsbericht_2017-2018_FINAL_01.pdf. Accessed 18 Dec 2018

[UNIC-2017] UNICEF: 2.1 billion people have no access to safe drinking water Media releases 12.07.2017. https://www.unicef.ch/de/ueber-unicef/aktuell/medienmitteilungen/2017-07-12/21-milliarden-menschen-haben-keinen-zugang-zu. Access 11 Dec 18

[Walk-2004] Walker, B., Holling, C.S., Carpenter, S.R., Kinzig, A.: Resilience, adaptability and transformability in social–ecological systems. Ecol. Soc. **9**(2), 5 [online]. http://www.ecologyandsociety.org/vol9/iss2/art5/ (2004). Accessed on 3 January 2019

[WBGU-2011] WBGU: World in Transition Social Contract for a Major Transformation. Major Appraisal. https://www.wbgu.de/fileadmin/user_upload/wbgu.de/templates/dateien/veroeffentlichungen/hauptgutachten/jg2011/wbgu_jg2011.pdf (2011). Access 20 Jan 2019

[WeAg-2009] World Agriculture Report. Synthesis Report. Hamburg University Press, Publishing House of the State and University Library Hamburg Carl von Ossietzky, Germany (2009)

[WEF-2019] World Economic Forum: WEF Global Risk Report. http://www3.weforum.org/docs/WEF_Global_Risks_Report_2019.pdf (2019). Access 16 Jan 2019

[WeLo-1997] von Weizsäcker, E.U., Lovins, A.B., Lovins, L.H.: Factor four. Double Prosperity—Halved Consumption. Knaur, Munich (1997)

[Welz-2013] Welzer, H.: Even thinking. A guide to resistance. Fischer Paperback Frankfurt am Main, 2013 (5th edition in 2015)

[Welz-2014] Welzer, H. (ed.): Futurzwei-Zukunftsalmanach 2015/16: Stories of Dealing Well with the World; Focus on Material. Fischer Paperback (2014)

[Welz-2017] Welzer, H.: We are the Majority. For an Open Society. Fischer Publishing House, Frankfurt am Main (2017)

[WWF-2018] WWF Report: Species Protection in Times of Climate Change. https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF-Report-Artenschutz-in-Zeiten-des-Klimawandels.pdf (2018). Access 18 Dec 2018

Chapter 6
Industrial Design

Thomas Gatzky

With the beginning of the mass production of goods of all kinds in the eighteenth and nineteenth centuries, new questions arose about their design. The artisanal production method, which was predominant for centuries, was characterised by a low degree of division of labour in design, engineering design, and execution (often in one person and in a very direct connection between designer, manufacturer, buyer and user). As industrialisation progressed, planning and production processes based on the division of labour developed and the relationship between planners and end customers became more anonymous.

One result of this development is the emergence of the profession of the industrial designer. At the interface of design and engineering design (in German: Konstruktion), it is his task to translate the cultural, social, and user-related design requirements into a contemporary design appearance. His special focus was directed towards the individual user of mass products in the context of social and economic interests.

For decades, the consideration of humans as users of products played a subordinate role in product development processes. Only when a modern education in industrial design became established and more and more companies understood design as an economic factor, can one speak of integrating industrial design into product development. Developments in art and culture of the twentieth century, especially the work of the Bauhaus in Dessau, changed the view on the design of mass products. The dynamics of economic processes and the emergence of the consumer society after the Second World War gave industrial design a firm place in the product development process. The field underwent further consolidation in the 1960s and 1970s through its integration into the development of capital goods and the inclusion of industrial design content in engineering studies.

Today industrial design is a natural part of interdisciplinary product development processes of consumer and investment goods. Industrial design as a training discipline

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and professional field of work is highly diversified according to the objects to be designed. The design of consumer and investment goods is described in this chapter under the term product design and described and stored within IDE with the attribute *Product Gestalt*[1].

Product design gives objects culture, identity and charisma. It is always an expression of values of the time in which it was created. In this respect, the human being is the yardstick of creative trade, not the technology. Product design develops product requirements such as sensuality and meaningfulness, because people in their role as buyers, owners and users expect product features that correspond to their individual ideas and possibilities.

However, the technical performance of the product alone is no longer sufficient to make it attractive to people, because it is the product design alone that makes products individually sensual to experience. Consequently, product design is a necessary component of the quality of a product. Good product design creates added value that pays off economically and contributes to the success of a company. For many companies, *good design* has become a distinctive mark. Scandinavian design, but also the label *Made in Germany* as a successful synthesis of technology and design, is part of an economic success and have changed the awareness for a new product culture worldwide.

In order to be able to meet these requirements, an intensive examination of *human-oriented product requirements* in the early phases of IDE is necessary. This approach is made possible and encouraged by the human-centred approach of IDE (Chap. 4).

In the design process, the industrial designer creates and materialises the entirety of all aesthetic relationships of use in a model-like manner. This is his core competence and his specific contribution to IDE.

User and product coalesce through the usage process an aesthetic relationship. The reciprocal effect of perception and behaviour as well as the quality of this effect determines the aesthetic utility value of a product. Accordingly, the aesthetic value of a product is not determined by the terms “beautiful” and “ugly”, but by the way in which the product is sensuous and/or meaningful.

Aesthetics always refers to the *human.* All questions of product perception, in particular, the design appearance, are connected with this.

So, what determines the *aesthetic value of* a product? Are there assessment criteria that describe good design?

Is Design for Perception the actual goal of aesthetic design [Gatz-2014], then *good design* is a value judgement in a broader sense. There are no binding standards for assessing the quality feature of *good design.* Rather, the standards are changing against the background of technical-economic, social and cultural changes in society.

[1]Editor’s note: The English translation of the German term “Produktdesign” results in “product design”. However, the English term is not unambiguous as the German, because it covers different meanings like, e.g., “product development”, “product design”, “product layout”, “product draft”, etc. In order to avoid definitional ambiguities when talking about the first product attribute, the IDE term “Product Gestalt” (in German: Produktgestalt) is used throughout this book except of this chapter. Apart from this, the term “product design” used in this chapter corresponds fully to the term “Product Gestalt” used otherwise.

However, evaluation criteria have developed which have been widely used in professional circles and are used, for example, to evaluate products in design competitions and awards. Today, they determine the economic and cultural view of what is meant by *good design.*

In summary, ten value-relevant criteria for *good design* are explained. These also show how closely technical, ergonomic and aesthetic product features are interlinked.

1. High practical benefit: *Good design* combines high usability and perfect functioning of the product (IDE attributes usability and functionality).
2. High product safety: *Good design* means the implementation of technical safety standards required by the attribute safety, including a good feeling of safety, especially when using the product.
3. Very good product ergonomics: *Good design* involves adapting the product to the physical and psychological requirements of the user and his anthropometric conditions. Product ergonomics is a particularly important quality feature that is part of the IDE attribute Usability.
4. Long product life and validity: *Good design* is durable. Today, the congruence of technical and aesthetic durability is regarded as ideal. The demand for a long product life is a rejection of short-lived fashions and planned service life reductions (planned obsolescence [VDMA-24903]) through technical and aesthetic design measures. Long-life design is considered a special quality feature.
5. Technical and formal independence: *Good design* is independent, innovative and capable of being protected. Design protection (utility models, design patents, word and figurative marks) is intended to put a stop to the development of plagiarism. Plagiarism is never good design.
6. Ecology: *Good design* always includes aspects of sustainability. A special requirement is the perceptibility of these aspects in order to support a cultural change in the evaluation of new technologies, materials (waste, recycling) and product appearances (eco-design).
7. Relationship of product and environment: *Good design* is meaningful and appropriate in its product environment. The product environment is seen as the respective objective, social and cultural space. For example, the working environment, the urban environment and the individual living environment differ in their design requirements. The product design responds to the specific needs of the users of these different spaces.
8. Visualisation of use: *Good design* creates a shape of the product that informs about its function and use and that supports and facilitates handling. The design of the interface between user and product (interface design) is becoming increasingly important, especially for digital products.
9. High quality of design: *Good design* is product design that meets the needs of perception.
10. High product aesthetics as individually perceived sensual appeal: *Good design* promotes the perception and sensation of harmony, well-being and grace, but also of contrasts and tensions. It is a sensual stimulation as a prerequisite for an individual experience of use.

Criteria 9 and 10 refer in a narrower sense to the aesthetic requirements and design possibilities in product design. They are explained in detail in this chapter.

A large part of the criteria testifies to the integrative or holistic view of *good design* as part of product quality. Good design as a quality feature can only be planned and implemented in an interdisciplinary, i.e., integrative, manner. A well-functioning product with poor design is just as unacceptable as good design that envelops a poorly functioning product.

This chapter describes ways of looking at problems of product design with the aim to inform product developers about design issues in order to promote the understanding of the integrative working method within IDE. The better the understanding of the development partners for each other is developed and the necessary structural prerequisites exist, the more effective the product development processes are, which are a prerequisite for high product quality.

6.1 Product Development and Product Design

Product development is an interdisciplinary process. The implementation of constructive, technological, safety, ecological, ergonomic, aesthetic and economic requirements brings together the relevant specialist areas. From the point of view of industrial design, there are many interfaces and integration germs. Figure 6.1 shows the variety of interrelationships and references to other subject areas.

The independent proportion of the product values developed by product design in relation to the total values of a product should be briefly stated.

- Economy: Good design generates economic added value. Brand products achieve higher profits through their design.
- Safety: The implementation of technical safety standards also includes a feeling of safety conveyed by the design.

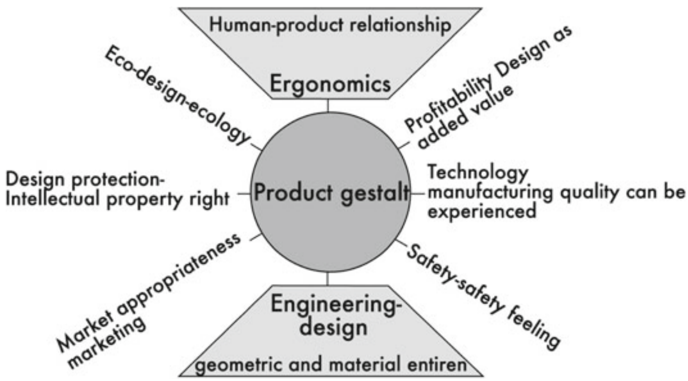


Fig. 6.1 Shape of the product as an interdisciplinary development goal

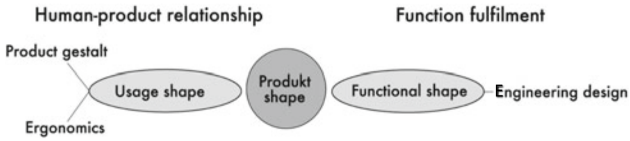


Fig. 6.2 Interdependencies of content and references of product design to other fields of expertise

- Marketing: Product design is an important marketing instrument. It creates distinctiveness, identity and uniqueness.
- Property rights: The protection of the product design ensures economic success.
- Technology: Manufacturing quality is demonstrated to the user by perfect surfaces and high-quality workmanship. High manufacturing quality conveys high product quality.
- Ergonomics: The ergonomic suitability of a product is inseparably linked to its design. Ergonomics and design refer to people in their role as users of products.
- Engineering design: The development of a technical form is closely related to the aesthetically based form, if the product has a distinct human-product interface.

Form and shape finding processes occupy a large space in product development and bring engineering design, ergonomics and product design as well as other areas (Fig. 2.2) closely together. From different perspectives and with different goals, engineers, ergonomists and industrial designers develop their ideas of form and design into a common development goal. The objectives and results pursued in this context show Fig. 6.2.

The shape of a product results from the fulfilment of its function and the objectification of the human-product relationships. Two design phenomena represent the process of form development.

- *Functional shape*: Formative criteria depend on the degree of fulfilment of technical-functional and economic requirements. Criteria such as load, material and manufacturing suitability are directly formative. In this context, a resulting geometric-material entity of a component, an assembly or an entire product is to be referred to as functional design.
- *Usage shape*: Formative criteria largely relate to the future use process by a user or user group. Aesthetic and ergonomic criteria are taken as a basis for the formation of a geometric-material whole.

The design of functional and utility shape is the prerequisite for the interdisciplinary development of a product design. The special relationship between engineering design, ergonomics and product design is determined by the common goal, the development of a geometric-material entireness of a product. Methodical procedures in design, conceptualisation and detailing phases, the use of analogue and digital design tools as well as structural-organisational relationships support the special relationship to each other. In the following, both interfaces will therefore be described in more detail from the point of view of cooperation.

6.1.1 *Product Design and Engineering Design*

Industrial designers and engineering designers are form designers! Both disciplines are united by the goal of jointly contributing to the development of the *objectivity of* a product. Both disciplines bear the main responsibility for the creation of a geometric-material whole of a product. Design and technological requirements such as load-bearing, material and manufacturing requirements (Chap. 9) are directly reflected in the geometry of components, assemblies and integrated products.

The design and creation of the geometric-material whole according to technical *and* aesthetic product requirements combine both fields of expertise, but are also fraught with problems. The common development goal *product* is being worked on from two very different perspectives. Different subject-specific goals, procedures, development methods and design tools have led to a pronounced *division of labour* in the early phases of product development. A different approach to product design and engineering design, which can be justified in terms of content, has often led and still leads to communication problems in practice. The temporal integration of creative activities, problems of communication and understanding, but also questions of organisational and structural linkage play a role.

Figure 6.3 shows the basic problem. It consists of the fact that in product design, a design appearance or a geometric-material whole is developed in the early design phases. This is the only way to analyse, evaluate and further develop the overall effect of a design concept. At this point in time, there are usually no design concepts for the overall appearance (structural design, housing). The coordination of product design (industrial design) and component design (engineering design) then becomes a problem with a lot of conflict potential.

Overall, the potential for conflict results mainly from the following circumstances:

- Increasing division of labour in the design processes, starting with industrialisation to this day
- Design methodological developments attached little importance to humans as users of technical products and therefore did not adequately reflect human-related product requirements

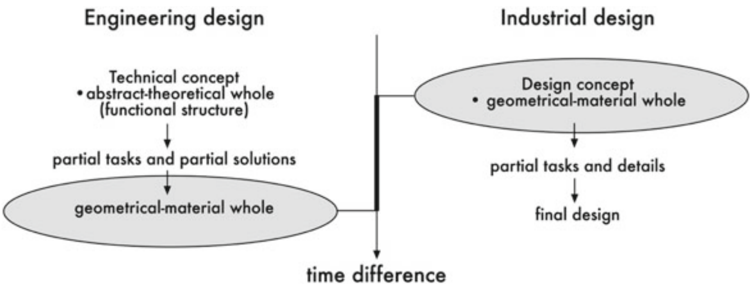


Fig. 6.3 Different time of the production of a geometrical-material entity [Gatz-2013]

- Development of design tools is strictly based on the division of labour.
- An engineering education follows the model of division of labour and thus attaches little importance to user relevance (human-machine interface), as well as an education of engineering designers and industrial designers "sealed off" from each other.
- An education of engineers and industrial designers "sealed off" from each other.

Even today, the classical engineering education is still composed of a multitude of teaching areas that operate without a view of an overall solution (overall design). In civil engineering, architecture assumes the role of the "design developer". The architect creates the design vision. Industrial design can and should play this role in engineering education. The different approaches to engineering design and industrial design are perceived as "normal" when they are explained in the training of engineers and designers, i.e., in terms of their tasks. A foundation laid in this way, as described in [NaGV-2004] and [Gatz-2008], creates the insight and willingness for an integrative approach in all design phases.

In practice, the problem has long been recognised. The development of a design vision, often in the form of a finish model of the future product, is increasingly becoming an important strategic and methodological instrument of development philosophy.

Designers and industrial designers, who both only know the procedures of "their" methods, are "at risk of conflict". Costly coordination and time losses occur when this difference is not recognised or accepted.

A number of possibilities can help to harmonise the relationship between engineering design and industrial design in the early stages of product development.

- Understanding and information about education and qualification in the respective field
- Parallelisation of the development steps with many iterations
- Integrative development environment (forms of organisation, structural assignments, communication)
- Common database and good interface design between the digital tools (CAD, CAID, RP, model making).

Procedures and methods of IDE accept the time lag and describe a development environment that is conducive to the collaboration of engineers and industrial designers within the holistic approach of product development within IDE.

6.1.2 Aesthetics and Ergonomics

Aesthetic *and* ergonomic product requirements refer to people in their role as users, buyers and owners of products. The concentration on product features and characteristics that relate to humans as biological and social beings has historically brought the fields of ergonomics (work science) and industrial design closer together.

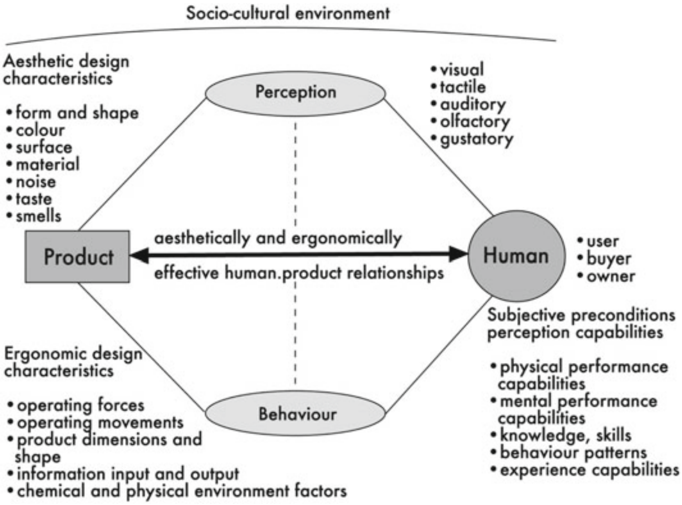


Fig. 6.4 Aesthetically and ergonomically effective human-product relationships [Gatz-2013]

The totality of all human-related product requirements bears aesthetic *and* ergonomic design features, Fig. 6.4. Therefore, in this context, the close and mutual penetration of *aesthetics* and *ergonomics* must be pointed out. The design of a chair is determined by ergonomic criteria, such as a fatigue-free posture. The geometry to be selected for this purpose also determines the aesthetic appearance of the design to be evaluated. The user expects these aspects to be combined in the sense of a holistic product design. In training and practice, however, industrial design and ergonomics are treated as separate fields of expertise, and accordingly, they are divided into two parts. IDE also provides a suitable development method for interdisciplinary and integrated design activities in both fields.

The reciprocal relationship of *perception* and *behaviour* which is a *usage process* combines aesthetic, ergonomic and perceptual psychological aspects of analysis and design.

SCHÜRER referred to the reciprocity of ergonomics and design. "In this sense, ergonomics is to be understood as a component of design and aesthetics as a component of ergonomics. However, this aesthetic is not to be understood as an associative, as a *pleasing aesthetic* but rather as an aesthetic that is related to the course of action and guides the action. On the one hand, it influences the experience of an object, and on the other hand, it influences the behaviour towards these phenomena, and finally, the action is related to them or to be carried out with them. Experience, behaviour and action are basic human dispositions. They cannot be met solely by properly trained elements for action execution, i.e., hardware-ergonomic. Rather, they are essentially influenced by the obvious, i.e., software-ergonomic training of action-guiding elements" [Schü-1988].

The design examination of usage processes also offers an opportunity to overcome the separation of design and ergonomics.

6.2 From the Idea to the Shape of the Product

In the development of a product, the creation of its geometric-material wholeness is the main focus of in the centre. Several engineering disciplines and industrial design make their own specific contribution. Depending on the profession and perspective, a geometric-material whole can mean a component form, an assembly form and its form and design appearance. The engineer and the industrial designer pursue goals that are directed towards the implementation of technical-economic and human-centric requirements.

The creation of a geometrical-material entireness of a product unites engineers and industrial designers. What is common and interdisciplinary is manifested very concretely in form and design finding processes, which make up a large part of the product development process.

Form and shape as technical *and* aesthetic categories and design objects are therefore the focus of the following explanations.

Designing means arranging! If the product developer recognises, the goal of arranging design measures within the framework of form and design finding processes, and if he understands how design *order* can be achieved, he will be open to the decisions of the industrial designer. Even for the design of the shape during engineering design, findings and design recommendations can be derived which support and accommodate the design intentions in product design. For this reason, the recognition of the *aesthetic design problem* in form and shape finding is *the* decisive prerequisite for a cooperative and integrative approach of engineers and industrial designers in the development of products.

Colour, material and surface aesthetic design aspects are indispensable for the development of the product design, but are deliberately excluded in the context of these considerations (for further information see [Seeg-2005]).

Designing, engineering and shaping are processes in which an immaterial state is advanced to a geometric-material state over many development steps. Descriptions of ideas, first sketches, abstract functional and usage structures describe the future characteristics of the product, but cannot yet be experienced sensually. From this, the first form and design concepts develop, which become more and more complete, holistic and perceptible in the development process. The advancing *specification of form and shape* is particularly driven by constructive, ergonomic and design objectives.

The development of a geometrical-material wholeness of a product is usually carried out as shown in Fig. 6.5.

The transition from immateriality to the geometric-material description of form and shape is also a transition from immaterial abstraction to perceptibility.

The shape of the product is thus determined from the point of view of the *human-product relationships* which are always part of the overall (technical, manufacturing,

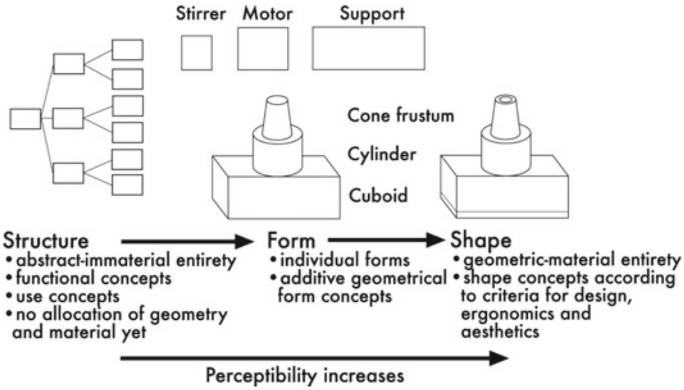


Fig. 6.5 Transition from the state of structure via the form to shape [Gatz-2013]

economic, etc.) product requirements. The shape combines the elements and their arrangement characteristics that enable the product to be perceived.

The stimuli required for sensual perception (aesthetics) are perceived via the *form*, the *colour*, the *material* and the *surface*.

The shape of the product is, however, not only the sum of the *design elements* but results from the elements and their relations (quantities and qualities) to each other. The relationships are called *shape structure*.

The attribute “Product Gestalt” describes the perception to be created as well as the perception of the prerequisites composed of the design elements form, colour, material and surface and the design structure in order to enable the use of a product in the sense of a perceptive human-product relationship.

From now on, concepts of form and design can be experienced by the senses and are therefore also subject to aesthetic analysis and evaluation. Interestingly, it is not only the constantly evolving shape of the product that can be sensually experienced, but also its representation in the form of design representations, engineering design drawings and representational models. Visualisation techniques for the early phases of a product development aim at an ever better perceptibility of design results.

6.3 Human-Product Relationships or the Basic Aesthetic Problem

In the traditional classical concept of art until the nineteenth century, *aesthetics* (Greek aesthesis: perception) is often equated with the doctrine of beauty. The focus of aesthetic considerations was on works of painting, sculpture, music, theatre and literature. Everyday products have traditionally not been evaluated according to the criteria of classical aesthetics. Reform movements of various kinds, however, brought *normal life* increasingly into the focus of aesthetic considerations. *The new unity of* *art and technology*, propagated at the Bauhaus in Dessau, led to a new view on industrially manufactured products.

The concept of beauty has been extended to industrially manufactured products. This required a new aesthetic approach. Aesthetics has now been defined as the theory and philosophy of sensory perception in art, design, philosophy and science.

Accordingly, the *aesthetic value* is not determined by the terms "beautiful" and "ugly", but by *sensuality* and/or *meaningfulness* of the product. Aesthetics therefore always refers to the human being. All questions of product perception, in particular the design appearance and all acts of use, are connected with this.

Products are recognised by means of sensory organs (receptors). This creates perception stimuli on the product side such as shapes, colours, materials and surfaces. The processing of the stimuli leads to *behavioural reactions* which the human being perceives as an *experience*, *Action* and *evaluation*, Fig. 6.6.

But perception also means recognising content and meaning.

Behaviour can be described as the human reaction to what is perceived. Observing or actuating is important actions. They can also be perceived as an experience. Experiences and actions cause the user to judgements and evaluations. Devotion or rejection and verbal judgments such as "do I like or dislike" often conclude a human-product relationship.

The degree of fulfilment of a human-product relationship always depends on the interrelation of perception and behaviour. It makes sense, then, to postulate *design for perception* as a design goal. For the design process, meeting the goal of design for perception means dealing with perceptual stimuli. An example of this is finding the shape of a product that meets not only technical but also aesthetic criteria. Perceptually appropriate design means taking into account requirements that arise from the physiology and psychology of the human perception process (Chap. 4) and the individual or the experiences of the individual influenced by the respective environment and which are used to design products with regard to their design appearance.

Design for perception as a design goal and requirement means making products meaningful.

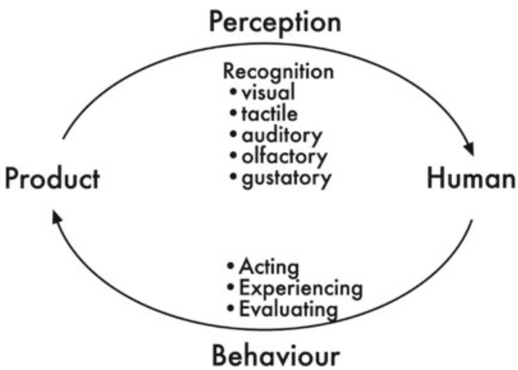


Fig. 6.6 Human-product relationship as a basic aesthetic problem [Gatz-2013]

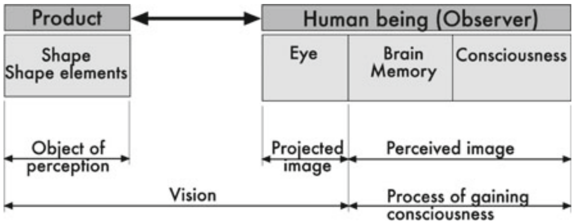


Fig. 6.7 Human-product relationship as a problem of perception [Gatz-2013]

6.3.1 Perception

Perception means seeing and becoming aware.

About 60–80% of all environmental stimuli are perceived visually. The *visual* thus plays an overriding role in human-product relationships and also explains the dominance of visual design aspects in product design. Figure 6.7 shows the basic relationships.

The human in his role as observer recognises the product. The prerequisite for this is the *shape of the product* and its *shape elements*. They are created in the visual process via the eye as a projection image. This is followed by a process of awareness, which leads to an individual image of perception.

So, there are two phases of *perception* to be differentiated:

Phase 1: The formation of a projection image is an objective, physical-chemical process that is developed in the same way in almost all people.

Phase 2: The formation of a perceptual image is a subjective process that depends on the individual memory content, experiences and values of the observer. The subjectivity of the viewer is co-determined by a socio-cultural framework that defines in particular values and norms.

In contrast to "objective" technology, product design has a *subjective aspect* as well. The user perceives and behaves subjectively. This poses a particular problem. Product design is part of a product development process for the creation of mass products that meet the needs of large groups of buyers or users, but where these groups always consist of individuals. It is therefore a particular challenge to develop mass products that can meet individual needs (i.e., leading to mass customisation). This is the reason for the intensive examination of user requirements in the product development process!

6.3.2 Perception, Behaviour and Usage

People *use* products to organise their lives and satisfy their needs. It is obvious that the design quality of the products has a decisive influence on the quality of life and meaningfulness. *Usage* or usage processes determine the active relationship between man and product. In product design, a particular focus of the design and creation work is therefore on the development of *usage processes* of a future object in thought and material terms and to objectify it as a model, Fig. 6.8.

The usage process makes the relationship between perception and behaviour transparent. The object *sends* out perceptual stimuli that the human receives and processes. This is followed by a behavioural reaction, sometimes as a haptic action (pressing a control button) or only as unconscious emotion (turning), often combined with an evaluation (verbal judgement). Figure 6.9 shows a typical everyday situation.

A woman cyclist notices a passing car. She recognises a car because the archetypal shape of a car is stored in her memory. But she also perceives individual design elements. She consciously (information) and/or unconsciously (impression) interprets the design appearance that she perceives and reacts in many different ways. It can be an active action, e.g., a change of direction, but it can also be a passive observation. In any case, the perception of objectively existing design features leads to a behavioural reaction, which in turn depends on the design situation.

Starting from Fig. 6.9, the question now arises of how a usage process can be described in more detail. What does it mean to *use* a product? The aim of this

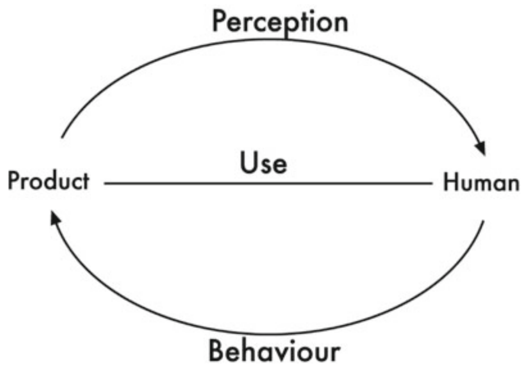


Fig. 6.8 General context of perception, behaviour and use [Gatz-2013]

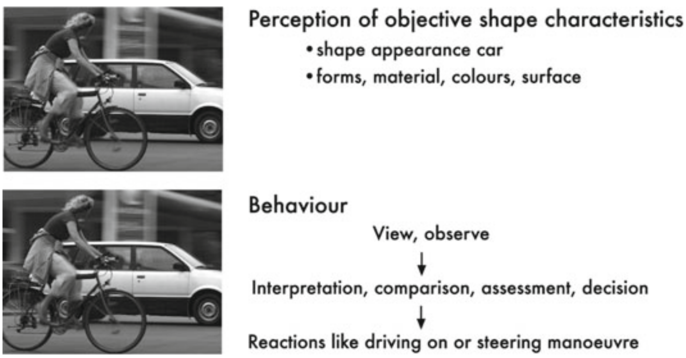


Fig. 6.9 Example of the relationship between perception and behaviour

examination should be to show design fields and to analyse all requirements that allow an assessment of the degree of fulfilment with regard to use and fairness of perception.

The use takes place on two levels, the level of perception and the level of behaviour. However, the process of use is also influenced by perceptual stimuli that people can consciously (information) and unconsciously (impression) recognise and experience as information and impression properties of the shape of a product, Fig. 6.10.

In the design process, information and gracefulness characteristics are developed. They can inform the future user of a product about certain facts and address his feelings and sensations.

A *design appearance* can provide information that can inform the user about different contents. For example, the user receives information about the design of the product or about form elements for purpose, function, use, value and much more.

The brush shown in Fig. 6.11 is a good example of the simultaneous clash of design and ergonomic intentions. The recessed grip on a brush is at the same time an ergonomic shape to allow good power transmission from the hand to the brush.

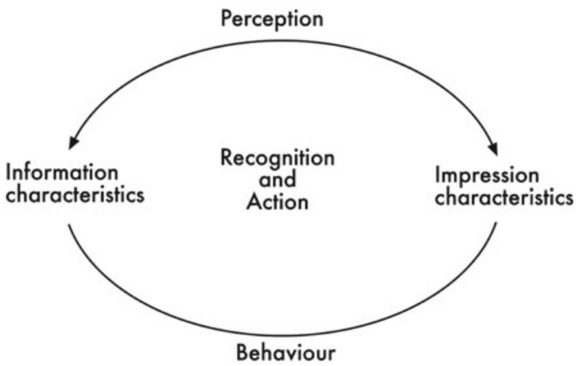


Fig. 6.10 Information and appearance properties in the use process [Gatz-2013]

Fig. 6.11 Brush with recessed grip

On the other hand, the trough is also a visual information that informs the user about the correct use of the brush. The correct recognition of this information can increase the feeling of security in the use process. Clarity, unambiguity, truth and easy accessibility are therefore quality features of good design. *Good design* should be self-explanatory, which means nothing else than that the design informs the user directly about usage properties and other facts.

The situation is different with the design characteristic of impression. *Impression* is the term for an unconsciously triggered emotion through perception. Product impressions address the subconscious and express themselves in *sensations*, *impulses* and *effects*.

Here are some examples of gracefulness qualities:

- Sensation: Feeling of well-being or discomfort, feeling of security or insecurity, feeling of prestige or inferiority
- Effects: large—small, fast—slow, harmonic—inharmonic, heavy—light
- Impulse: Stimulate spontaneous activities, e.g., touching (grip shapes, material surfaces), using, playing, etc.

As a quality feature or design goal, the accordance between objective design features and subjectively perceived expectations must be recorded.

Two examples are intended to make a correct and a wrong product impression understandable, Fig. 6.12.

Using the example of a wristwatch, design requirements that are related to perceptual correctness will be analysed. This leads to design requirements for a watch, for example, which enable or support recognition and operation, Fig. 6.13.

In this example, perception means to seeing a watch and to perceiving many things, among others:

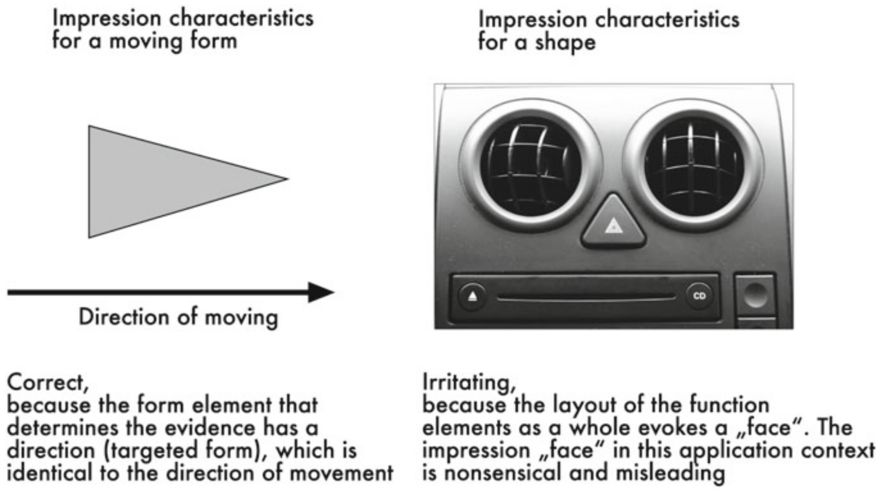


Fig. 6.12 Correct and irritating product appearance [Gatz-2013]

Fig. 6.13 Example: Using a wristwatch (photos from the Manufactum catalogue, 2009) [Gatz-2013]

- The shape has an archetypal form, corresponds to the cultural context and is therefore assigned to the product group watch and recognised as such.
- Recognition of purpose and function, modes of use as well as materials and processing quality and
- Conveying values.

Possible types of behaviour:

- Reading the time,
- In take the hand and wear it on the wrist and
- User actions such as winding up, setting the time.

The example is intended to make us aware that the relationships between people and products (user and watch) are determined by aspects of perception and behaviour and that the quality of these relationships can be consciously influenced by design in the design process.

6.4 Design for Perception as a Design Task

The design task in industrial design can be seen as the creation of a state of a proper design for perception.

By means of designing and model-like objectification, immaterial ideas (thoughts, ideas) are made sensually tangible through drawings and physical models. This also allows the following basic statement to be made for the design process.

When designing products according to aesthetic criteria, it is all about perceiving and feeling harmony, well-being and grace, but also about contrasts and tensions. The user experiences a sensual stimulation during the use process, which he perceives as an individual experience.

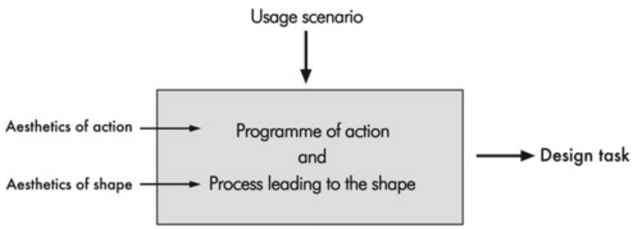


Fig. 6.14 Usage scenario as a design task [Gatz-2013]

The "dimensioning" of sensual stimulation is a crucial design problem. It is determined by the interrelation between perception and behaviour. In the design process, design measures are used to develop and simulate the future behaviour and experience of an individual user when using a product.

6.4.1 The Usage Scenario

At the beginning of every design process, there are questions such as:

- How should the future (and intended) user handle the product?
- What shape should the product to be designed have?
- Which action and operating procedures are correct or appropriate?

These and similar questions lead to design tasks that determine the future *usage scenario*. The usage scenario is determined by the entirety of aesthetic requirements in terms of action and design (Fig. 6.14).

6.4.2 Aesthetics of Action

Actuation and use operations are part of the product perception, and the actuation behaviour is experienced and assessed by the user. The quality of these operations often determines the value of a product.

Aesthetics of action is the sensual and meaningful component of user-oriented design. In the sense of a perceptual design, it deals with the management, inclusion and development of action situations of objective action. The criteria that can be shaped and evaluated are, in particular, action competence and control.

Perceptual design is characterised by the following principles, which explain the relationship between *perception* and *behaviour* reflect this.

- Principle of *simplicity*: The effort and benefit are in the right ratio. The correct appropriateness of design expenditure (design appearance) in relation to the purpose, the utility value and the value in itself is one of the most important quality criteria. Simplicity appears honest, authentic, clear and orderly. Complexity (or overload) is often confusing, disorienting and inappropriate.

- Principle of *unambiguity*: Quick and clear recognition of a design situation leads to controlled and safe action operations.
- Principle of *visibility*: Well perceivable "signals" (information) are the prerequisite for safe action. For example, a coffee cup should have a sufficiently large handle. Not only so that particularly large fingers fit into it, but above all because of the recognisability of the usage function. The absence of these signals can lead to irritation and wrong actions.
- Principle of *feedback*: Both important action signals and their feedback must be perceptible, best visible. Feedback should appear immediately after the action. If they fail to appear or arrive too late, the user does not know whether the action was correct and successfully completed.
- Principle of *mapping*: Mapping refers to the meaningfulness of the representation of a functionality in the context of action and its result. The visualisation of function, action and real execution makes it easier for the user to recognise connections. Analogies and compatibilities to known experience values support the user in operating actions. A well-known example is the "trash" function on the user interface of a computer (the so-called "desktop"). The design is based on the design and organisation of a natural office. The "dispose" function is conveyed via the image of a wastebasket. The virtual disposal, insertion and retrieval is realised in analogy to the waste paper basket from the real world. Although data on the computer is disposed of differently than normal garbage, the user is familiar with the usage process via a pictorially represented but virtual wastebasket.

Particularly with electronic products and software interfaces (interface design), the design quality of action aesthetics is of paramount importance, since the use process is almost exclusively realised and experienced via an *interface* to be used. Action-aesthetic solutions are based on ergonomic, psychological and design knowledge. The cooperation of industrial designers, ergonomists and psychologists proves to be advantageous for the solution of action-aesthetic problems.

6.4.3 Gestalt Aesthetics

Perceptual design always aims at finding a design in its unity of form, colour, material and surface.

Since the geometrical-material wholeness is also and especially determined by technical product requirements, the design process results in manifold relationships to engineering design and technology.

Finding and creating a perceptual shape take up a large part of the design process. In the following, therefore, the basics of form and design aesthetic contexts will be described.

6.5 Introduction to a Perception-Oriented Theory of Form and Shape

The task of the *theory of form and shape* is to understand the recognition and application of objectively acting criteria in order to create form and shape and to be able to judge them according to appropriate criteria. In engineering, mathematical/geometrical descriptions are generally valid due to technical requirements such as load, function fulfilment and‘ manufacture. In product design, it is a matter of formal-aesthetic or perceptual descriptions based on aesthetic requirements.

A perception-oriented theory of form and shape can support the recognition and shaping of effects on humans under the aspect of the way in which form and shape is perceived.

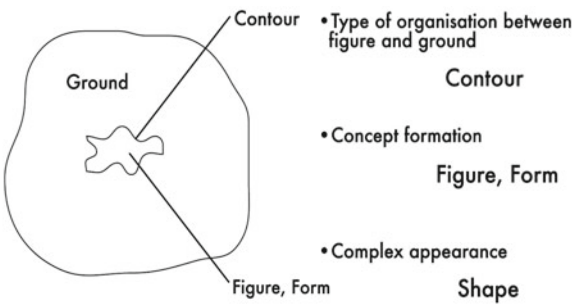
6.5.1 Fundamentals of the Perception of Form and Shape

The most elementary way of perception is the *figure-ground relationship*, Fig. 6.15.

The contour in Fig. 6.15 closes to a form and contrasts with the surroundings or the ground. This makes the form perceptible. The course of the contour is decisive for the interpretation of the form and determines the expression of the form. The following example is representative for all contrast phenomena.

A circle has a typical contour, and a triangle has a different contour. The observer assigns corresponding terms (here: circle and triangle) to these different contours. Thus, form becomes distinguishable and describable. The results are different perceptual impressions. A circle has a different effect on an observer than a triangle. Here are the approaches for a creative knowledge that is applied in the design process.

Fig. 6.15 Figure-ground relationship [Gatz-2013]



6.5.2 Form and Shape

The distinction of *form* and *shape* is important for practical design, as it allows investigations into the results of perception to be designed, Fig. 6.16.

A form is understood as a self-contained individual phenomenon. The contour encloses a surface form, and the surface course describes a spatial form. Creating a form or rather shaping a form means the design of *a contour* or *surface*. Contours and surfaces determine the perceptual impression.

- For the *area form*, the *course of contours* is the prerequisite for perception. The contour geometry determines the shape expression.
- For the *spatial form*, the *surface course* is the prerequisite for perception. The surface geometry determines the form expression.

Figure 6.17 shows an example of the relationship between contour and surface progression and their effects on an observer. This is the basis for a perception-oriented theory of forms, which is described in more detail in Sect. 6.6.

From the point of view of design, a shape is understood to be a group of forms. Shape formation describes the way in which individual forms are combined to form a shape. Different perceptual impressions can be consciously influenced by design options such as structuring and ordering measures.

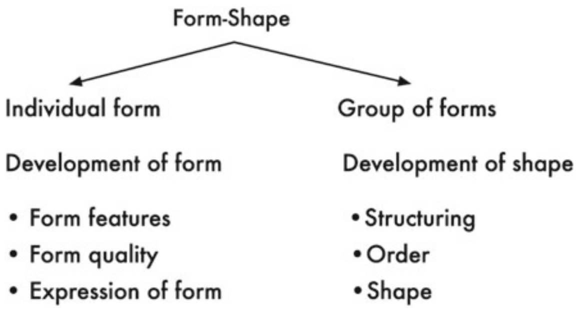


Fig. 6.16 Concepts of shape aesthetics [Gatz-2013]

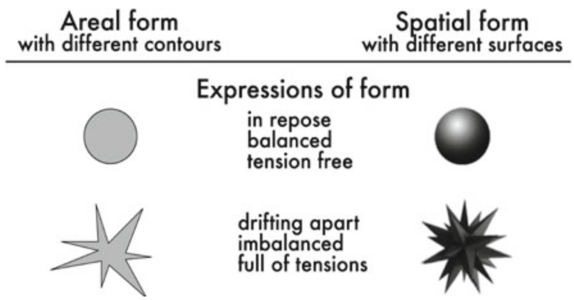


Fig. 6.17 Examples of surface and spatial forms and their different expressions

Form and shape in their geometric-material expression are the most effective elements in terms of perception. The human draws the most intensive and comprehensive perceptual impressions from the perception of form and shape. This is also the reason for the particularly intensive design debates in design processes.

At this point, the complexity of a shape appearance must be pointed out. A shape is not only a geometric group of forms, but the totality of the aesthetic elements form, colour, material and surface as well as their individual characteristics, such as the constellation of the design elements to each other. The *shape structure* describes the interaction of all elements of design aesthetics. It is only now that something arises what becomes a shape or design appearance that is a prerequisite, for e.g., complex product perception, Fig. 6.18.

Developing the shape of a product means dealing with a future situation of perception. The degree of coupling relationships between the aesthetic elements, described as the structure of form, is of great importance. This measure decisively determines the designed perception impression.

- The *shape structure* results from
- the type of design elements used,
- their quantitative distribution on the product and
- the relationship of the individual to the wholeness.

Depending on the conditions of the product, two perceptual impressions arise: the impression of order or the impression of complexity. Figure 6.19 shows the impression of order and complexity using the example of two clocks. Already this distinguishing feature leads to different effects.

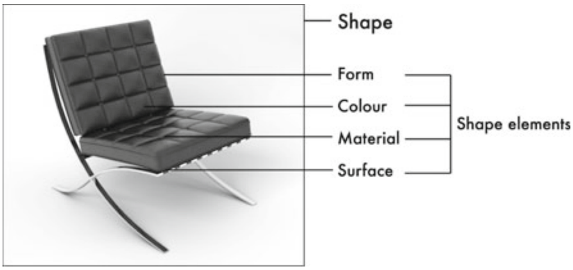


Fig. 6.18 Design structure (product example: Barcelona armchair by Ludwig Mies van der Rohe, 1929) [Gatz-2013]

Fig. 6.19 Different design structures with different effects using the example of wristwatches [Gatz-2013]

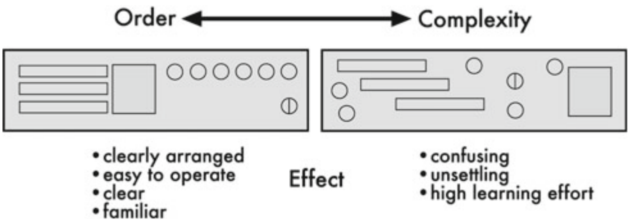


Fig. 6.20 Different states using the example of a radio user interface [Gatz-2013]

Order means:

- Small number of design elements
- Small number of arrangement properties.

Complexity means:

- Many design elements
- Many arrangement properties.

Order and complexity are the result of conscious design with the aim of achieving perceptible effects for the user.

Effects can be, for example,

- Simple—complex
- Clear—confusing to chaotic
- Expensive—cheap
- Old—new
- Interesting (attention)—uninteresting (indifference).

The example in Fig. 6.20 also shows how the two states order and complexity work.

Figure 6.21 shows a current example of the cockpit design of a car. The analysis only considers the design of the control elements. Other design features are not taken into account.

Above:

Means of design: Application of identical and related forms
Effect: High level of order appears to be tidy, safe to use and familiar.

Below:

Means of design: Application of the most varied forms
Effect: High complexity or chaos of forms is confusing, unsettling and irritating.

To sum up, it can be said that
Only the conscious design achieves the intended effect!

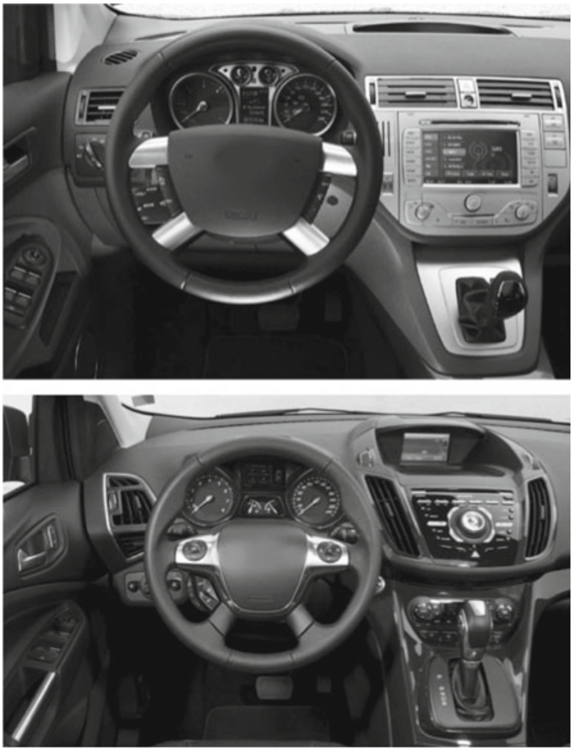


Fig. 6.21 Example for the cockpit design of a middle class car (upper picture: predecessor model, lower picture: model year 2013)

Figure 6.22 shows a graphic with two designs that consist of identical design elements but differ in only one arrangement. This small (design) difference makes the different effect.

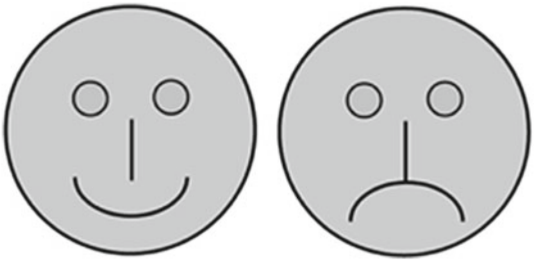


Fig. 6.22 Two designs made of identical design elements [Gatz-2013]

6.5.3 Design Rules

The examples show the connection between design and effects produced by the user. This also raises the question of applicable rules, recommendations, criteria and examples. JAKOBY gives a good overview with practical recommendations for perceptual design in [Jako-1993]. The recommendations are addressed to engineers and designers.

Unlike in mathematics, physics and technology, the application of rules does not necessarily lead to good results, i.e., well-designed products. In product design, it is always important to visually check the effects that occur on the shape of the product with the intended targets and to correct them if necessary. The design rules are based on the characteristics of the visual perception system. They represent regularities that are felt by all people to be almost the same and can therefore contribute to an objectivisation of creative action. In principle, all rules are based on the relationship between *order* and *complexity* back.

Reference should be made to design rules that are particularly important for product design. More detailed descriptions and examples can be found in [Jako-1993]. Only a few explanations will be given here to underline their relevance.

6.5.3.1 Qualitative Statements on Shape Formation

Strong, clear and concise design appearances are characterised by

- Regularity
- Uniformity
- Closeness
- Simplicity
- Symmetry.

According to [Ehre-1954], the following statements can be made for an overall shape and its partial shapes:

An overall shape is equal to the sum of its individual parts, but:

- The experience (impression, statement, evaluation,…) of an overall shape is clearly different from the sum of the experiences through the partial shapes.
- The perception of an overall shape takes place before the perception of its partial shapes.
- The impression gained by the perception of an overall shape dominates the perception of the partial shapes.

The additive assembly of the shape of a product only according to technical considerations does not necessarily result in a "correct" shape appearance developed on the basis of the sensory impressions.

6.5.3.2 Qualitative Statements on the Structure of a Shape

So-called laws of shape describe how points, lines (edges), surfaces and bodies can be structured and joined together with the elements in a way that is appropriate for perception. These laws are applied in product design.

6.5.3.3 Qualitative Statements on the Ordering of a Figure

Only through the conscious ordering of a shape, there is a development of statements like

Clearly arranged
Familiar
Useful
Easy to understand and
Sure,

i.e., statements that correspond to the goal of perception correctness. Designing order can be achieved by

- Classification according to specific criteria such as function, usage and significance
- Standardisation
- Simplification.

The degree of creative order can only ever be determined in connection with the design of the product and its product statements. What is right for one occasion may be wrong or inappropriate in another.

6.6 Introduction to a Perception-Oriented Theory of Forms

Basis of the methodical approach for a perception-oriented *theory of forms* is the assumption that the human sense of form is dominated by the perception of natural forms. Archetypal natural forms accompany humans in a permanent way, shape their geometric ideas of form and anchor interpretations and meanings. It is therefore obvious to use these natural basic forms and to transfer them to "artificial", i.e., man-made forms.

The aim is the design of effects on humans under the aspect of the way they perceive form.

In terms of developmental history, the sense of form can be derived from the perception of nature. It should be noted that natural forms are always the result of natural processes. The natural variety of forms is infinite and is not oriented to human standards and needs. The situation is different with forms created by humans. These designs reflect human needs and are based on human standards.

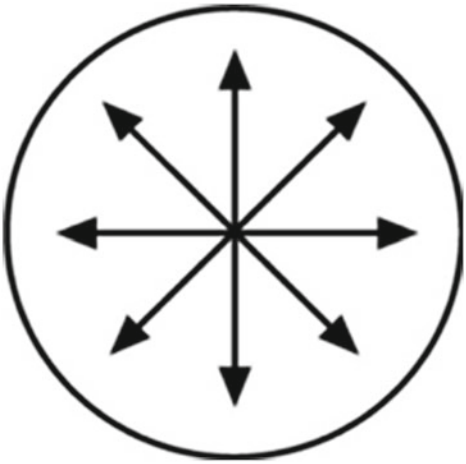


Fig. 6.23 Unorientet shape character [Gatz-2013]

Natural forms and forms created by humans give distinction to the human perceptual environment. Therefore, natural forms can also serve as a basis for a perception-oriented form methodology or theory.

The human *sense of form* is determined by the *contour course* for surfaces and the *surface course* for body shapes. A method for systematising the variety of forms asks for the direction of the contour or surface as distinguishing and ordering features.

The principle of distinctness is illustrated using the example of a circle in Fig. 6.23.

The circle is perceived as a circle because its contour has no direction. For the purpose of typification, its formal character is described as "unoriented". Following this principle, basic forms derived from nature can be developed.

Around the years of the 1970s, ZITZMANN created training foundations for designers at the University for Industrial Design, Halle-Burg Giebichenstein. The methodical systematisation of the forms described here goes back to these works [ZiSc-1990].

6.6.1 Form Methodology—Form Character

In the following, four form characters are derived from natural forms. The aim is a design-based methodology for distinguishing forma according to criteria of perception. With this methodology, it is possible to analyse forms with regard to their visual effect on a user and to apply them purposefully for design tasks. Moreover, this methodology offers the possibility of overcoming the often observed "speechlessness" in analysis and argumentation of and for forms, Fig. 6.24.

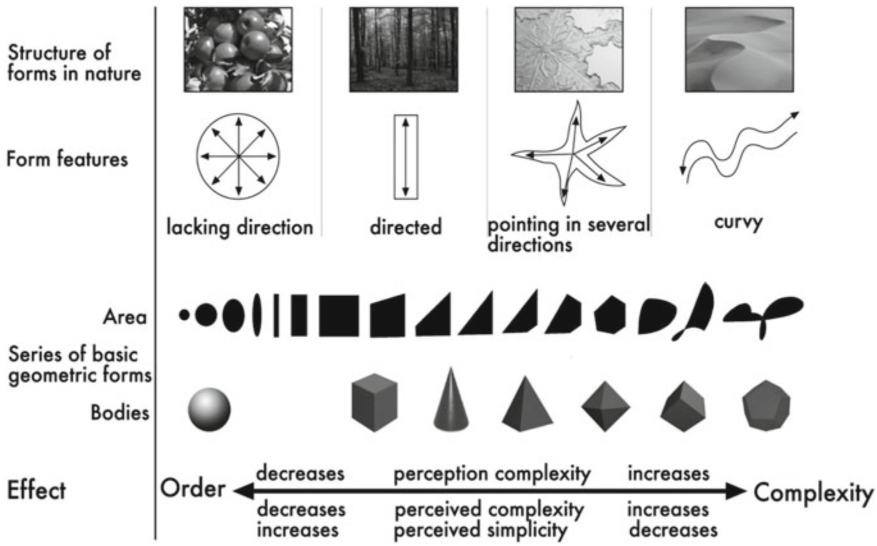


Fig. 6.24 Taxonomy of forms [Gatz-2013]

6.6.2 Taxonomy of Forms

As a result of the analysis of natural forms and their simplification to simple geometric basic forms, a taxonomy can be developed based on different perceptual efforts.

It is assumed, for example, that a circle is perceived faster, safer and more definite than a polygon or a complicated moving form. However, it is not only the perceptual effort that is a distinguishing or systematising feature, but also the different effect of the form on the observer. A circle is perceived as a calm, tension-free form, a triangular form, in contrast, as aggressive and often as moving.

From this observation, a series of forms differentiated by perceptual effort and triggered sensation can be set up, which is of great importance for practical design. A planned sensation that occurs in the viewer can be achieved with a high degree of probability by using the appropriate shapes.

6.6.3 Forming Quality

The taxonomy of forms provides important insights to the industrial designer for designing effects, because a further step towards the perceptual correctness of form lies in the consideration of the following three characteristics of aesthetic quality:

- The purity of the form,
- The continuity of the form and
- Transitional forms and details.

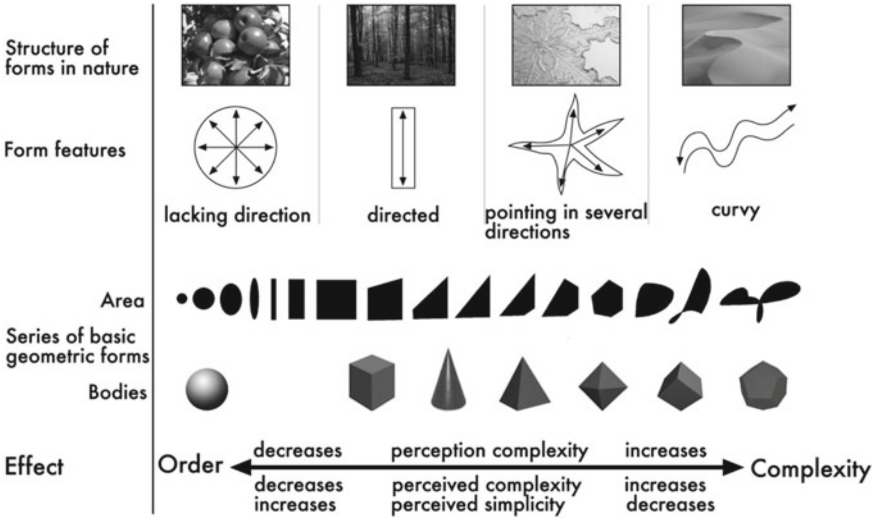


Fig. 6.25 Differentiation of body shapes according to the criterion of purity [Gatz-2013]

As soon as the goal of perceptual correctness is set, these characteristics can also be linked to goals. The aim is to achieve a high degree of purity, consistency and form locking (Sect. 6.6.3.1).

6.6.3.1 Purity of Form

The relationships described in Sect. 6.6.1 and the series of forms shown in Fig. 6.24 are now transferred to body forms.

For example, a sphere differs from a tetrahedron in terms of the effort required to perceive it and the effects it produces on the observer.

High purity as a quality characteristic of good design has a low number of species and form elements. Simple geometric side shapes, low number of surfaces and low number of edges are design features to be aimed for, Fig. 6.25.

6.6.3.2 Continuity of Form

The continuity of form is often associated with the impression of harmony and discontinuity with disharmony. If the "harmonious" form is the design goal, then certain features must be implemented in the design.

- Continuity of the course of a contour or a surface
- Continuity of direction and
- Continuity of curvature.

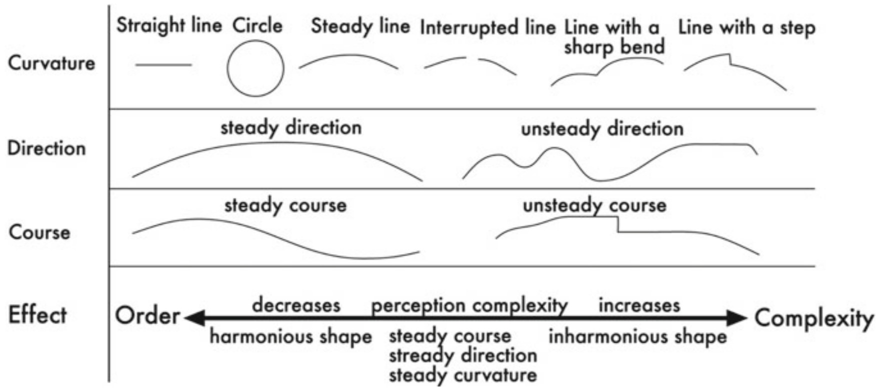


Fig. 6.26 Differentiation according to the criteria of the quality of the training [Gatz-2013]

Continuity of the course means not to allow any cracks and kinks in the form. Points of discontinuity disturb the harmonious impression and can be superimposed on each other in terms of design. One could also say that the eye "gets stuck" at this point. It should be noted, however, that kinks or jumps can be deliberate and intentional, for example if they are to be perceived as superimposition (special place of attention), Fig. 6.26.

As a third characteristic of continuity, there is an influence of perception by the curvature of a contour or a surface. The more complex the curvatures are, the more "disturbances" are felt, and, all the more, the form can appear disharmonious.

6.6.4 Design Methods for Perceptual-Oriented Design

The relation of *order* and *complexity* determines the degree and the characteristics of the shape structure. It is not possible to set fixed standards for this ratio. Too many factors influence the design trend. Social and cultural values, zeitgeist, individual perceptions, marketing aspects and design qualifications shape the ideas about this design problem.

And yet a design tendency and a recommendation for the product design can be derived. With industrialisation and the accompanying cultural-theoretical movements and changes, there is a clear tendency towards consciously ordered design phenomena. Attributes such as *simple, clear, understandable* and *honest* have become established as quality features in the design of the twentieth and twenty-first centuries.

Of course, their implementation requires complex professional design. However, the designer can also influence the perception of the design appearance in the process of form and shape finding. Two methods are particularly suitable for implementation in the design process, namely *form locking* and *form calming*, which are methods for increasing visual *order*.

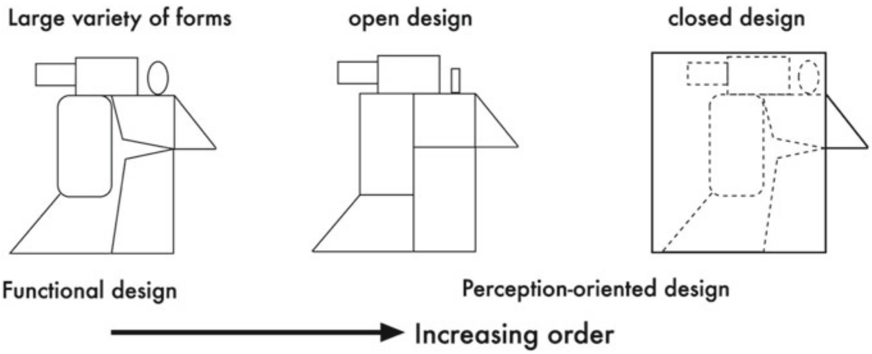


Fig. 6.27 Two methods for form calming [Gatz-2013]

Under form locking, the joining of individual forms to form a less complex form appearance is to be described. If the criteria of perceptual correctness are used as a yardstick, a very complex variety of forms can appear restless, unbalanced, unbalanced and overstraining. The functional shape shown in Fig. 6.27 is an example of a shape that is not perceptively correct. It arises when a design is created exclusively according to technical-functional requirements and without taking aesthetic considerations into account.

Design with the aim of simplifying and standardising forms is thus a step towards a form that is fair to perception.

In principle, two ways are possible:

- Composition of the form from identical or related forms is individually visible and shows themselves in an open design appearance. This creates the impression of openness.
- Masking of the variety of forms is by an "imposed over-cover" (cladding, housing). The variety of forms is concealed, and the cover takes over the aesthetic function of the design appearance. The impression of unity is created.

Both methods are common in practical forming and are known as form calming.

Figure 6.27 shows the design path from a functional form to a perceptually appropriate design appearance.

Form calming is a design possibility to make a creative decision between order and complexity of the perceived form. The degree of order to be created determines the intended effects.

As a design orientation and also as a quality criterion for design, a turn towards orderly form and design appearances can be observed. A high order of forms means effects like

- Clarity
- Transparency
- Security and safety
- Perfection

- Soundness
- High quality, high valence and
- Longevity.

The respective individual and social evaluation always takes place within a socio-cultural framework. Valuation standards and values are therefore dependent on time and culture. High order = high quality = premium = durable, for example, stand for design concepts that have been established as the standard since the end of the nineteenth century until today.

The methods of form locking and form calming are clearly favoured in product design, if the nature of the product and its method of use allow it. Open, understandable, accessible design appearances become possible. In consideration of functional and especially safety-related requirements, a disclosure of the design and operating principle shall be aimed at. The diversity of design forms is then reduced by a targeted simplification and calming of forms, so that a feeling of order can develop. The use of simple geometric basic forms is an important design approach.

The covering of a polymorphism often has technical reasons, especially safety reasons, because often the wrapping is also a protection against external and internal dangers. In this sense, it also has a protective effect. The visual effect is based on the principle of contraction. One does no longer see the diversity of many individual forms, but only the overall shape.

There is something calming about this, but at the same time, there is something confusing or mysterious about it. In any case, a cover has an ordering effect, since the shape of the cover can greatly reduce the diversity. Both methods are practiced in product design. Both methods can be used to order design phenomena or to reduce or calm their visual complexity. This method also supports the search for product identity via design.

Figure 6.28 shows an example of both possibilities. A bicycle usually has an open design. The form elements that determine function and use create an open, perceptible design appearance by applying the principles of engineering design and shape design (arrangement). The machine tool is closed by a cover. Here the housing design takes over the aesthetic function.

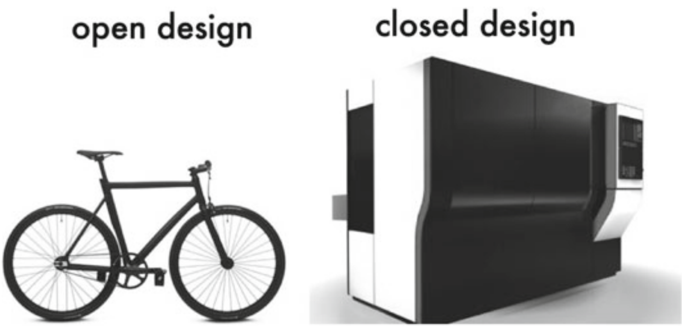


Fig. 6.28 Bicycle and machine tool as open and closed design-product examples [Gatz-2013]

6.7 Summary

Form and shape are the central functional and perceptual prerequisites for the implementation of technical and aesthetic product requirements in product development. If the product developer strives for functional fulfilment through form, the industrial designer creates the conditions for perception, which take place primarily in processes of use. Both stakeholders plan, visualise and materialise the geometrical-material entireness of a product against the background of their specific objectives.

The development of meaningful and perceptive design solutions is a decisive concern in product design. The approach for creative results lies in designing the interrelation between perception and behaviour. Perception, sensation and behaviour of a user or user group can be specifically influenced via the shape of the product.

A perception-oriented theory of form and shape shows the basics and connections, but also shows the directions to be taken in design. *Order* and *complexity* are two design directions in order to design the structure of the shape differently according to the intended effects. However, this exploits far from over the entire repertoire of creative decision-making possibilities. The trained industrial designer applies these possibilities with compositional skill and through the skills he has acquired in creative practice. A high degree of sensitivity for form, colour, material and surface aesthetics constitute the individual prerequisites for professionalism.

Product development generally is an interdisciplinary process. In order to bring out all the characteristics expected of a quality product, interdisciplinary and integrative performance is required, which can only be achieved in appropriate structural and organisational environments such as IDE. From the perspective of industrial design, the particular strength of IDE lies in the comprehensive consideration of humans not only as users of products, but also as their creators and developers, and as those who are not involved *in the* life cycle of the product, but are affected *by it*.

References

[Ehre-1954] Ehrenstein, W.: Probleme der ganzheitspsychologischen Wahrnehmungslehre. Johann Ambrosius Barth Verlag, Leipzig (1954)

[Gatz-2008] Gatzky, T.: Industriedesign in der Ingenieurausbildung: Über ein Ausbildungsmodell, das auf Integration setzt. In: Industriedesign und Ingenieurwissenschaften, TUDpress 2008, Verlag der Wissenschaften

[Gatz-2013] Gatzky, T.: Vorlesungs- und Übungsmaterialien zu den Lehrveranstaltungen Industriedesign/Produktdesign und Entwurf für Ingenieurstudenten der Fakultät Maschinenbau an der Otto-von-Guericke-Universität Magdeburg (2012)

[Gatz-2014] Gatzky, T.: Wahrnehmungsgerechtheit als Gestaltungsaufgabe im Produktdesign. In: Krzywinski, J., Linke, M., Wölfel, Chr., Kranke, G. (Hrsg.) Entwerfen – Entwickeln – Erleben Beiträge zum Technischen Design. TUDpress, Dresden (2014)

[Jako-1993] Jakoby, J.: Ein Beitrag zum wahrnehmungsgerechten Gestalten, Reihe Konstruktionstechnik. Shaker Verlag, Aachen (1993)

[NaGV-2004] Naumann, T., Gatzky, T., Vajna, S.: Integrierte Produktentwicklung als Ausbildungskonzept. In: CAD-CAM Report, Nr. 2, 23. Jahrgang (2004)

[Schü-1988] Schürer, A.: Entwicklungstendenzen im Investitionsgüterdesign in Design aktuell1, Schriftenreihe des design center stuttgart (1988)

[Seeg-2005] Seeger, H.: Design technischer Produkte, Produktprogramme und – systeme – Industrial Design Engineering, zweite Auflage. Springer, Heidelberg Berlin (2005)

[VDMA-24903] Verband Deutscher Maschinen- und Anlagenbau: Obsoleszenzmanagement – Informationsaustausch zu Änderungen und Abkündigungen von Produkten und Einheiten. Entwurf VDMA 24903:2017-06. Frankfurt (2017)

[ZiSc-1990] Zitzmann, L., Schulz, B.: Dokumente zur visuell-gestalterischen Grundlagenausbildung, Hochschule für Industrielle Formgestaltung. Halle-Burg, Giebichenstein (1990)

Chapter 7
Functionality

Kilian Gericke and Boris Eisenbart

The functionality of a technical product encompasses all direct and indirect functions as well as their interactions, which the product provides for use. In interaction with the attributes Product Gestalt and Usability, the Functionality describes the ability of the product to adequately fulfil a specific requirement or a group of requirements.

7.1 Functionality and Function in the Context of Technical Systems

The functionality of a technical system (as defined by HUBKA, Sect. 1.1.1) enables users to derive value from the system and for the system to fulfil a specific purpose. Synthesis and analysis of the functionality of a system require a clear understanding of the individual functions of a system, their interactions with each other and with the environment.

Functionality is closely related to, on the one hand, to the Product Gestalt, which contributes to the realization of functions through design and shape, and, on the other hand, to the Usability of the product, which describes the fitness for use of the system in the planned application context by the intended user. For the Functionality, it is decisive

- the way in which individual functions are implemented (fulfilment type)

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- what proportion of the requirements are fulfilled by the implemented functions (degree of fulfilment) and
- how well the fulfilment is achieved (fulfilment excellence).

Meaning of the term "function"

There are various definitions of the term "function" that can be found in the literature. Often, function describes the specific purpose or activity for which a thing exists. In mathematics, a function is a clear relationship between a series of inputs and permissible outputs, and terms such as *transformation* or *operator* are sometimes used synonymously [Halm-1974].

In engineering, the term "function" can have very different meanings. For one, function is frequently defined as the *ability of* a system to achieve a certain goal, e.g. by showing a certain *behaviour* [Buur-1990, RoEe-1995]. Alternatively, the term is used to describe an intended or required *transformation* or *conversion* of operands (e.g. [Cock-2000, Fowl-1998, BeGe-2020, Rode-1970], i.e. the transformation of input variables into distinct output variables, whereby input and output variables differ from each other, as shown in Fig. 7.1. PAHL and BEITZ [BeGe-2020] define the term as "general and intended relationship between input and output of a system with the aim of fulfilling a task".

Another interpretation of the term refers to the ***purpose*** or ***goal*** of the system [Bucc-2010, SaSh-2007, Ullm-2010, USDD-2011]. This is often discussed as a *teleological* concept of function [HuEd-1988].

The various interpretations of the term tend to revolve around similar aspects and may even overlap with one another; however, none of them includes all aspects associated with function. And although there is no uniform cross-disciplinary definition of the term, there are several central interpretations in connection with the description of functions that can be considered archetypal for engineering. In general, three such functional archetypes can be distinguished [CaGa-2011, Verm-2011]:

1. *Behavioural interpretation:* Function as the intended behaviour of a system;
2. *Result-oriented interpretation:* Function as the desired effects of the behaviour of a system;
3. *Task or goal-oriented interpretation:* Function as the purpose for which a system is intended.

When describing the functionality of a system, a distinction can also be made between different types of functions. One possible distinction is the differentiation between the *overall function* of a system and *sub-functions* [BeGe-2020]. The overall function of the system describes its purpose. HUBKA [Hubk-1984], therefore, also

Fig. 7.1 Understanding a function as transformation from input to output variables

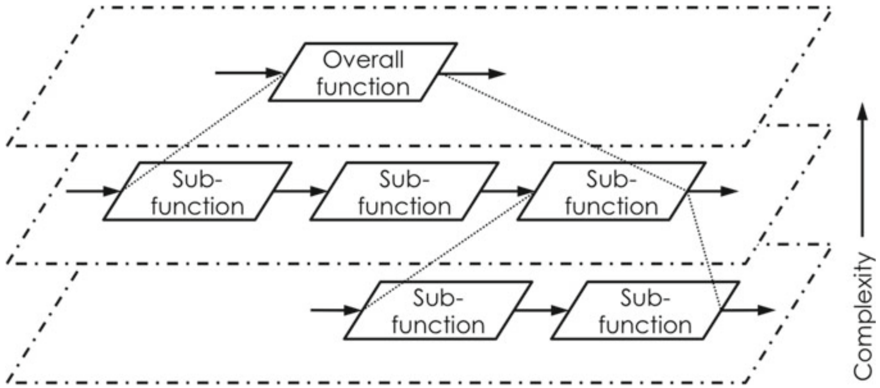

Fig. 7.2 Decomposition of the overall function of a technical system into sub-functions [BeGe-2020]

refers to it as a purpose function or, according to ROPOHL [Ropo-2009], as the teleological function of the system. The overall function can be divided into sub-functions, as shown in Fig. 7.2 The sub-functions are sometimes also referred to as technical functions [Hans-1955, Hubk-1984] and follow the classical input/output paradigm, as shown in Fig. 7.1.

Sub-functions can also be distinguished into main functions and auxiliary (or secondary) functions. Main functions serve directly to fulfil the overall function while secondary functions are of supporting character and depend on the realization of the main functions [BeGe-2020].

7.2 Benefits of Functional Analysis

In most cases, it is impossible to move directly from a given technical problem to a solution, especially if the problem itself is not yet fully understood [BrRe-2003, ChBl-2001]. Starting from the intended purpose of the product, the functional analysis enables product developers and designers to gradually gain a deeper understanding of the necessary central processes required for function fulfilment for which solutions are to be developed subsequently. Both the decomposition of the overall function into sub-functions and the description of the interactions between them reduce the complexity and enable a better understanding of the development task [ErKo-2008, Paet-2006]. Decomposition thus makes it easier to make the so-called creative leap from a problem to a solution [BlUp-1997].

Functional analysis provides developers with the necessary means to make the functions and the resulting functionality of a system clear to themselves or to others. This is especially important in the early phases of product development, when the individual developer does not yet have a clear mental model of what the final system will look like and the development team has to work out a common mental model of what the system should do and what purpose it serves [EiKl-2017]. This is essential both for the division of work in the team (and the subsequent seamless integration of the partial solutions developed), for the validation of the fulfilment of the system's functionality and thus also for the feedback on the development progress to project managers and customers.

Comprehensive functional descriptions support product developers in the early investigation of new solution concepts and enable recurring verification and validation of the emerging or final design by comparison with the original intentions and requirements. The longer product developers remain on the abstract level of functions and functional considerations, the less likely they are to get fixated too early on a single, potentially unsuitable, solution [JaSm-1991].

The consideration of a function is a way to explicitly examine what the proposed system is intended to achieve even before it is designed, thus allowing discussions on these issues during the synthesis of potential solutions. The functional analysis helps developers to thoroughly explore the solution space and to determine step by step a physical, procedural or virtual implementation.

Methodologically, the function is, regarding its position in the overall development process of a product or system, part of the early phases. In this stage, the product development team is still working on clarifying the central tasks and has not yet drawn up a concept (or only an incomplete one). This phase is typically referred to as the concept phase. The concept is based on the product requirements and essentially comprises both *functionality* and *principle solution*, i.e. *the Wirk concept* and the *design concept*. The concept phase thus includes the central transition from a description of the problem to an initial description of what the solution as a whole will achieve and how this could be realized on the basis of current circumstances (although it is possible that other forms of realization are preferred at other times or in the case of different or changed requirements). It is the phase that has the greatest influence on system development and thus on all subsequent development steps [EhMe-2013, GeQu-2013, MaHo-2006]. The overall concept and structure of the solution can be changed most easily in this phase. The decisions made on these aspects will significantly influence the production costs and applicability of the system in later phases of its life cycle.

As a result, Product Gestalt, Functionality and Usability play the key roles in the transition from the description of the desired system or product to a new technical solution for its creation. The function remains an abstract concept in this process. Ultimately, it is the shape or behaviour of a product or system that is visible to humans, not its function as such.

Functional modelling helps product developers to describe the functionality of a system and to reflect on the information in a more structured manner, to revise and refine content and to gradually supplement the model by extending and detailing it as needed. A frequently formulated requirement of functional models is solution neutrality.

The requirement to obtain a solution-neutral description of the technical system has two objectives. On the one hand, the convergence of the solution space should be carried out as late as possible in order to be able to respond as flexibly as possible to changing requirements and new findings. This is intended to reduce additional development costs through complex iterations. On the other hand, conscious abstraction should avoid a fixation on known solutions and thus help to find new and better solutions.

As the degree of concretization of the solution increases, the function model can be extended by secondary functions that depend on the choice of a realization form of main functions. While individual functions can be formulated in a solution-neutral way, the description of secondary functions and their logical combination typically already requires assumptions regarding possible implementations. As the level of detail of a function model increases, additional assumptions must be made about interactions between sub-functions. The decisions made in this way may limit the solution space for the overall solution to a certain extent. This is not necessarily a problem. However, it is important to document these assumptions or to be aware of the resulting limitation of the solution space. Every step of detailing the functional structure should therefore be checked as the possibilities resulting from solution neutrality are limited.

Whether detailed assumptions/decisions influence the development strongly depends on the modeller, the chosen functional modelling approach and the way the model is used. If a functional model is understood as a representation of only one of several alternatives, this is less problematic. The convergence of the solution space is then either done consciously or alternative functional models are compared before further concretization takes place.

7.3 Modelling of Functions and Their Structures

To describe the functionality of a system, it is necessary to describe the overall function and sub-functions as well as their interactions. As already explained, sub-functions can be subdivided into main and secondary functions, if necessary.

The system technical view on which the functional description is based describes the transformation of input variables into output variables that differ from them. The so-called operands, i.e. the entities that are transformed, can be divided into energy, matter and signal, as shown in Fig. 7.3.

The description of the transformation performed by the respective function requires a concretization of the respective operand and the corresponding activity. A function should therefore be described by a noun (which specifies the operand) and

Fig. 7.3 Transformation of energy, material and signal in a technical system [BeGe-2020]

Table 7.1 Operands and activities

Operand	Example	Activities
Energy	Electrical, mechanical, thermal, chemical, nuclear, optical…	Guide, convert, store, enlarge, reduce…
Material	Solid, liquid, gaseous…	Guide, transform, store, mix, separate…
Signal	Analogue, digital…	Manage, input, output, display, save, change…

a verb (which specifies the action), as shown in Table 7.1. As examples, the function of a heating element is to "convert electrical energy into thermal energy", and the function of a drive shaft is to "transfer mechanical energy (from the engine piston to an output gear)".

For the description of the functionality of a system based on its sub-functions, two views are available, the *hierarchical view* and the *transformation view* [BeGe-2020].

7.3.1 Hierarchical View

Individual partial functions can be further subdivided. The functions found in this way describe the necessary transformations of operands of the superordinate sub-function. These relationships between sub-functions of different levels of concretization form a hierarchical structure of all sub-functions necessary to fulfil the overall function, as shown in Fig. 7.4. This view is helpful if the interactions between sub-functions within a concretization level are not (yet) clearly defined.

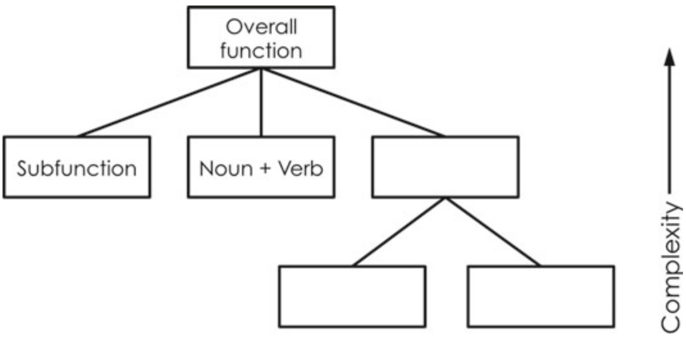

Fig. 7.4 Hierarchical description of functionality [BeGe-2020]

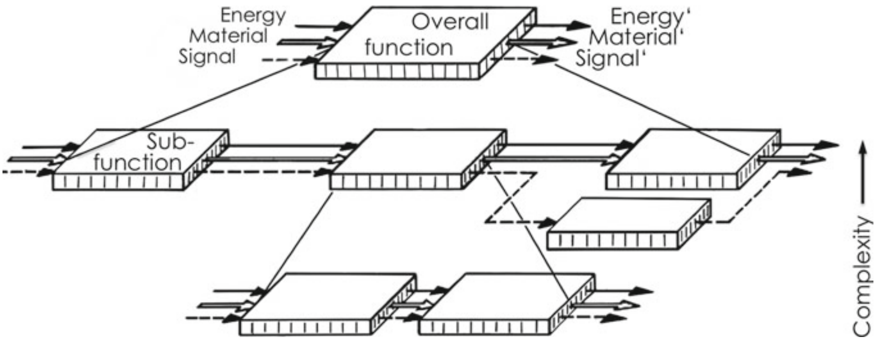

Fig. 7.5 Subdivision of an overall function into partial functions and linking of the flows of the operands involved—function structure [BeGe-2020]

7.3.2 Transformation View

The partial functions of a system interact with each other. Interactions can, for example, affect the temporal or logical sequence of partial functions. If a partial function requires that another partial function was previously realized, this means that the output variables of the first function become input variables of the subsequent function. In this way, the result is a flow of operands through the various partial functions, which are necessary to fulfil the overall function. The transformational view visualizes these flows of operands through the system; it is often referred to as the functional structure, as shown in Fig. 7.5.

7.3.3 Functional Modelling Using an Example

The modelling of the functional structure of a glue gun is explained below, as shown in Fig. 7.6. The overall function (purpose function) of a glue gun consists of connecting several parts with each other, as shown in Fig. 7.7. This can of course be achieved

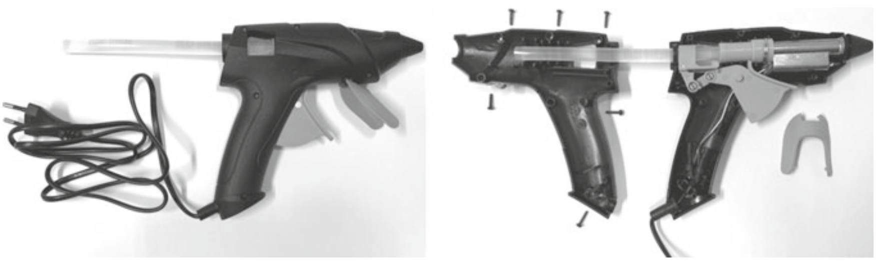

Fig. 7.6 Glue gun [GeEi-2017]

Fig. 7.7 Black-box model to describe the overall function of a glue gun [GeEi-2017]

in different ways using different types of closure (form, force, material closure). Assuming that the bonding of the objects is to be realized by means of material closure using a thermoplastic adhesive, the functional model can be further detailed.

First, the overall function should be decomposed, taking into account the assumptions that limit the solution space. This can be done as a simple list. Then the main flow (here the material flow) should be modelled with regard to the logical sequence of the partial functions. Subsequently, the other partial functions and accompanying flows can be added. This modelling step often requires iterations, since the decomposition of the overall function into partial functions can be performed in different ways and some partial functions are only recognized during subsequent modelling steps. The overall function of *joining parts* can be divided into, e.g. *converting electrical energy into thermal energy, conducting thermal energy, heating adhesive, storing liquid adhesive, dosing adhesive,* etc. At this point, only main functions and no secondary functions should be considered. These modelling steps result in a function structure, as shown in Fig. 7.8.

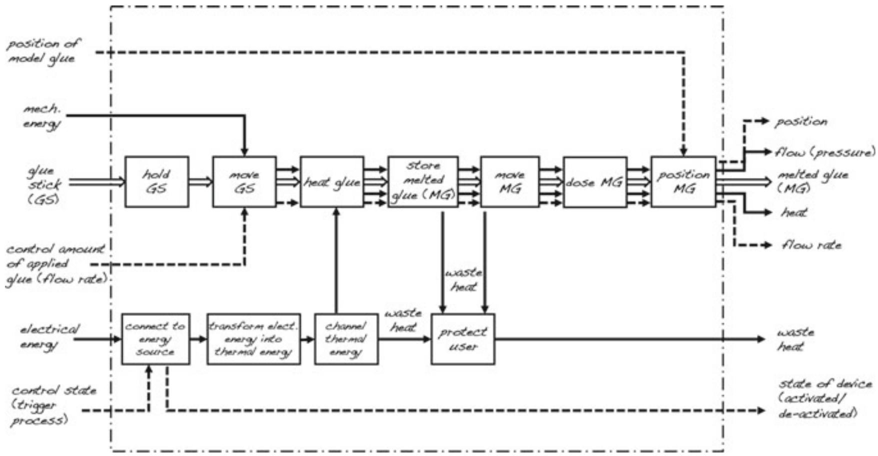

Fig. 7.8 Functional structure of a glue gun [GeEi-2017]

7.4 Supplementary Views on Both Functionality and Functions of Technical Systems

Not all functions can be represented as transformations since the fulfilment of a purpose by a technical system often cannot be reduced to input/output relationships (see also [CaGa-2011, Verm-2011]). In addition to technical functions, further classes of functions can be distinguished. In addition to technical functions, which can usually be described as transformations, there are also social functions (related to the social context of a user, e.g. status function) and aesthetic functions (e.g. "conveying beauty" [Crill-2010]).

The modelling of the functionality of a system can be facilitated by the use of formalized taxonomies (e.g. *Functional Basis*[1] [StWo-2000]) in view of the variety of views on functions and different conceptual understandings. They contain different classes of verbs. In it, the verb shows the special effect on an object that is represented by the noun. A disadvantage of using taxonomies for functional modelling is the loss of contextual information during the transformation of natural language into the language defined by the taxonomy [AhWa-2003].

The described limitations of the modelling approaches and the plurality of the understanding of functions reflect the diversity in the handling of functions and in the description of functionality [Verm-2011].

Importance in functional modelling is the awareness that alternative perspectives and understandings can exist and that these have to be put into relation to one's own understanding. Often these perspectives can be considered complementary. An overview of common perspectives that can be adopted in function modelling is shown in Table 7.2.

There are various modelling approaches that aim at integrating several of the modelling perspectives listed in Table 7.2. One example is the integrated function modelling (IFM) framework [EiGe-2017]. However, such modelling approaches usually require a higher modelling effort and are only recommended for the detailed design of the concept; however, compared to simpler modelling approaches, they then offer clear advantages for the formation of a common system understanding and for accompanying analyses (e.g. costs, risks, system architecture) [EiGe-2017].

7.5 Concretization of the Solution

The concretization of the solution should, if possible, only take place after the functional understanding has been developed. Based on the functional model, alternative solutions in the form of working principles are sought for all partial functions.

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[1] The *functional basis* is a taxonomy for the uniform formulation of functions and their links. The terms, hierarchically structured in eight classes and 30 subclasses, support the uniform description of partial functions using generic, recurring formulations. The flows of the operands are divided into three classes (material, energy, signal) and various subclasses.

Table 7.2 Perspectives of functional modelling [EiQu-2013]

Perspective	Description
States	Representation of the states in which a system can be, or the states of operands before (input) and after (output) an operation (e.g. transformation or technical process)
Transformation processes	Representation of the processes executed by or within the technical system to change the state of the system or the operands. **Technical processes** within the system require different physiochemical effects to make the processes possible. An example is the technical process structure of Hubka [Hubk-1984]. The detailing of the individual technical processes finally leads to a representation as fundamental physiochemical transformation processes in the system, i.e. the effects. There may also be **human processes** within the system, e.g. if a service is part of the technical system (e.g. in a product service system; PSS)
Effects	Presentation of the necessary **physiochemical effects** that enable the transformation of one state into another. Typical examples are the representation of **transformations of an operand**
Interaction processes	Representation of **interaction processes of users** (who are not part of the system) **or other technical systems** with the technical system to be developed. A typical example is the service process model according to [WaMi-2011]
Use cases	Presentation of various cases of **application of the technical system**. This is typically associated with the interaction of an actor (either the user or another technical system) with the technical system, which triggers or requires subsequent processes within the system. A typical example is a *use case scheme* [KrKr-2003]
Technical systems allocation	Description of the **role of an additional or supporting technical system that** is intended to perform or enable a subset of the required effects or processes either within the technical system or through interaction with it. A typical example model is the technical process structure of Hubka [Hubk-1980]
Stakeholder allocation	Representation of the **roles of the various stakeholders**, i.e. users who benefit from a system or operators who contribute to the system, e.g. by executing necessary processes or providing resources, etc. (c.f. also Sect. 4.3). A typical example is a service process model according to [WaMi-2011]

Working principles describe the solution principle on the basis of the underlying physical, chemical or biological effect and define the basic active geometry and active movement. There is a variety of methods that can support the developer in this creative activity. For frequently recurring functions, solution catalogues (e.g. [Roth-2000]) can be used, which describe suitable operating principles in a structured way [BeGe-2020].

The more the active principles are found for individual sub-functions, the greater the possible number of alternatives is. A suitable method for combining partial solutions is the morphological matrix (see also Sect. 15.7 and there the footnote 24).

An overall solution that describes the fulfilment of all partial functions requires the combination of compatible operating principles. Such a combination is known as the active structure. The mode of action of a proposed solution described by the effect structure enables the assessment of the fulfilment of the required functionality on an abstract level even before design, producibility, manageability and other attributes are detailed.

References

[AhWa-2003] Ahmed, S., Wallace, K. Evaluating a functional basis. In: Proceedings of the ASME Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDEC/CIE (2003)

[BeGe-2020] Bender, B., Gericke, K. (eds.): Pahl/Beitz Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung. Springer, Heidelberg Berlin (2020)

[BlUp-1997] Blessing, L.T.M., Upton, N.: A methodology for preliminary desing of mechanical aircraft systems. In: AIAA/SAE World Aviation Congress, American Institute of Aeronautics and Astronautics. Reston (USA) (1997)

[BrRe-2003] Braha, D., & Reich, Y.: Topological structures for modeling engineering design processes. Res. Eng. Design 2. **14**(4), 185–199 (2003)

[Bucc-2010] Bucciarelli, L.L.: From function to structure. Retrieved 10 Dec 2018, from https://dspace.mit.edu/handle/1721.1/51789 (2010)

[Buur-1990] Buur, J.: A Theoretical Approach to Mechatonics Design. Technical University of Denmark, Lyngby (1990)

[CaGa-2011] Carrara, M., Garbacz, P., Vermaas, P.: If engineering function is a family resemblence concept. assessing three fomalization strategies. Appl. Ontology. **6**(2), 141–163 (2011)

[Cock-2000] Cockburn, A.: Writing Effective Use Cases, vol. 1. Addison-Wesley, Indianapolis (USA) (2000)

[Crill-2010] Crilly, N.: The roles that artefacts play: technical, social and aesthetic functions. Des. Stud. **31**(4), 311–344 (2010). https://doi.org/10.1016/j.destud.2010.04.002

[EhMe-2013] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit (5.). Carl Hanser Verlag (2013)

[EiGe-2017] Eisenbart, B., Gericke, K., Blessing, L.T.M., McAloone, T.C.: A DSM-based framework for integrated function modelling: concept, application and evaluation. Res. Eng. Des. **28**(1), 25–51 (2017). https://doi.org/10.1007/s00163-016-0228-1

[EiKl-2017] Eisenbart, B., Kleinsmann, M.S.: Implementing shared function modelling in practice: experiences in six companies developing mechatronic products and PSS. J Eng Des 2. **28**(10–12), 765–798 (2017)

[EiQu-2013] Eisenbart, B., Qureshi, A., Gericke, K., Blessing, L.: Integrating different functional modeling perspectives. In: Proceedings of the International Conference on Research into Design (ICoRD'13). Springer, Chennai (2013)

[ErKo-2008] Erden, M., Komoto, H., van Beek, J.T., D'Amelio, V., Echavarria, E., Tomiyama, T.: A review of function modeling. Approaches and applications. Artif. Intell. Eng. Des. Anal. Manuf.—AIEDAM. **22**(2), 147–169 (2008)

[Fowl-1998] Fowler, M.: Analysis Patterns: Reusable Object Models. Edison Wesley Longman Inc. Boston (1998)

[GeEi-2017] Gericke, K., Eisenbart, B.: The integrated function modeling framework and its relation to function structures. Artif. Intell. Eng. Des. Anal. Manuf. AIEDAM **31**(4), 436–457 (2017). https://doi.org/10.1017/S089006041700049X

[GeQu-2013] Gericke, K., Qureshi, A.J., Blessing, L.: Analyzing transdisciplinary design processes in industry—an overview. In: Proceedings of the ASME Design Engineering Technical Conference, vol. 5. https://doi.org/10.1115/DETC2013-12154 (2013)

[Halm-1974] Halmos, P.R.: Naive Set Theory. Springer, New York (1974)

[Hans-1955] Hansen, F.: Konstruktionssystematik; eine Arbeitsweise für fortschrittliche Konstrukteure (2.). Verlag Technik, Berlin (1955)

[Hubk-1980] Hubka, V.: Allgemeines Vorgehensmodell des Konstruierens: Konstruktionsmethodik, vol. 1. Fachpresse, Goldach (1980)

[Hubk-1984] Hubka, V.: Theorie technischer Systeme: Grundlagen einer wissenschaftlichen Konstruktionslehre (2.). Springer, Berlin (1984)

[HuEd-1988] Hubka, V., Eder, W.E.: Theory of Technical Systems: A Total Concept Theory for Engineering Design. Springer, Berlin (1988)

[JaSm-1991] Jansson, D., Smith, S.: Design Fixation. Des. Stud. **12**(1), 3–11 (1991)

[KrKr-2003] Kroll, P., Kruchten, P.: The Rational Unified Process Made Easy: A Practitioners Guide to the RUP. Addison-Wesley, Boston (2003)

[MaHo-2006] Maarten Bonnema, G., Van Houten, F.J.: Use of models in conceptual design. J. Eng. Des. **17**(6), 549–562 (2006). https://doi.org/10.1080/09544820600664994

[Paet-2006] Paetzold, K.: On the importance of a functional description for the development of cognitive technical systems. In: Proceedings of 9th International DESIGN Conference DESIGN 2006. Dubrovnik, Croatia (2006)

[Rode-1970] Rodenacker, W.G.: Methodisches Konstruieren. Springer, Berlin (1970)

[RoEe-1995] Roozenburg, N.F.M., Eekels, J.: Product Design: Fundamentals and Methods. Wiley, Chichester (1995)

[Ropo-2009] Ropohl, G.: Allgemeine Technologie—Eine Systemtheorie der Technik. Univ.-Verl. Karlsruhe, Karlsruhe (2009)

[Roth-2000] Roth, K.: Konstruieren mit Konstruktionskatalogen—Band 1: Konstruktionslehre (3rd ed.). Springer, Berlin (2000)

[SaSh-2007] Sakao, T., Shimomura, Y.: Service Engineering: a novel engineering discipline for producers to increase value combining service and product. J. Clean. Prod. **15**, 590–604 (2007)

[StWo-2000] Stone, R.B., Wood, K.L.: Development of a funcional basis. J. Mech. Des. **122**(4), 359–370 (2000)

[Ullm-2010] Ullman, D.G.: The Mechanical Design Process, 4th edn. Boston and Mass, McGraw-Hill (2010)

[USDD-2011] US DoD.: Systems Engineering Fundamentals. Fort Belvoir (USA): Defence Acquisition University Press (2001)

[Verm-2011] Vermaas, P.E.: Accepting ambiguity of engineering functional descriptions. In: Procs of 18th International Conference on Engineering Design (ICED11) p. 10. (2011)

[WaMi-2011] Watanabe, K., Mikoshiba, S., Tateyama, T., Shimomura, Y., Kimita, K.: Service design methodology for cooperative services. In: Proceedings of ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC CIE. Washington D.C. (2011)

Chapter 8
Product and System Ergonomics

Harald Schaub

This chapter deals with the basics of Usability, the third IDE product attribute. The interaction of Product Gestalt, Functionality and Usability lead to the Usability of a product. For this purpose, the product must also be well designed from an ergonomic point of view, so that it fulfils the customer's demands both in physiological and psychological-cognitive terms. Thus, the inclusion of ergonomic principles in IDE ensures the Usability of the product.

8.1 Introduction

The basis of product and system ergonomics is human-system interaction, which is often characterised by the term "socio-technical system" [TrBa-1951, Ropo-2009]. The focus is on the task to be accomplished (work, leisure time): people, organisation and technology are equal resources for the fulfilment of the tasks. In many developments, a factual and temporal dominance of technology can be observed. This dominance is a general problem, as brain researcher Ernst PÖPPEL states analogously: One gets the impression that technological developments are mainly driven by young male right-handed engineers who enthusiastically develop what they can. But too seldom is it asked what people need and how they can use it [Pöpp-2000].

Both in the physiometric area, mistakes will be made in the conception and project planning phase of product and system development (with regard to the ergonomic factors of the user, for example with regard to body size). But also psychosocial and communicative factors such as cognitive processing mechanisms, thinking traps, perception deceptions, expectation breaks, communication problems, emotional and motivational imprints, social processes etc. will be either insufficiently or not at all

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considered in the conception and project planning phase. This leads to products and systems that are difficult or error-prone to operate, with high frictional losses and high error probabilities. This becomes fatal when the user has to use the technical systems under critical conditions with stress, hazards and uncertainty (an overview can be found in [BaHL-2008]).

The product and system ergonomics serve different purposes. Within the framework of the user experience (UX), it is intended to give the user an appropriate feeling in dealing with the product or system. In addition, it should also be usable and safe (cf. [Norm-2002]).

In order to ensure safe operation of the system and to prevent damage to persons directly or indirectly affected, it is necessary to regularly review occupational safety and the associated laws, guidelines and regulations. Before commissioning, a product-related risk assessment must be prepared and updated for the system and all planned products and their expected conditions of use. With the commissioning of the system (whether only partially or in the form of a demonstrator), a risk assessment must be carried out in relation to the workplace, activity or occupation by determining the work processes and activities.

This concern questions of occupational health and safety with the essential tasks of preparing risk assessments, ensuring the operational safety of the system and the product safety of the products used, as well as providing appropriate instruction and training. The commissioning phase is critical from an occupational health and safety perspective. Here, based on the product-related risk assessments, the workplace or work process-related risk assessments must be verified.

Within the framework of this concept, an essential selection of general legal bases, standards and regulations specific to the German armed forces is named.

A central element of ergonomic design and occupational safety is the risk assessment (and the measures derived from it). A product-related risk assessment must be prepared and updated for the system and all planned products and their use, accompanying the course of the project (cf. [HaKM-2004]).

8.2 Ergonomics

The design of a product, in addition to compliance with occupational health and safety regulations—especially for work equipment and workplaces—primarily involves ergonomic issues. Thus, in the risk assessment, the products must also be evaluated within the framework of the regular and expected work processes with regard to risks to the health of the person working there. In order to ensure the lowest possible risk or the best possible design of the work equipment, it is important to provide a working environment that is sensibly designed with regard to use and tasks (human-compatible design).

8.2.1 Delimitation of Terms

8.2.1.1 Ergonomics

The aim of ergonomics ("ergon": engl. "work", "nomos": engl. "rule") is to optimise the holistically considered work system consisting of people, organisation and technology. In general, the aim is to reduce the workload on people, to avoid physical and psychological (consequential) damage and to increase work performance.

In the ergonomic design of a workplace, it is therefore essential to consider all interfaces between man and work system. This includes the technology used, the processes and the organisation of work. In addition to the anthropometric-physical design of workplaces, this also includes, for example, ensuring good usability of the software used and providing environmental conditions that promote concentration and attention [ScBL-2010].

8.2.1.2 Usability

Usability according to DIN EN ISO 9241-11 [DIN-9241-11] means the extent to which a product or system can be used for effective, efficient and satisfactory processing of the intended tasks. Both the user groups and the application context must be defined.

8.2.1.3 User Experience (UX)

The term User Experience (UX), often used in the marketing context. UX means all perspectives and impressions of a user during product or system interaction. An important aspect of the UX view is the question of how the product or system fulfils the user's expectations.

DIN ISO 9241-210 [DIN-9242-210] describes user experience as the behaviour of a user that results from interaction with the product or system. This includes the emotions of the user, his or her psychological and physiological reactions, expectations and behaviour.

8.2.1.4 Human Factors

Human factors sometimes referred to as human factors or human influencing variables in German, are used to summarise the psychological, cognitive and social factors that influence human-product/system interactions in socio-technical systems. Human Factors focuses less on the physical and anthropometric characteristics of humans [BaHL-2008].

Despite many attempts, including norm-based ones, to define the terms, their use in literature is hardly uniform. In the context of this chapter, therefore, the term ergonomics is preferred, which—depending on the context—may also include aspects of other terms.

8.2.2 Introduction to the Topic "Workload"

The ergonomic design of products and systems has as an essential goal to control the load and stress ("workload") during a product or system use (depending on the application, not too high or not too low).

Under *strain*, all external influencing factors are subsumed which are capable of triggering a reaction of the organism. *Stress* is understood to mean any reaction caused by an external influencing factor. This can affect the entire body, an organ system, a single body organ or an isolated function of an organ. Nevertheless, stress on the human body must be seen as a reaction of the whole body and always as a consequence of stress from all areas of life [JexS-1998].

The exposure at a specific product, system or workplace can result from

- nature and difficulty of the work task itself,
- physical, chemical, biological working environment conditions,
- specific enforcement conditions (e.g., technical aids, time limits),
- social relationships with superiors and employees.

and can lead to stress which is

- non-specific (e.g. in the sense of a general activation with each activity, recognisable by an acceleration of heart and respiratory rate, increase in the degree of alertness) and/or
- specific (e.g. sweat secretion under the influence of heat, activation of certain enzyme systems when exposed to pollutants, special adaptation mechanisms when similar stresses are repeated).

Mental stress and strain are defined in DIN EN ISO 10075 [DIN-10075]. The concept of mental stress is based on the occupational psychological stress and strain concept and includes all (objective) factors acting on the person from outside, which require the worker to be involved. Thus, stress results from the requirements of the respective work activity and can lead to psychological stress via the working person. Thus, stresses and strains represent the consequences of stress. These are changes in the performance, well-being and health of the working person

The objective of a workload analysis is the investigation of the perception, communication and information processing processes as well as the operating and decision-making processes of the users when operating a system. The load/stress analysis (or workload analysis) identifies technical, social or psychological conditions for inefficiencies and wrong conclusions/actions. Conversely, possibilities of

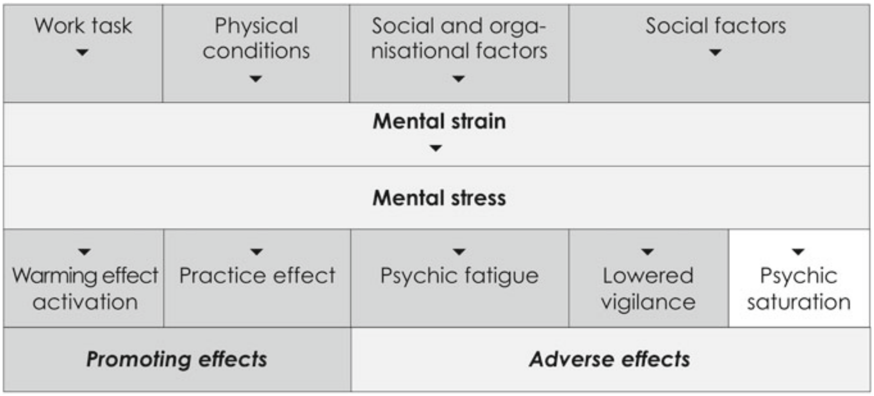

Fig. 8.1 Mental stress and strain

stress regulation for coping with stressful situation conditions, improvement possibilities for attention and vigilance and the restoration of the ability to use the system for certain tasks are worked out.

On the one hand, the workload analysis examines the performance of the crew under various requirement conditions. The performance is evaluated according to the crew's existing understanding of the situation, the tactical performance and the subjective and objective experience of stress and psychological strain. On the other hand, the competence requirements of the core crew are assessed [GaRo-2013].

Mental stress is also dependent on personal characteristics, qualifications and current performance, Fig. 8.1.

In order to systematically determine potential stress factors of work activity, it is first necessary to consider which aspects of a work activity have an influence on the operator. These are three main areas:

- Work activity
- Environment conditions
- Work organisation conditions.

The work activity itself influences not only the quantity and quality of the work results through its content, i.e. through the main work task and its associated partial and secondary activities but also the strain and possible errors of the operator. For example, a varied activity can prevent early signs of fatigue caused by monotony. The responsibility assigned to an operator/guide with a task can have a beneficial effect on the one hand, but also a dysfunctional one on the other, for example in the form of stress. Requirements for the design of the workplace and work activities are formulated in EN ISO 9241 (Ergonomics of human-system interaction) [ISO-9241-110] or ISO 13407 (User-oriented design of interactive systems) or in MIL-STD-882 (System Safety) [MILs-882D], among others.

The environmental conditions in which a work activity is embedded include the design of the workplace. A dysfunctionally designed workplace represents a stress factor that can have a dysfunctional effect not only on the strain on the operator but above all on the work result (incorrect work results).

Work organisation conditions include potential stress factors that do not result from the work activity itself, but from its framework conditions. For example, an inadequate shift or break system can lead to states of exhaustion among operators.

Stress factors that are objectively present in different workplaces do not necessarily lead to dysfunctional stresses. The extent to which determined stress factors cause dysfunctional stresses always depends on several factors:

- On the strain itself (type of stress, intensity, importance within the work activity, duration and frequency of its occurrence);
- On the design of the framework conditions of the work activity;
- On characteristics, abilities and skills of the operator or the typical characteristics of the role/job description.

A fairly common measure used to determine workload is the NASA Task Load Index (NASA-TLX). The NASA TLX was developed by HART and STAVELAND [HaSt-1988]. Workload is measured across six dimensions: mental demand, physical demand, time demand, performance, effort, and frustration. The quality of the measurement depends on how well the respondents understand the dimensions. So the NASA TLX uses a multidimensional approach to measuring workload, capturing the construct in its complexity. The application context was initially the aerospace industry. However, the tool has since been used in a wide variety of contexts, including the automotive industry and the use of computers. Compared to other common indicators, the NASA TLX has comparably good sensitivity. Clear advantages are its ease of use and comprehensibility. The NASA-TLX is considered a very practical tool.

Basically, a workload analysis is used to determine the characteristics of product and system usage, work activity, work environment, work organisation and special requirements. These characteristics are either recorded explicitly or can implicitly influence the recording and evaluation of the workload.

It can be recorded in various aspects, each with the appropriate (objective and/or subjective) methods, including:

- Ergonomic characteristics of the task in product/system use
  - Variety
  - Holistic
  - Scope for action
  - Responsibility
  - Feedback from the activity or the result
  - Task-related communication and information
  - Tools used
  - Complexity of the work tasks
  - Error tolerance
  - Completeness of work tasks, disruptions in the workflow

- Adjusted qualification
- Emotional demands
- Adjusted working hours, time requirements, work intensity
- Social inclusion
- Task-based attention and vigilance
- Task-related cognitive requirements
- Knowledge and problem-solving parts
- Adequacy of tasks
- Self-descriptiveness
- Controllability
- Compliance with expectations
- Error tolerance
- Customizability
- Learning facilitation
- etc.

• Ergonomic characteristics of the working environment when using the product/system:

- General description
- Lighting
- Noise
- Climate
- Hazardous substances
- Olfactory stress
- Ergonomics of the workplace: console, work table or desk, work chair, etc.
- Ergonomics of work equipment: apparatus, boards and shelves, monitor, keyboard, etc.
- Ergonomics of the software
- Social rooms
- etc.

• Ergonomic characteristics of work organisation in product/system use

- General description of the organisational structure
- Work organisation form
- Process organisation
- General working time arrangements
- Shift system
- Break regulation
- Overtime
- Opportunities for advancement
- Remuneration
- guided tour
- Error and safety culture
- Possibilities of informal communication/support
- etc.

- Other relevant ergonomic requirements/specific stresses and strains during product and system use:
  - Training
  - physical performance/strength
  - Attention/vigilance/monotony
  - Times of special performance requirements/adaptation to the circadian rhythm
  - Time constraint/time limits/time pressure
  - Interruptions to work
  - Discrepancies between performance and requirements
  - Social conflicts
  - Forced postures
  - Job insecurity
  - etc.

The collection of the characteristics is embedded as an analysis phase in the general procedure of a workload analysis. Only if the objectives and scenarios to be considered are clarified, if the questions/hypotheses are appropriate, and if the evaluations are methodologically sound and pragmatically oriented, can reliable and useful results be expected.

8.3 Procedure for the Ergonomic Design of Products and Systems

First of all, a delimitation of the ergonomic aspects to be considered is made. Based on the process of user-centred development anchored in ergonomics, future user groups and activities are described in more detail. The basis for this are frequently provided documents, findings from the inspection of previous versions, demonstrators and explanations resulting from the various workshops with users and other information exchange.

The following reference documents are examples of relevant for the design of work centres:

- Handbook of Ergonomics (HoE) [BJRS-2013],
- DIN EN ISO 9241-5 to -6 “Ergonomics of human-system interaction”
- DIN EN ISO 11064-4 and -6 “Ergonomic design of control centres”,
- DGUV[1] Information 215-410 “VDU and office workplaces—Guidelines for design”,
- DGUV Information 215-441 “Office space planning—aids for the systematic planning and design of offices and,
- MIL-STD-1472G “Human Engineering” (for military products).

[1]German Statutory Accident Insurance (Deutsche Gesetzliche Unfall-Versicherung, DGUV, www.dguv.de).

Specific ergonomic analyses can be supported by "ergonomic" CAD systems (e.g. the software RAMSIS [FATB-1995]. Typical results of these analyses are questions concerning the

- perceptibility of information (visual analyses),
- accessibility and operability of devices and control elements and
- necessary adjustability and customizability of the products (for example, in the case of an office workplace, the adjustability of chairs and tables).

Ergonomics concepts should be developed under the condition that they meet the requirements of the respective laws, regulations and information and the resulting requirements (for Germany, for example, these are the guidelines of the DGUV). Any conflicts arising with regard to the fulfilment of the requirements must be recorded and resolved with the client and the developers.

8.3.1 General Analysis

This section explains ergonomic aspects and recommendations that can be applied in the ergonomic analysis. First of all, the intended user group and their expected activities with the product or the system have to be defined. Subsequently, the generic activities that are necessary to fulfil future usage scenarios should be described.

The user group to be considered can be classified according to age, gender, body measurements (for example, typical legal requirements for office workplaces are the consideration of the size range from the lower 5th percentile, female to the upper 95th percentile, male; here, the respective reference year of the statistics used must be taken into account, cf. [DGUV-2017]).

Excessive strain on users with or at a product can be avoided by a safe and ergonomic design with regard to the use of work equipment (in the case of office workplaces, for example, work tables, office chairs, monitors, etc.). A correctly designed product/system also ensures that users can work without health problems or reduced performance. This is of great importance, for example, in monitoring activities to ensure a high level of concentration and attention of the operators.

In the case of office workplaces, ergonomic considerations with regard to lighting, room climate and noise protection are important. Here, the recommendations of the DGUV (www.dguv.de), the Handbook of Ergonomics [BJRS-2013] and ISO 11064 Part 6 [DIN-11064] can be referred to. It must be taken into account that the evaluation of the relevant requirements must be adapted to the respective time and progress of product or system development.

For example, the following statutory requirements for office workplaces with regard to lighting can be identified [DGUV-2017]:

- Natural light is always preferable to artificial light
- Screens should be placed at a 90° angle to the window
- Matt screen surfaces should be used to avoid reflected glare

- Artificial lighting should be provided by a combination of direct and indirect lighting
- Too small differences in luminance between the workplace and its surroundings should be avoided, and
- The required reflection and gloss levels of the work equipment and environment are maintained.

8.3.2 Ergonomic Specifications During Development and Design Recommendations

Beyond the physiological factors of product ergonomics, design recommendations are formulated for the cognitive factors of ergonomics. This is mainly covered by the ISO 9241-110 standard [ISO-9241-110], which relates to interaction with products and systems. Originally it was formulated with regard to the dialogue design of software, but today it is applied to practically all interactive systems.

The standard formulates seven guiding ideas which are relevant for the design of a human-system (product, machine, system) interface:

- Task Adequacy: "An interactive system is a task adequate if it supports the user in completing his or her work task, i.e. if functionality and dialogue are based on the characteristics of the work task rather than on the technology used to complete the task" [ISO-9241-110].
- Self-descriptiveness: "A dialogue is self-descriptive to the extent that it is obvious to the user at all times in which dialogue, at which point in the dialogue he is, what actions can be taken and how these can be carried out [ISO-9241-110].
- Conformity with expectations: "A dialogue is in conformity with expectations if it corresponds to the user concerns foreseeable from the context of use as well as generally accepted conventions [ISO-9241-110].
- Learning facilitation: "A dialogue is learning facilitating if it supports and guides the user in learning how to use the interactive system" [ISO-9241-110].
- Controllability: "A dialog is controllable if the user is able to start the dialog flow and influence its direction and speed until the goal is reached" [ISO-9241-110].
- Error tolerance: "A dialog is error-tolerant if the intended work result can be achieved with either no or minimal correction effort on the part of the user despite recognisably incorrect entries [ISO-9241-110].
- Individualisability: "A dialogue is individualisable if users can change the human-system interaction and the presentation of information to adapt it to their individual abilities and needs" [ISO-9241-110].

Empirically, the questions of attention, stress and personal preferences can be recorded using various methods (the bases are, for example, DIN EN ISO 10075 and DIN EN ISO 6385).

In order to be able to realistically assess ergonomic requirements and effects, it is necessary to survey the physical and psychological factors (attention, stress, strain, etc.) in interaction with the product, the system or at the workplace in the form of ergonomic task and process analyses. These analyses should be carried out for the different user roles to be expected and for different usage scenarios. Specific framework conditions such as use in private or professional environments, levels of automation of the systems or different shift or role plans must be taken into account.

In order to be able to realistically and practically record the ergonomic implications, the necessary task, load and stress analyses should ideally be carried out directly during product or system use, for example at the workplace with realistic, practical tasks. The ergonomically relevant factors are recorded by technical recording methods, in particular by so-called eye-tracking measurements. The use of eye-tracking measurements usually offers a high measurement quality and good resilience of the results.

The knowledge gained in this way is verified and expanded through observations by ergonomics experts, through interviews with users, but also with trainers and other persons if necessary, and—if available—through document analysis of existing work processes (including job description, job specification, job planning, training and further training, employee qualifications, safety-relevant regulations, checklists, etc.).

Since not all situations can be depicted in an empirical setting (for example, because the product does not yet exist or the application situation is dangerous or can only be produced at great expense), the method of the so-called "Cognitive Walkthrough" lends itself. This involves thinking through the respective usage scenario and the associated interaction processes with the product or system. With the Cognitive Walkthrough, ergonomics experts, developers and users put themselves in the shoes of a hypothetical user and work through the various work steps, stress, strain and error possibilities. The Cognitive Walkthrough [WRCP-1994] is a proven usability/workload inspection method in the context of expert/user/operator surveys in analytical evaluation procedures and is used when empirical evaluation procedures (e.g. analysis directly at the workplace) are not possible to capture the work process.

In order to identify ergonomic weaknesses in the lived procedures and the given processes, the data and findings resulting from the observations, from the analysis of the documentation and from the workshops and interviews with the users are analysed with the common methods of weak point analysis, For example, structured analysis, SWOT analysis, Ishikawa diagram (Sect. 13.3.1), FMEA (Failure Mode and Effects Analysis, Sect. 13.3.2), causal tree method, root cause analysis, FTA (Fault Tree Analysis), ECFA (Events and Causal Analysis), fault tree analysis, HFIT (Human Factors Investigation Tool)—to name but a few—are examined.

8.4 Ergonomics and Occupational Safety

Occupational health and safety measures serve to prevent accidents and health hazards at work. A further objective is the humane organisation of work. The employer is responsible for a functioning occupational health and safety organisation in the company with the obligation to carry out a risk assessment. For this reason, questions of ergonomics cannot be dealt with without simultaneously taking occupational health and safety into account.

Occupational health and safety management systems (OSH management systems) are an effective instrument for supporting and improving occupational health and safety [BrSI-2008].

According to the Occupational Safety and Health Act, the employer is obliged to appoint company doctors and occupational safety specialists according to certain requirements. These have the task of supporting him in occupational health and safety and accident prevention in his company. They are not bound by instructions when applying their expertise and must not be disadvantaged in the performance of their duties.

The Occupational Safety Act is substantiated by the accident prevention regulations of the statutory accident insurance institutions.

Statistics show a high proportion of accidents occurring during the use of workplaces. For example, floors, traffic routes and stairs are named as accident black spots in the first place. In order to prevent accidents, the ordinance specifies suitable measures or protection targets for the setting up and operation of workplaces, including traffic and escape routes, storage and ancillary rooms, but also sanitary, break/standby and first aid rooms as well as accommodation.

8.4.1 Risk Assessment

The risk assessment forms the basis for comprehensive occupational health and safety to prevent accidents at work and work-related health hazards. The risk assessment forms the basis for an appropriate selection of work equipment, working materials, working procedures, workplaces and work processes. The employer must observe various principles in occupational health and safety measures and identify possible limitations of these principles in the course of the risk assessment.

- Any danger to life, physical and mental health must be avoided or minimised as far as possible.
- Dangers must be tackled at their source.
- The state of the art, occupational medicine, hygiene and assured ergonomic findings must be taken as a basis.
- Technology, work organisation, working conditions, social relations and the environment must be considered in a meaningful way with regard to the workplace.
- Individual protection measures are secondary to other measures.
- Special risks for particularly vulnerable groups of employees must be taken into account.
- Appropriate instructions of the employees must be ensured.
- Gender-specific regulations are inadmissible (except such biological ones that are mandatory).

In order to comply with these principles and to avoid the hazards listed below, a risk assessment must be carried out. This can use various methods/procedures (plant inspections, employee surveys, safety inspections of work equipment, special event, safety or risk analyses). The type and scope of the risk assessment are determined by the expected risk potential, the work processes and work equipment used, experience and personnel and organisational requirements in the company.

The following hazard classes must always be considered:

- Mechanical hazards: Controlled moving unprotected parts, parts with dangerous surfaces, transport and mobile work equipment, uncontrolled moving parts, falling/slipping/tripping/buckling, falling.
- Electrical hazards: Electric shock and arcing, static electricity.
- Hazardous substances: Lack of hygiene when handling hazardous substances, inhalation of hazardous substances, skin contact with hazardous substances, physical and chemical hazards (e.g. fire and explosion hazards, uncontrolled chemical reactions).
- Biological agent: Infections, sensitising effects (for example aerosol formation).
- Fire and explosion hazards: Flammable solids/liquids/gases, explosive atmospheres, explosives and pyrotechnic articles.
- Thermal hazards: Hot media/surfaces, Cold media/surfaces.
- Hazards due to specific physical agents: Noise, Ultrasound/Infrasound, Whole body vibration, Hand-arm vibration, Optical radiation, Ionising radiation, Electromagnetic fields, Vacuum/Overpressure.
- Hazards due to working environment conditions: Climate, lighting, suffocation/drowning, inadequate escape routes, insufficient space for movement at the workplace/unfavourable workplace layout/inadequate breaks/sanitary facilities, man-machine/computer interface.
- Physical load/work severity: Lifting/holding/carrying, pulling/pushing, manual work with low physical forces, forced posture (forced posture), climbing/climbing, work with increased exertion and/or force.
- Psychological factors: Work content/task, Work organisation, Social relations, Working environment.
- Other hazards: Violence in the workplace, by animals, by plants/plant products.

8.4.2 Ergonomics and Operational and Product Safety

Operational safety is the safety of plant, machinery, equipment and working materials used in commercial operations. The Ordinance on Industrial Safety and Health summarises the occupational safety requirements for the provision of work equipment by the employer and the use of work equipment and systems by employees at work, including the operating regulations for systems requiring monitoring.

Product safety covers a wide range of legislation relating to the making available of products on the market. The supplier must prove compliance with the relevant directives when using the product.

8.4.2.1 CE Marking

A requirement of the area regulation C1-2010-7001, risk assessment as well as determination of safe commissioning within the framework of Customer Product Management (amended) [C1-2010-7001], is that military products if they are covered by at least one CE directive, should also undergo a CE conformity assessment procedure.

The supplier of work equipment must, therefore, state in the offer whether the work equipment offered are covered by at least one CE directive and whether an EC declaration of conformity is the delivery item and whether the product will be CE marked[2].

The CE marking indicates that the product complies with the basic product safety regulations applicable to the product. This represents a guaranteed product property. If it is subsequently established that, for example, a harmonised standard applicable to the product states a protection objective that has not been implemented, this constitutes a defect in the product. In this case, the manufacturer/supplier can be requested to remedy the defect.

8.4.2.2 Own Production

During configuration, care should be taken to ensure that the functional interlinking of different installations does not result in a system that would result in an independent EC conformity assessment procedure. Equipment from different manufacturers is often purchased and used by the operator as a stand-alone system. The result is a "chained" system, in the parlance of the Machinery Ordinance a "totality of machines". As a rule, each manufacturer issues an EC declaration of conformity for the plant supplied. Whether a CE conformity assessment procedure must be carried out for the interlinked system and an EC declaration of conformity issued depends on the following factors.

- There must be a functional link,
- There must be a control system link and,
- There must be a safety link.

Only when all three of the above conditions are met is it necessary to draw up an EC declaration of conformity for the linked system. In this case, care should be taken to ensure that in the procurement process this task is entrusted to a single contractor.

8.4.3 Ergonomics Together with Instruction and Training

Hazards can also arise in particular from insufficient qualification, ability and skill as well as insufficient instruction of the employees.

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[2]CE is the abbreviation of "Conformité Européene" ("European Conformity" in French).

The employer must instruct the employees in such a way that they are able to recognise health hazards as such and react to them appropriately. A prerequisite for regular instruction is a precise adjustment to the respective work situation in the company.

Instruction and training is a subordinate measure to counteract hazards and is only chosen if the technical or organisational possibilities are exhausted.

It is important to exclude hazards in the following order:

1. Avoid/eliminate source of danger.
2. Safety-related measures to separate the hazard from humans (spatial separation, e.g. encapsulation, extraction, protective grids, light barriers).
3. Organisational measures to separate the hazard from the person (work organisation, work sequence, working time and break arrangements).
4. Use of personal protective equipment to prevent/reduce exposure to humans (e.g. gloves, hearing protection, safety shoes, breathing protection).
5. Behaviour-related measures for safety-oriented behaviour (testing, monitoring, training and instruction of employees).

For emergencies, safety training courses shall be defined and conducted regularly (e.g. evacuation, behaviour in emergencies, e.g. in case of fire and the like).

At this point, the effects of automated functions should be pointed out. Contrary to the frequently expressed opinion that automation reduces the need for training and proven competence of operators, the opposite is true for safety-critical systems, especially, but not only, for weapon systems. In order to be able to act in case of compromise, failure or malfunction of the system, the operator needs comprehensive training.

8.4.4 Ergonomics and Implementation

The following principles must be observed during implementing:

- In the case of machines, commissioning may only take place when the machine meets the requirements of the relevant EC directives and has been verified and documented by the EC declaration of conformity and CE marking.
- A hazard assessment must be available with the statement of safe implementation (FSI) prior to first commissioning by a member of the German Federal Army.
- The risk assessment must be updated during use.

During implementation, further sources of danger must be evaluated from the point of view of occupational safety (with regard to the requirements of the Product Safety Act and within the framework of a risk assessment). This assessment can only be made once the work system has been specifically configured.

8.5 Selection of General Legal Bases and Standards

The following list is a compilation of legal bases and standards, which have to be observed when developing and designing products. The legal bases and standards given below are valid in Germany and in Europe. Most of them are as well parts of the ISO, the International Organisation for Standardisation. This means that the same, equivalent or similar legal bases and standards exist and can be observed appropriately worldwide.

- Health and Safety at Work Act,
- Workplace regulations, workplace rules,
- Occupational Safety and Health Act,
- Industrial Safety Regulation,
- Screen handling regulations,
- Chemicals Act,
- Youth Employment Protection Act,
- Air Traffic Act,
- Medical Devices Act,
- Maternity Protection Act,
- Product Safety Act and its regulations,
- Regulation (EC) No. 216/2008 (aviation),
- Regulation (EU) No. 1907/2006 (REACh),
- Load Handling Ordinance,
- Ordinance on Biological Substances,
- Ordinance on Hazardous Substances,
- Workplace ordinance and workplace directive,
- Noise and vibration occupational health and safety ordinance,
- Technical regulations in occupational health and safety (including TRBS, TRGS),
- Regulations and rules of the German statutory accident insurance (DGUVV),
- Road Traffic Licensing Regulations,
- Regulation implementing Directive 2006/25/EC on the protection of workers from risks arising from artificial optical radiation and amending occupational safety and health regulations of 19 July 2010 (OStrV),
- Federal Law Gazette 2002 Part I No. 36 v. 21.06.2002: Ordinance on the modified application of provisions of the Occupational Safety and Health Act for certain activities in the federal civil service in the area of responsibility of the German Federal Ministry of Defence (Bundesministerium der Verteidigung, BMVg; BMVg Occupational Safety and Health Act Application Directive 8),
- Handbook of Ergonomics (HdE),
- DIN EN ISO 9241-5 to -6 “Ergonomics of human-system interaction,
- DIN EN ISO 11064-4 and -6 “Ergonomic design of control centres”,
- DGUV Information 215-410 “VDU and office workplaces—Guidelines for design”,
- DGUV Information 215-441 “Office space planning—aids for the systematic planning and design of offices and,

- MIL-STD-1472G “Human Engineering” (for military products),
- DIN 33402-(1,2,3): Human body dimensions,
- DIN EN ISO 7250-(1,2): Dimensions of the human body for technical design,
- [DIN 7250-1] [DIN 7250-2],
- DIN EN 547-(1,2,3): Safety of machinery—Human body measurements,
- DIN EN 1005—(1,2,3): Safety of machinery—Human physical performance.

References

[BaHL-2008] Badke-Schaub, P., Hofinger, G., Lauche, K.: Human Factors. Psychologie sicheren Handelns in Risikobranchen. Springer Medizin Verlag, Heidelberg (2008). ISBN 978-3-540-72320-2

[BJRS-2013] Bullinger, H., Jürgens, H., Rohmert, W., Schmidtke, H.: Handbuch der Ergonomie in fünf Bänden, zweite Auflage. Bundesamt für Wehrtechnik und Beschaffung (2013)

[BrSI-2008] British Standards Institution/ Reinartz, G., Pautmeier, L.: OHSAS 18002:2008—Deutsche Übersetzung: Arbeits- und Gesundheitsschutz- Managementsysteme—Leitfaden für die Implementierung von OHSAS 18001:2007, (2009). ISBN 978-3-8249-1272-8

[C1-2010-7001] Gefährdungsbeurteilung sowie Feststellung der sicheren Inbetriebnahme im Rahmen des Customer Product Managements. Bundesamt für Ausrüstung, Informationstechnik und Nutzung der Bundeswehr (www.baainbw.de). Zugriff am 30 Mar 2020

[DGUV-2017] Deutsche Gesetzliche Unfallversicherung e.V.: IFA—Arbeiten 4.0: Neue Formen der Arbeit—Neue Bürowelten—Büroarbeitsplätze mit mehreren Bildschirmen. Abgerufen am 7 Feb 2017 (deutsch)

[DIN-10075] Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung—Teil 1: Allgemeine Aspekte und Konzepte und Begriffe (ISO 10075-1:2017); Deutsche Fassung EN ISO 10075-1:2017. www.beuth.de/de/norm/din-en-iso-10075-1/271934702, Zugriff am 13 Mar 2020

[DIN-11064] Ergonomische Gestaltung von Leitzentralen—Teil 6: Umgebungsbezogene Anforderungen an Leitzentralen (ISO 11064-6:2005). www.beuth.de/de/norm/din-en-iso-11064-6/77521891. Zugriff am 13 Mar 2020

[DIN-9241-11] Ergonomie der Mensch-System-Interaktion - Teil 11: Gebrauchstauglichkeit: Begriffe und Konzepte (ISO 9241-11:2018); Deutsche Fassung EN ISO 9241-11:2018. Zugriff am 13 Mar 2020. www.beuth.de/de/norm/din-en-iso-9241-11/279590417

[DIN-9242-210] Ergonomie der Mensch-System-Interaktion - Teil 210: Prozess zur Gestaltung gebrauchstauglicher interaktiver Systeme (ISO 9241-210:2010); Deutsche Fassung EN ISO 9241-210:2010. www.beuth.de/en/standard/din-en-iso-9241-210/135399380, Zugriff a, 13 Mar 2020

[FATB-1995] FAT Report 123: RAMSIS- ein System zur Erhebung und Vermessung dreidimensionaler Körperhaltungen von Menschen zur ergonomischen Auslegung von Bedien- und Sitzplätzen im Auto” Frankfurt, 1995

[GaRo-2013] Ganster D., Rosen C.: Work stress and employee health: a multidisciplinary review. J. Manage. **39**(5), 1085–1122. https://doi.org/10.1177/0149206313475815

[HaKM-2004] Hauptmanns, U., Knetsch, T., Marx, M.: Gefährdungsbäume zur Analyse von Unfällen und Gefährdungen (= Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin. Forschung Bd. 1028). Wirtschaftsverlag NW, Bremerhaven 2004, ISBN 3-86509-208-X

[HaSt-1988] Hart, S., Staveland, L.: Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: Hancock, P., Meshkati, Najmedin (eds.). Human Mental Workload (PDF). Advances in Psychology. 52. North Holland Amsterdam, pp. 139–183 (1988)

[ISO-9241-110] Ergonomie der Mensch-System-Interaktion - Teil 110: Grundsätze der Dialoggestaltung (ISO 9241-110:2006). www.beuth.de/de/norm/din-en-iso-9241-110/110514174. Zugriff am 13 Mar 2020

[JexS-1998] Jex, S.: Stress and job performance: Theory, research, and implications for managerial practice. Sage, Thousand Oaks, CA

[MILs-882D] Department of Defence (US-Army): MIL-STD- 882D, Standard Practice for System Safety. www.system-safety.org/Documents/MIL-STD-882D.pdf, Zugriff am 13 Mar 2020

[Norm-2002] Norman, D.: The Design of Everyday Things. Basic Books (2002). ISBN 0-465-06710-7

[Pöpp-2000] Pöppel, E.: Grenzen des Bewußtseins, Insel, Frankfurt am Main 2000 (2. Aufl.), ISBN 3-421-02735-8

[Ropo-2009] Ropohl, G.: Eine Systemtheorie der Technik, 1979, 2. Aufl. u. d. Titel Allgemeine Technologie. Carl Hanser Verlag, München Wien 1999 ISBN 3-446-19606-4. 3. Aufl. Karlsruhe 2009

[ScBL-2010] Schlick, C., Bruder, R., Luczak, H.: Arbeitswissenschaft, 3rd edn. Springer, Berlin (2010)

[TrBa-1951] Trist, E., Bamforth, K.: Some social and psychological consequences of the long wall method of coal getting. Hum. Relat. **4**, 3–38

[WRCP-1994] Wharton, C., Rieman, J., Lewis, C., Polson, P.: The cognitive walkthrough method. A practioner's guide. In: Jakob Nielsen, Robert L. Mack (Hrsg.) (eds.). Usability Inspection Methods, pp. 105–140. Wiley, New York NY u. a. S. (1994)

Chapter 9
Producibility

T. Ehlers, R. Lachmayer, S. Vajna, and T. Halle

Sándor Vajna

Within IDE, no product can be produced without product development. Also, it is not useful to develop a product without having the production of this product as a goal (even if the product is not produced by the supplier himself, but by a third party). It is also irrelevant whether the product is a tangible or intangible product or combinations thereof, since the main development activities are comparable (For the possible variations in the creation of physical and intangible products and their combinations, see for example Figs. 2.10, 2.13, 2.14 and 2.15). The production of a physical product includes materials management, manufacturing, assembly and testing, the associated logistics and the control mechanisms and support measures used for this purpose (for example, CAM and ERP systems).

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9.1 Introduction

The attribute producibility provides information on whether, how and under which conditions of a technical, organizational and financial nature the product can be produced internally with the possibilities available to the provider and/or externally with/by third parties or in mixed forms, Fig. 9.1.

The neutral description of the performance offer of the product to be developed using the target profile of the attributes allows both development and implementation of the production of the product as well as the necessary means of production at the latest possible point in time on the basis of the knowledge then available about the realization possibilities at the provider (Sects. 3.2 and 3.4.2). If, on the other hand, ideas and concepts had to be checked for feasibility immediately in the early stages of development, the possible variety of solutions for different realization possibilities would be restricted too early, which would be an obstacle to the inclusion of further realization possibilities, also from other disciplines, and (above all) to the development of new types of product and production concepts.

The possibility of simulating components and behaviour of production in the sense of predictive engineering and securing them with feedback (reverse engineering) (Chap. 1 and [VaWe-2000]) means that, in the event of realization, the current production possibilities of the supplier can be taken into account and/or prerequisites for production can be compiled (e.g. further production technologies, also from other disciplines, additional production locations, inclusion of external service providers).

With the methods of Design for X (DfX) and its reversal in the form of the early provision of opportunities by those areas downstream of product development

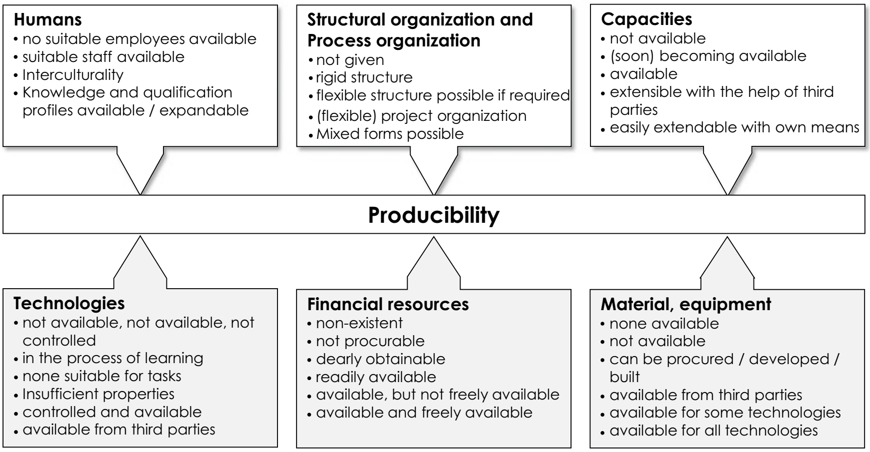

Fig. 9.1 Selected influences on the producibility and its gradations using the example of physical products (in the first lines the respective influence is negative, which however becomes increasingly positive with the further lines downwards)

(XfD, Chap. 16), it can be ensured in product development, at the desired time of the start of production (SOP), that products can be created with the (adapted or extended) technological possibilities of the provider's production in conjunction with the available capacity and funds, so that their producibility is given.

As a result of product planning, there should already be ideas about the order of magnitude of later production, since different quantity structures require different production strategies, essentially independent of the disciplines of the realization possibilities.

- In the case of mass customization (e.g. automotive industry with high volumes, where individualization is achieved through flexible configuration and combination of as few modules as possible and costs are limited by as many common parts as possible, which are not visible to the customer), the proportion of in-house production is minimized, but the proportion of purchased parts (especially common parts) is maximized. High volumes (mainly of combinable modules, regardless of whether they are produced in-house or purchased from third parties) create a scale effect that leads to cost savings.
- In small series production (for limited markets), the focus is on independent production, where the proportion of in-house production is maximized and the proportion of purchased parts is minimized.
- Single-part production (often in the capital goods industry, for example in special purpose machinery manufacture, where a product is only developed and manufactured individually on order) is carried out in-house (except for standardized bought-in parts such as fasteners and bearings). Production is designed for maximum flexibility. Depending on the load and intended service life of a product (e.g. an injection moulding tool for very small quantities), additive manufacturing processes are increasingly used (see Sect. 9.2).

Regardless of the choice of implementation options in production[1], product development should aim to that

- the simplest of the possible solutions is always applied (Sect. 1.8),
- clear forms and shapes for individual parts and assemblies are developed, which facilitate and accelerate activities in production and distribution (e.g. quality control, packaging activities) as well as the exchange of components during maintenance and return, and
- only those production processes are used, whose sustainability is given and which require little or no non-productive time and additional costs.

In this chapter, the focus is on additive manufacturing (Sect. 9.2). This production technology allows for a significantly higher complexity and shape variance of a product (and thus creates completely different freedom and possibilities for the realization of the product concept), requires very little to no tools and operating resources (manageable investments), works on demand (low to small storage costs

[1]A detailed overview of different production technologies and their possible applications can be found in [Hehe-2011] and in Chap. 7 in [Vajn-2014].

for components), can also produce small quantities economically and quickly (hardly any set-up and waiting times, no tool changes, no reclamping, little tied up capital) and is not necessarily location-bound. In this way, additive manufacturing enables completely different dimensions for the realization and individualization of products and thus forms a very powerful realization option for IDE.

9.2 Additive Manufacturing

Tobias Ehlers and Roland Lachmayer

In additive manufacturing (AM), components or entire assemblies are produced based on digital geometric models by building and joining material layer by layer. In contrast to conventional production, no tools are required, so that small quantities can be produced economically and quickly. However, AM also offers the possibility to effectively manufacture components of high complexity and shape variance, up to a machine from one production step. For example, it is also possible to integrate flow channels with almost any geometry and to manufacture components from material combinations up to graded (continuous) material transitions [LaLi-2017].

First applications of this technology based on digital—3D product models were invented in the 1980s [Hull-1984]. For a long time, due to its high production times and material- and quality-related restrictions, it was only used for rapid prototyping and partially for tool-making tasks. Only with the progress of digitalization, the hype of the maker community and the vision of the digital product that every customer can print out himself, the idea of printed end products was promoted from about 2005 onwards. It was found that the mere replacement of existing manufacturing by additive processes is often not worthwhile, but that new business models and changed processes often allow additive manufacturing steps to be used sensibly due to many advantages.

It is also appropriate for thinking in terms of potentials and new processes that the following content is not structured in the sense of *Design for X* (i.e. the question of how must be designed so that good manufacturing can be achieved), but rather according to the approach *X for Design*, i.e. the questions of what possibilities the AM offers and what can be effectively achieved with it (see also Sect. 9.2.2).

This Section starts with the definition of terms and the presentation of the process chain for AM. Based on this, an overview of different additive manufacturing processes will be given. Strengths and potentials are then described using a SWOT analysis. Process limitations of the AM are discussed as weaknesses, and then opportunities and threats are presented to give an outlook on the development of the coming years. Building on this, design objectives and design rules are presented in Sect. 9.2.2. Section 9.2.2 analyses the procedures for each development. Finally, the contribution of AM to increasing sustainability is discussed and quality assurance is addressed.

9.2.1 Definitions and Description of Additive Manufacturing

In each of the years 2017 and 2018, more than 30% more components were manufactured in an additive way than in the previous year. The reasons for this are the further development of the processes, the increasing suitability of more and more materials and the overall high quality of the components that can now be achieved [Gebh-2016, Kran-2017]. The application areas of AM are divided into the areas rapid prototyping, rapid tooling, direct manufacturing and additive repair.

- **Rapid prototyping** is defined as the "additive production of components with limited functionality, but where specific features are sufficiently well developed to enable model investigations to be carried out" [VDI-3405]. Specific characteristics can be, for example, both geometry and haptics of the component, whereas the materials of the prototypes do not necessarily have to be identical to those of the series parts.
- **Rapid tooling** is the "application of additive methods and procedures to the design of end products used as tools, moulds or mould inserts" [VDI-3405]. A distinction is made between direct and indirect rapid tooling. In direct tooling, the tool inserts are manufactured and reworked by means of additive manufacturing. In the process chain of indirect tooling, only a first process step—usually the production of a mould—is performed applying AM. For example, the negative moulds of casting tools can be produced additively and the subsequent manufacture of the tools can be carried out using conventional production methods. Rapid tooling promises a time reduction of 50–80°% compared to traditional tool making [Gebh-2016].
- **Direct manufacturing** is the "additive manufacturing of end products" [VDI-3405]. Only with direct manufacturing, it is possible to make full use of the design freedom of the AM.
- **Additive repair** takes place in the product life cycle during the use phase and describes an "additive manufacturing process for reconstructions and modifications of already manufactured components" [Zgha-2016, Zgha-2019]. The main field of application is thus the repair of high-quality capital goods.

Figure 9.2 shows exemplary components for the four application areas.

Other terms such as 3D printing or Rep-Rap usually only refer to individual processes or are manufacturer-specific and are often misused in colloquial language.

The application of a procedure of AM does not take place in a single process step, but requires the passing through a process chain. This can be divided into five categories, product development, pre-process, in-process, post-process and finishing, as shown in Fig. 9.3, each of which consists of several process steps. When running through the process chain, iterations should be provided in the categories product development and pre-process. For reasons of clarity, iterations are not shown in Fig. 9.3. Product development in the AM is described in Sect. 9.2.3. In the following, the process chain starting with the pre-process is presented.

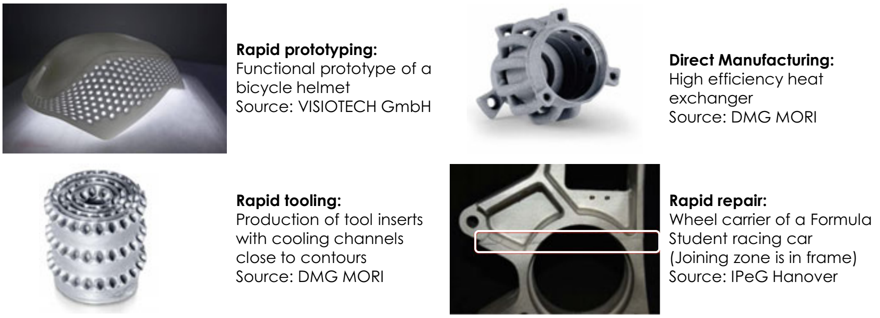

Fig. 9.2 Fields of application of the additive manufacturing

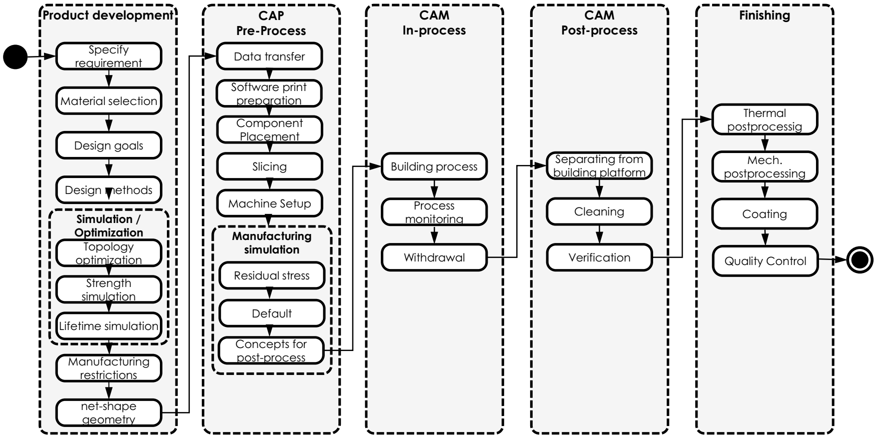

Fig. 9.3 Process chain of additive manufacturing [Lipp-2018]

The prerequisite for the production of additively manufactured components is digital 3D volume models of the geometry. These can be created in the CAD system, read in by re-engineering or taken from databases. For the **pre-process**, these CAD data must be read into a machine manufacturer-specific or special software for print preparation. This is used to place the component on the virtual build plate. In the following step of the so-called slicing process, the solid model is then virtually cut into parallel layers (slices), to which layer information such as laser power and scanning speed is then assigned. The machine is then set up (machine set-up). Depending on the method used, this set-up also includes the setting of installation space and builds plate temperature or the definition of a protective gas atmosphere. Depending on the component and the manufacturing process, a manufacturing simulation can be carried out. The aim is to detect the thermal distortion and compensate it by an offset on the model. Furthermore, thermal residual stresses can be identified and concepts for the post-process (e.g. stress-relief annealing) can be selected at an early stage.

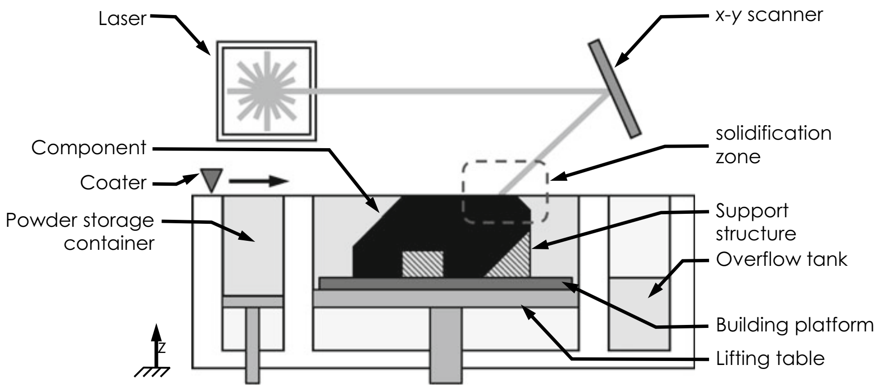

Fig. 9.4 Composition of a system for selective laser melting according to [Lipp-2018]

The **in-process** differs greatly depending on the selected process and will be explained here using selective laser melting (SLM) as an example, Fig. 9.4. The SLM process has established itself in the industry for the production of metallic components and is characterized by a lower layer thickness, greater design freedom compared to powder deposition welding and the possibility of processing even metals that are difficult to weld, such as aluminium and titanium. Compared to other additive manufacturing processes in the metal sector, SLM offers the highest dimensional accuracy and surface quality [GMWP-2012]. The available space (working space) of large systems is 500 × 500 × 500 mm. The layer thicknesses are between 30 and 200 μm. The smallest producible dimensions are approx. 100 μm. In SLM, the powdered starting material is melted with a laser beam deflected by an *x-y* scanner. The build platform is then moved by the thickness of one layer in the negative *z*-direction. The powder is then conveyed upwards from the powder storage container and applied to the powder bed via the coater.

It should be noted that the layered structure results in direction-dependent mechanical properties. For example, the mechanical properties in the *z-direction* (build direction) can differ significantly compared to the *x*- or *y-direction*. This can be counteracted by adjusting process parameters. Alternatively, this property can be taken into account in product development.

Since AM is a thermal process, residual stresses are induced in the component which can lead to distortion. For this reason, support structures are sometimes used to improve heat conduction from the component to the build plate. In addition, support structures provide an advantage by mechanically stabilizing the geometry during the printing process. In SLM, oxidation of the metal is prevented by flooding the installation space with protective gas such as argon or nitrogen. Newer machines have a monitoring system to evaluate shift information during the build process. This allows early detection of component defects and inhomogeneities.

In the **post-process**, the component is separated from the build platform and cleaned. Subsequently, individual component properties are verified. This includes the evaluation of the process monitoring as well as the detection of form deviations, such as collapsed overhangs or detached support structures due to thermal distortion by visual inspection.

The **finishing process** is highly dependent on the selected manufacturing process and the component requirements. As a rule, the components are first heat-treated (stress-relief annealed) to relieve internal stresses. Subsequently, machining is often carried out to remove supporting structures and functional surfaces and fits.

If there are high demands on operational stability or if internal structures or channels are integrated, it is advantageous to examine the components as part of a quality assurance process using suitable imaging techniques such as X-ray or CT scan to ensure that there are no defects and that all powder has been removed from the cavities.

In addition to many other finishing processes, internal channels can also be polished wet-chemically, for example, and the components anodized or painted.

9.2.1.1 Overview of the Processes of Additive Manufacturing

In addition to SLM, there are further AM procedures. For their differentiation, the design catalogue shown in Fig. 9.5 is used, which has been developed by the authors of this section. The catalogue classifies the processes according to the aggregate state of the processed material (solid or liquid), the form of preparation of the material (powder, strand, foil or liquid) and the binding mechanism used (direct thermal fusing, fusing via binder, bonding or curing by means of UV light). In principle, the liquid or powder-based processes can be implemented both by means of a powder/liquid bed and by feeding via nozzles.

In the access section, the design catalogue differentiates between the materials to be processed, the precision of the layers, the use of support structures, and typical processing speeds and installation space sizes. The various procedures of the AM have been described in numerous publications (for example, Chap. 11.4 in [VWZH-2018]) and described in the VDI guideline 3405 [VDI-3405]. The process development is by no means complete, but the progressive development of AM is characterized by new materials, effects and qualities as well as the design of on-going new machine concepts.

In the following, electron beam melting, fused layer modelling and stereolithography are presented as further typical representatives of AM [LaLK-2018].

In electron beam melting, the powder is applied to the building platform in a thin layer over the entire surface with the help of the coater. The layers are gradually melted into the powder bed by controlling the electron beam according to the layer contour of the component. For this purpose, the electrons are generated, accelerated, focused and deflected by a coil. The build platform is now lowered slightly and a new layer is applied, Fig. 9.6.

Fused layer modelling is the most frequently used additive method due to its inexpensive machine technology. Thin thermoplastic threads are melted. The layers are generated in the X-Y direction by the nozzles that trace the component contour.

Outline section			Main part	Access section							
State of aggregation	Form	Bonding mechanism	Designation	Plastic	Metal	Ceramics	Coating thickness [µm]	Support structure	Chamber-bound	Multi-material capability	Installation space
Party	Powder	Merge	Laser intering	X	X	X	< 10		Yes	Limited	medium
			Laser beam melting		X		10-100	X	Yes	Limited	medium
			Electron beam melting		X		10-100	X	Yes	Limited	small
			Laser powder cladding		X	X	>200		No	Yes	medium
		Binder	3D printing	X		X	> 100		Yes	No	big
	Strand	Merge	Fused Layer Modeling / Manufacturing	X			10-100	X	No	Yes	big
			Laser Wire Deposition Welding		X		>200		No	Yes	medium
	Slide	Bonding	Layer-laminated manufacturing	X	X	X	10-100	X	Yes	No	big
Liquid	Liquid	UV	Stereo-lithography	X		X	< 10	X	Yes	No	big
			Multi-jet modelling	X		X	10-100	X	Yes	Yes	medium
			Two-photon polymerization	X		(X)	< 1		Yes	No	small
			Digital light processing	X		X	10-100	X	Yes	No	medium

Fig. 9.5 Design catalogue of additive manufacturing processes [LaLi-2017]

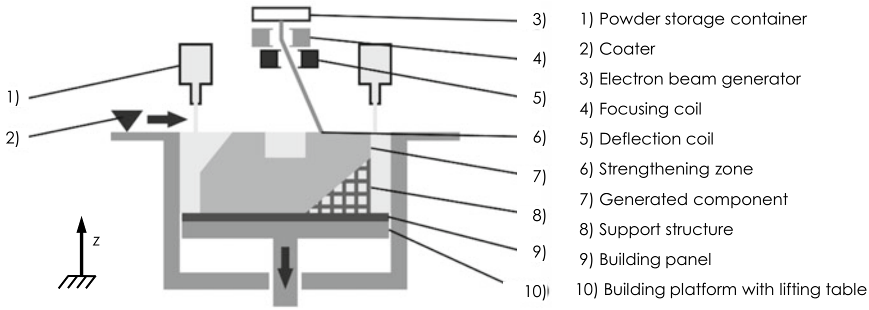

Fig. 9.6 Electron beam melting (EBM)

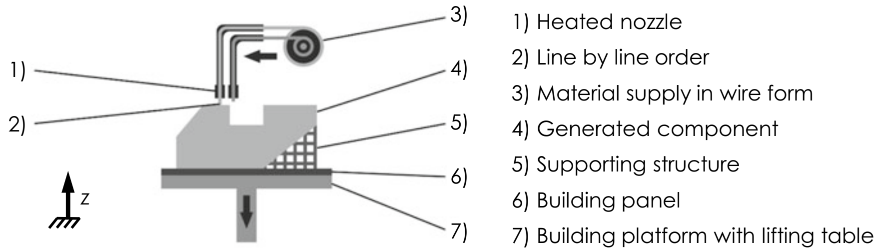

Fig. 9.7 Fused layer modelling (FLM)/fused deposition modelling (FDM)

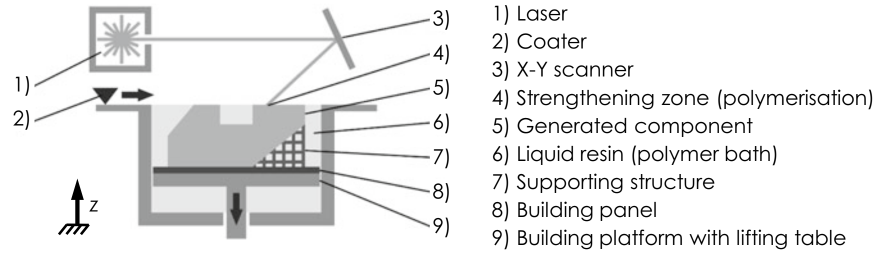

Fig. 9.8 Stereolithography (SL)

The heated nozzles melt the material that is applied to the build platform line by line by moving the nozzle head. The building platform is now lowered according to the layer thickness and a new layer is generated, Fig. 9.7.

In stereolithography, a laser hardens liquid photopolymer in thin layers. After complete exposure of a layer, the generated component is lowered into the liquid resin by one layer thickness. The coater then distributes the material evenly over the previously generated component and the next layer is solidified, Fig. 9.8.

9.2.1.2 Strengths of Additive Manufacturing

AM's strengths include the ability to easily produce prototypes and functional samples to avoid errors in product development, resulting in shorter development times and improved development results.

Design complexity and freedom result from the producibility of geometries that cannot be produced with other manufacturing processes or only with greater technical and economic effort. This possibility allows designers and artists new forms of expression and in industrial applications the production of topology and shape-optimized components. Figure 9.9 shows two components whose shape was determined by topology optimization. These components are difficult to produce by conventional manufacturing methods.

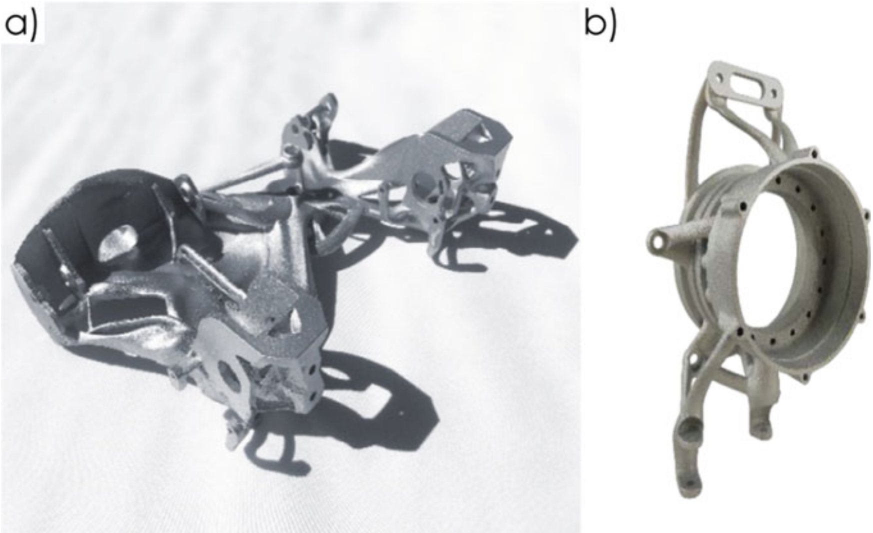

Fig. 9.9 **a** Pedals of a formula student racing car, **b** Wheel carrier of a formula student racing car

In addition, complex components can be manufactured without tools within a few hours. The personnel deployment is limited to the machine operator, who is only required for data and material loading and at the end of the process for component removal and post-processing. The actual manufacturing process is automated.

Furthermore, AM enables a high degree of product individualization with the aim of personalization or differentiation to specific needs. Requirements from mass customization, from modular product structures and thus differentiation strategies can be supported in this way.

In addition, AM enables the realization of ultra-lightweight design concepts that follow new design approaches (e.g. from bionics), of more efficient internal structures in components as well as results from topology optimization. In this way, resources can be saved both during production and over the product life cycle, especially with moving masses. The high degree of design freedom also allows new functions to be integrated into a component, such as internal cooling channels. However, high functional integration also leads to lower assembly effort and generally to a reduced number of components and smaller installation spaces.

9.2.1.3 Weaknesses of Additive Manufacturing

The additive manufacturing process usually takes place within a process chamber, which limits the size of the component. Additionally, the dimensions of the process chamber are limited by the physical limits of the respective processes.

Contrary to common perception, AM does not work without residual material. This results (depending on the process) from scrap, (lost) support material and only partially reusable residual material from the production process. In particular, the commercialization of 3D printers for home use is expected to lead to an increasing environmental impact due to the increased production of plastic parts and the resulting residual materials.

Depending on process and material, AM can release emissions that are hazardous to humans. These are, e.g. toxic vapours when melting certain plastics or fine metal powder in the inhaled air. In order to prevent damage to health, protective measures are therefore prescribed in industry for employees affected by such damage. There are currently no legal regulations for home use of 3D printers.

Long in-process production times make it difficult to integrate AM into interlinked productions. A significant increase in process speed or the rethinking of plant concepts would be necessary to remedy this situation.

9.2.1.4 Opportunities and Risks of Additive Manufacturing

With AM, new materials can be processed. Opportunities range from the production of porous or functionally graded materials to bio-printing, i.e. the production of patient-specific organs, or even food printing [MuAt-2014, SPZF-2015].

AM allows the reduction of the material input to achieve an improved material utilization and consequently minimize waste. In this way, topology and shape-optimized components can be produced with the best possible material distribution. Likewise, the sustainability of processes and products is increasingly becoming the focus of political and public attention.

Replications (copies) enable new dimensions of product piracy. 3D scanners and file-sharing networks pose a risk for the protection of intellectual property. Especially single parts can be easily replicated, which can be printed by the end customer as spare parts.

With the home use of 3D printers, geometries can be modelled and materialized at will without having to comply with legal regulations. This applies both to the protection of intellectual property and new dimensions of product piracy, and to the production of prohibited articles.

The possibilities offered by decentralized production give rise to new questions regarding product liability. In the event of damage to a component or injury to a human being, the question currently arises of the responsibility of the machine manufacturer, material supplier, provider of the CAD model and machine operator. The same questions come into play for quality aspects.

9.2.1.5 Application Areas and Business Models

New business models are emerging from the megatrends of digitization and individualization, and especially in the context of product-service systems (PSS). These arise, for example, in co-design (see also Sect. 15.9), the shifting of value chains, training concepts, the sale of machines and models, the distribution of special materials or in preparatory and follow-up activities. In the following, a selection of suitable application areas and business models of the AM is presented.

- **Small quantities**: For small quantities, the savings in expensive tools or manual work can also make work preparation and fast availability with extensive freedom of form economical. This applies, for example, to samples in technology and science, but also to handling and logistics aids and tools. Typical applications include printing instead of producing moulds and parts.
- **Production of optimized parts in larger quantities**: Expensive components that have a high added value during the product life cycle due to AM are conceivable, for example, in ultra-lightweight design and with maximum functional integration. Here, solutions can be realized that cannot be produced in any other way or only with great effort. The aerospace industry or the military sector as well as the design of sports cars and patient-specific prostheses in medical technology can justify the high expenditure.
- **Integration into a line production**: AM can be used to produce single individualized elements of a product. AM is integrated into the production process chain together with classical production methods. The added value for the customer comes from individualization.
- **Artistic design**: By eliminating the mould making and handicraft work steps, artistic objects can be produced directly from the CAD model. Furthermore, unique specimens can be digitized by means of 3D scanning and then printed. This allows art treasures to be preserved for future generations and to be exhibited in several locations.
- **Decentralization of production versus warehousing**: Printing digital models on site saves warehousing and logistics costs. However, the solution must prove to be economical.
- **Additive repair**: In the case of high-quality capital goods and components, the component can be repaired with AM. One of the applications known best is the repair of turbine blades in aircraft engines by laser deposition welding.
- **Collaborative customer (printing via home printers)**: Due to the growing market of home printers for private users and their networking among each other in so-called maker communities, the trading of digital models for printing and the sale of instructions for modifying or building small printers has become a lucrative market.
- **Rapid tooling**: In tool and mould making, very small quantities are typical. If complicated geometries are added, for example, for internal cooling channels or free forms, AM is a frequently used technology today, whereby the parts produced with additives essentially replace semi-finished castings and usually have to be machined and reworked by grinding and polishing. High-performance materials for this application have been available for years. Typical applications are injection moulding tools for plastics processing, but also tools for gravity die casting or sheet metal forming.

- **Manufacturing service provider**: A currently common business model is that of a manufacturing service provider for additive manufactured components. The latter has additive manufacturing equipment and experience in the field. The manufacturing service provider manufactures components for various clients, whereby one or more additive manufacturing technologies are offered depending on the machinery. The services include preparation of machine data and, if necessary, revision of the design. Often the manufacturing service provider comes from the era of rapid prototyping and has been in business for years with the design of samples.
- **Rapid prototyping**: In contrast to the manufacturing service provider, this is not primarily about the additive production of components. Rather, these are embedded in the design of prototypes and models. In terms of AM, this means that the investment in machines and technology is lower, as the highest quality machines are not always required, but only represent a part of the performance. AM is embedded in the design and trade of models and plans. These usually include surface finishing processes, but also methods of industrial and graphic design. Typical applications are the production of samples and demonstrators during development, Rep-Rap (**rep**lication and **rap**id prototyping), model building or teaching/learning concepts for linking the virtual and real world.

9.2.2 Design Goals and Design Guidelines

AM allows a high degree of design freedom, which can lead to new potential in product development. These can be structured in the form of ten design goals [Lipp-2018]. During the development process, several design objectives must always be pursued in order to achieve a considerable technical added value compared to conventional production and thus ensure economic efficiency. In addition, through the use of additive manufacturing processes, throughput times can be significantly reduced. In the following, ten design goals and the corresponding design freedoms (levers) are described which contribute to achieving these goals [Lipp-2018].

- **Material savings**: Both the reduction of material input and the saving of resources are achieved by increasing the material utilization. The material savings can be implemented by the following levers: joining point reduction, sandwich design, small distances between features, multi-material design, thin walls, internal structures, integral design/component number reduction.
- **Functional integration**: Implementation of the largest possible number of technical functions with a minimum use of components. Functional integration can be implemented by the following levers: Cooling close to contours, movable elements, small distances between features, multi-material design, free-form surfaces, internal structures, embedding of additional components, integral design/component number reduction.
- **Thin-walled**: Use of thin-walled and filigree geometries is to reduce weight under constant conditions. The thin-wall approach can be implemented applying

the following levers: bionic design, internal structures, small distances between features, free-form surfaces.

- **Force flow adjustment**: Material arrangement according to the stresses to reduce weight or improve mechanical component properties. The force flow adjustment can be implemented by the following levers: bionic design, topology optimization, undercuts, joining point reduction, free-form surfaces, internal structures, wall thickness combination, continuous material transitions.
- **Integrated channels**: Use of internal channels is to meet specific applications, such as the flow of liquids or the integration of cable ducts. Integrated channels can be implemented by the following levers: near-contour cooling, surface textures, large cross-sectional changes, free radius design, undercuts, free-form surfaces, internal structures, porous structures.
- **Mass customization**: With the customized mass production, the adaptation of a component is adapted to specific customer requirements takes place, among other things, by means of individual solution elements or by involving the customer in the product development process.[2] Mass customization can be implemented through the following levers: embedding of additional components, function expansion, surface textures, small distances between features, movable elements, undercuts, free-form surfaces, integral design/component number reduction.
- **Shaping and design**: Individual design as well as increasing the ergonomics and usability of a component. Both shape and design can be implemented by applying the following levers: outer lattice structures, surface textures, undercuts, free-form surfaces, small distances between features.
- **Net-shape geometries**: A net-shape geometry is the actual geometry of a part created with AM, which corresponds to the desired final geometry without further processing. The design goal is the implementation of predefined complicated precast surfaces based on simulation results, for example, flow-optimized surfaces or light distributions. Net-shape geometries can be implemented using the following levers: near-contour cooling, movable elements, function integration, self-supporting overhangs, free-form surfaces, internal structures.
- **Local property adjustment**: Local adjustment of the properties of a voxel[3] by material grading or parameter variation. A voxel is the smallest realizable volume element during material application. Local property adjustments can be implemented using the following levers: assignment of different properties to each voxel, continuous material transitions, variation of component density, powder incorporation, multi-material design, internal structures, wall thickness combination.
- **Internal effects**: Implementation of actuator or sensory properties by powder incorporation, variation of melting behaviour or geometric measures. Internal effects can be achieved by applying the following levers: continuous material

[2]Further possibilities for the customer-specific design of mass products result from the provision of a small number of configurable modules that can be combined with one another in a wide variety of ways to create the individual product from configuration and combination.

[3]A voxel is the smallest realizable volume element during material application.

transitions, embedding of additional components, powder incorporation, multi-material design.

Once the design goals have been defined, it must be specified what concrete added value (value proposition) can be derived from them. For this purpose, Fig. 9.10 links the design goals with the individual benefit promises. Economic aspects have not yet been taken into account here, but are decisive for the selection of solutions in terms of a technical and economic evaluation. Thus, an interdependency exists between the levers of AM and the added value over and above the design objectives. One benefit promise is, for example, a *reduction in weight,* which can be achieved by several levers, such as internal structures, topology optimization and thin-walled design.

In the past, one focus of design for additive manufacturing (DfAM) was the development of design guidelines. Although AM offers a high degree of design freedom, there are also manufacturing restrictions for these production processes, which will be discussed in detail here. The aim of this section is to provide the product developer with a collection of rules for the development process. Since design guidelines can be contradictory or strongly influenced in some cases, it is advisable not to apply them simultaneously, but to apply them one after the other in accordance with the sequence of operations placing the component, dimensioning, cleaning and supporting (Fig. 9.11).

The frequently cited complete freedom to design components to be manufactured additively must be put into perspective in the concrete context. Depending on the process and the equipment, restrictions will always have to be taken into account, which are explained below using the example of SLM [Lipp-2018].

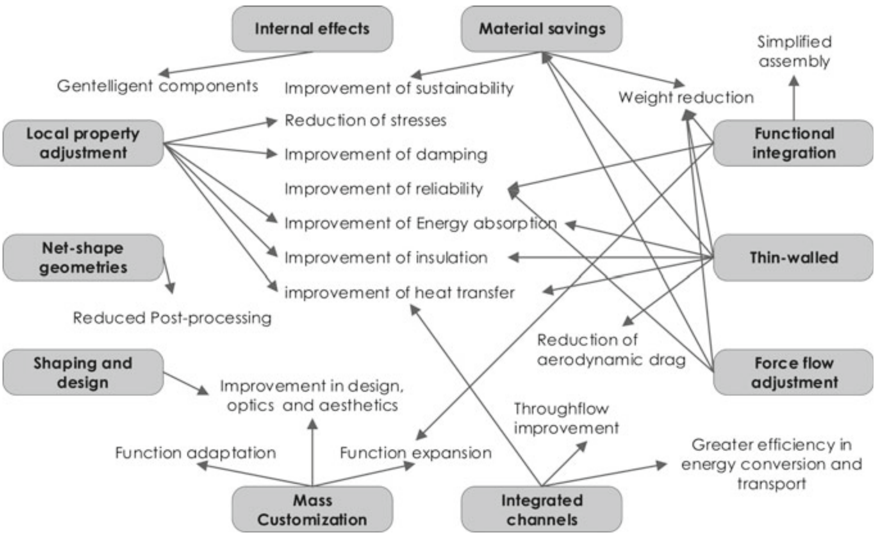

Fig. 9.10 Design goals with assigned levers and technical added value

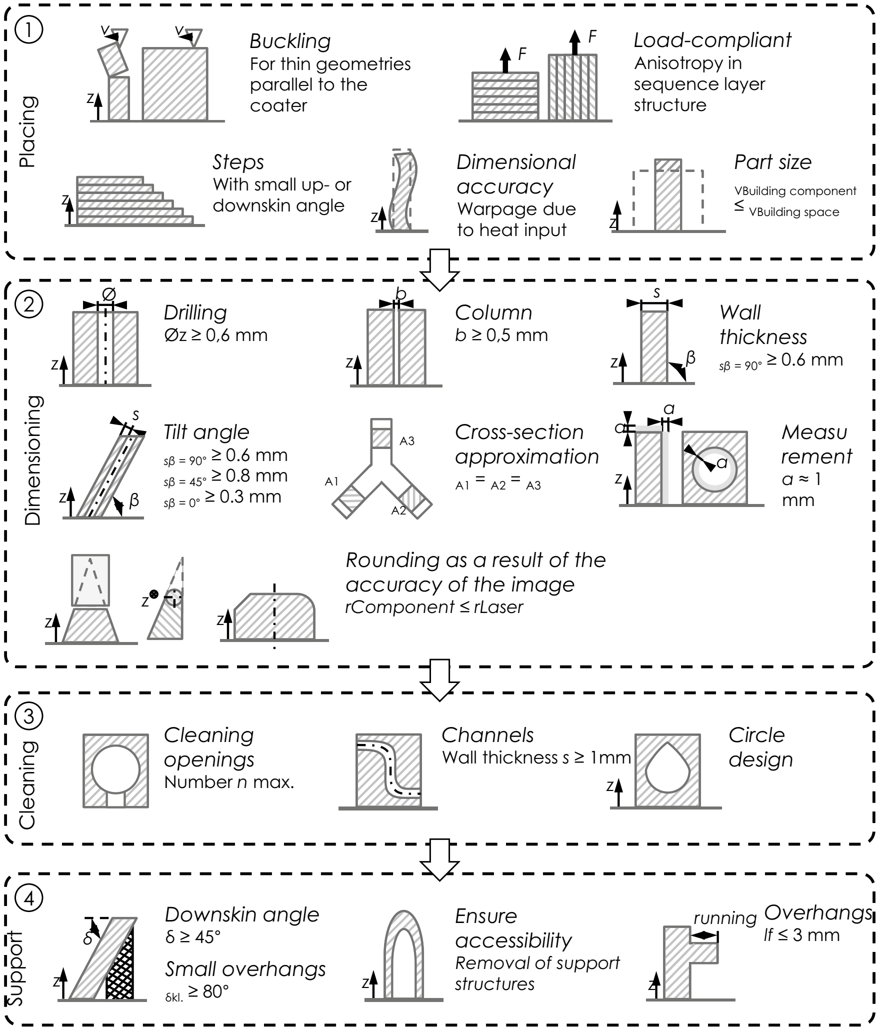

Fig. 9.11 Design guidelines sorted according to work sequence [Lipp-2018] (the numerical values contained here were validated for a specific machine, but also represent the current state of the art of series machines for SLM)

As described at the beginning, a component is created in AM in layered structure. This build-up strategy has an effect on the imaging accuracy between target and actual geometry in the direction of build, which becomes more accurate the smaller the layer thickness *h* is. This relationship, also known as the stair-step effect, is shown in Fig. 9.12. Although the surface quality is increased with a lower layer thickness, this also increases the production time and thus the costs [GMWP-2012, Buch-2013].

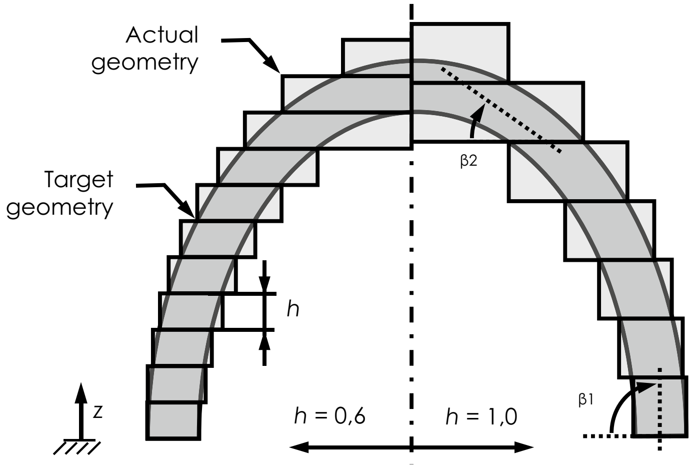

Fig. 9.12 Relationship between stair-step effect and layer thickness [Lipp-2018]

On surfaces with a flat build-up angle β_2 (see Fig. 9.12), the stair-step effect is pronounced, whereas with $\beta_1 = 90°$ it is hardly noticeable. This relationship can be generalized by the following quantities, which are shown in Fig. 9.13:

- Downskin area D (Partial) surface whose normal vector $\vec{n}$ is negative with respect to the direction of build z.
- Downskin angle δ Angle between the build platform and a downskin area, which can take values between 0° (parallel to the building platform) and 90° (perpendicular to the build platform).
- Upskin area U (Partial) surface whose normal vector $\vec{n}$ is positive in relation to the direction of build z.
- Upskin angle γ Angle between the build platform and an upskin area, which can have values between 0° (parallel to the building platform) and 90° (perpendicular to the build platform).

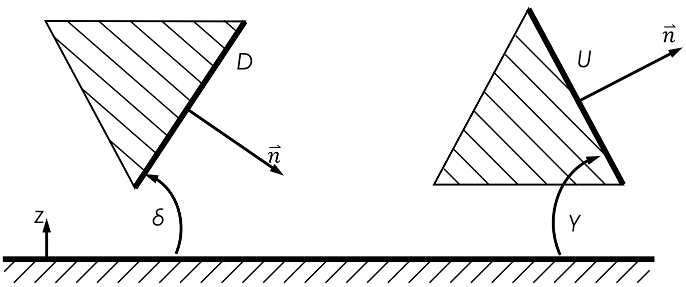

Fig. 9.13 Upskin and downskin areas and angles [Lipp-2018]

These terms can be used to define limit values, for example, for overhangs. Since every surface has a normal vector $\vec{n}$, this vector is used to characterize the reference surface. If the normal vector points in the positive *z-direction*, the reference surface is called upskin area U and in the negative *z-direction it is* called downskin area (see Fig. 9.13).

The surface roughness of a downskin area *D* or an upskin area *U* increases with decreasing downskin angle δ or upskin angle γ. In order to improve the surface quality, it must therefore be ensured during component placement that relevant surfaces are provided with a down or upskin angle $\delta \cap \gamma = 0° \cap 90°$ to the build platform [Buch-2013].

Often, before a component is printed, several layers of support structures are generated and then the component is printed on them. This makes it easier to remove the component from the building platform, e.g., by sawing. In addition, support structures secure the part to the building platform, preventing it from being pulled along with the coating [ASTM-52910].

Support structures are used during the build process to support geometries that fall below a certain downskin angle δ. Melting increases the density of the material (transition from material in powder form to fused material). The supporting effect of the powder bed is limited in the SLM, so that structures that are not self-supporting can sink into the powder bed and cause defects. Support structures are required for three design features (overhangs, ceilings and islands, see Fig. 9.14).

- An overhang is created when a process-specific downskin angle δ *is* undershot, which must be supported by supporting structures [Buch-2013, SDKV-2013]. However, small overhangs of a few millimetres can be self-supporting.
- A ceiling is an overhang that is supported on both sides. Here, too, support structures must be used in the space between.
- Islands are most critical in the manufacturing process, as they are not connected to any other geometry in the first layers. A sagging in negative build direction is thus possible and should be prevented by supporting structures [KrLN-1998].

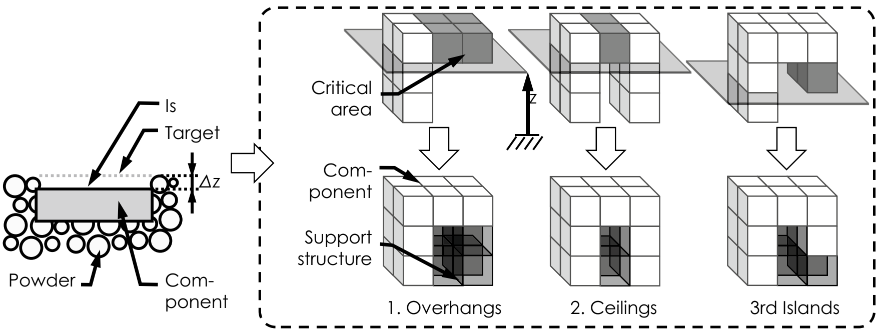

Fig. 9.14 Support structures for overhangs, ceilings and islands [Lipp-2018]

Due to the local heat input of the laser in SLM, stresses can be induced in the component, which can lead to component distortion. This phenomenon can be prevented with constructive adjustments and the use of supporting structures for heat dissipation, as heat cannot be dissipated via the powder bed [Buch-2013, Mich-2014].

Applying SLM, the melted material webs are positioned next to and above each other. The aim is to create homogeneous material volumes so that the layer structure has the least possible influence on the component properties [TVCV-2010]. If the webs in the later component are loaded in the z-direction, the adhesion in these areas is of particular relevance. Insufficient adhesion leads to component failure. It is more suitable for the flow of forces if the force vector acts in x- or y-direction. The material is stressed along an applied layer, so that the cohesion of the material is the decisive factor. To avoid early component failure, the anisotropic material properties must be taken into account when designing a component. The laser beam causes a temperature difference ΔT to melt the material in the powder bed. The required temperature difference, which can be adjusted by the laser power and the scanning speed, results from the melting temperature of the material and the build space temperature [RWES-2009].

In the powder bed, the energy input of the laser causes a heat-affected zone to spread beyond the focus diameter (see Fig. 9.15). As a result, adjacent powder particles are also melted so that the actual diameter is larger than the laser diameter. Since this effect occurs over the entire path length and all layers, the actual geometry ultimately deviates from the target geometry. This can be prevented by using smaller powder grains, but their size is physically limited by the flow ability of the material and additionally by the manufacturing process of the powder. The deviations in the geometry can be recognized by an increased surface roughness on the upskin and downskin areas.

The quality of the component surface can be achieved by adjusting the exposure strategy on the upskin and downskin areas (Fig. 9.16, left side). Figure 9.16 on the right shows the path curve that the laser beam travels along (hatch line), the necessary

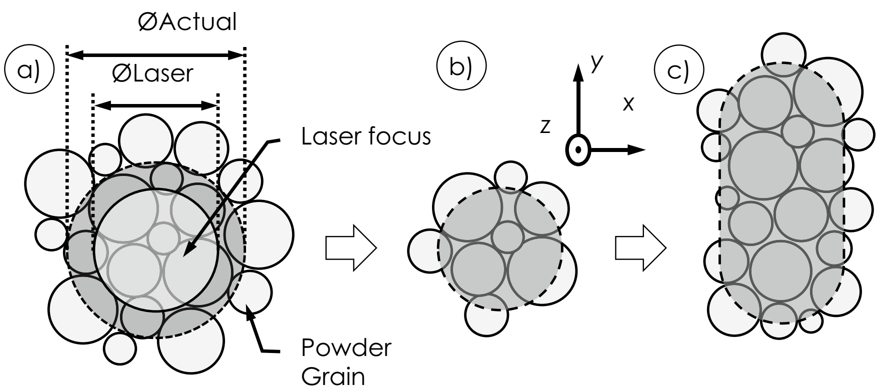

Fig. 9.15 Heat-affected zone (grey). **a** Laser beam. **b** Voxel. **c** Path [Lipp-2018]

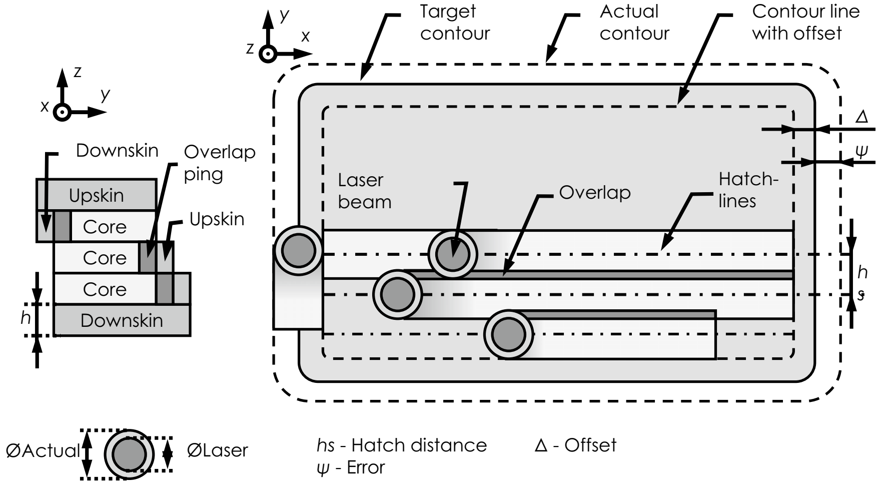

Fig. 9.16 Geometric deviations in the in-process [Lipp-2018]

overlaps for the material webs to be joined together, the deviations of the exposure strategy from the actual contour and the necessary offset of the contour line. The hatch distance is the distance between the individual hatch lines. The overlap is therefore set via the hatch distance.

Deviations that cannot be compensated for by adjusting the exposure strategy are, for example, the production of corners and thin-walled geometries (Fig. 9.17). At acute angles, the laser beam omits part of the target geometry. In the case of thin

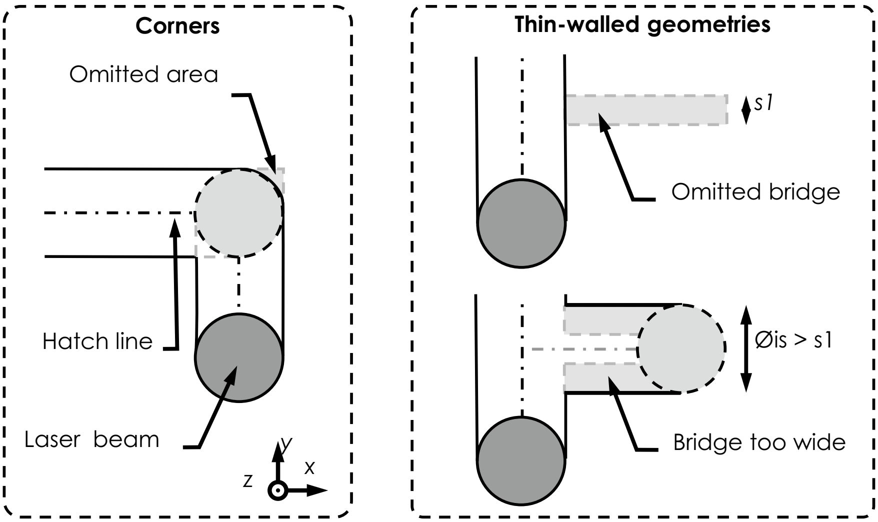

Fig. 9.17 Error caused by the laser beam [Lipp-2018]

geometries that are narrower than the laser diameter, this can either not be melted or the laser beam melts it with its actual diameter to [Kadd-2010]. The result is a too wide web, which defines the minimum producible web thickness in *z-direction* [Kadd-2010].

9.2.3 Development Methodology for Additive Manufacturing

The complex aspects of AM have a direct impact on product development. A development methodology cannot offer a closed solution approach, but can only support the product developer by providing and structuring processes and procedures, heuristics and methods, tools, specifications and business models. Also, the development process for AM does not need to be reinvented. Rather, along a process-related procedure, for example, according to the VDI Guideline 2221 [VDI-2221/2019], the tools already available today can be allocated and a framework for future findings can be provided.

Design for Additive Manufacturing (DfAM) is a field of research that encompasses the development process and related tools and methods for AM. In the literature, a large number of approaches have been described which can be taken into account during component design. These include approaches to exploit the constructive freedom and potential for expanding the solution space as well as methodologically prepared overviews of the manufacturing restrictions that are used to restrict the solution space. Approaches are also being developed to select areas of application, components and manufacturing processes for AM. Furthermore, there are concrete approaches with which a component designed for AM can be analysed with regard to manufacturability by means of certain additive processes.

Since the added value can only be achieved by complying with the restrictions that also exist with regard to AM while at the same time exploiting the potential, newer methods combine the approaches (Fig. 9.18). The basic idea is based on the idea of first enlarging the solution space in the concept phase through the potential of AM (Design *with* X) and then restricting it in the design and elaboration phase through technological and organizational restrictions (Design *for* X, see also Chap. 14).

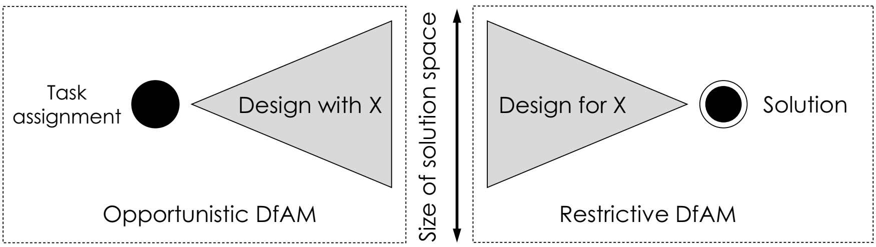

Fig. 9.18 Combination of design with X and design for X approaches to find solutions [Kumk-2018]

The methods for AM can be classified into the general model of the product development process of VDI 2221 [VDI-2221/2019]. It is useful to assign the methods to the various activities of product development (Fig. 9.19). This does not establish a rigid sequence of methods and process steps, but supports a flexible selection of suitable methods that varies according to the company-specific development process. The methods and tools shown in Fig. 9.19 in bold are described in the text and some are provided with references.

In the following, a selection of methods and tools that support the product developer in his work is described. The methods presented below support the efficient achievement of the target profile of the attributes (Chap. 6). They can be used in the various activities of VDI 2221. This includes checklists, design guidelines and rules, potential systematics and illustrative objects.

Activities in product development according to VDI 2221 (year 2019)	Methods and tools related to additive manufacturing
Clarify and specify the problem or task	• Business Case of Additive Manufacturing • **Identify application areas** Fig. 10.2 • **Prioritizing design goals** Section 10.2.2
Determination of functions and their structures	• Bionics and TRIZ-based Invention Methodology
Search for solution principles and their structures	• Method of the one-piece machine • Bionics and TRIZ-based Invention Methodology • **Examples of use** • **Illustrative objects and mood boards** • **Classification of potentials** Section 10.2.2 • **Process chain of additive manufacturing** Fig. 10.3 • Additive manufacturing in the product development process
Evaluation and selection of solution concepts	• VDI 2225

Structuring in modules and interface definition	• Potential assessment of the AM
	  • Factors influencing component suitability
	  • Assessment criteria for evaluating the suitability of components
	• Method of the one-piece machine
	• **Classification of potentials** Section 10.2.2
	• **Design catalogue of AM processes** Fig. 10.5

Designing the modules	• **Examples of use**
	• **Illustrative objects and mood boards**
	• FEM simulation and optimization
	  • Topology optimization
	  • CFD simulation
	  • Lifetime simulation, etc.
	• **Design guidelines** Section 10.2.2
	• **Classification of potentials** Section 10.2.2
	• Internal structures
	• Production process simulation
	• Evaluation of the design objectives on realised components
	• Selection of a development environment

Elaborating the details of execution and use	• Especially 3D models mainly in STL
Other context-specific activities	**Checklists**

Fig. 9.19 Collection of methods for additive manufacturing according to VDI 2221 [VDI-2221/2019]

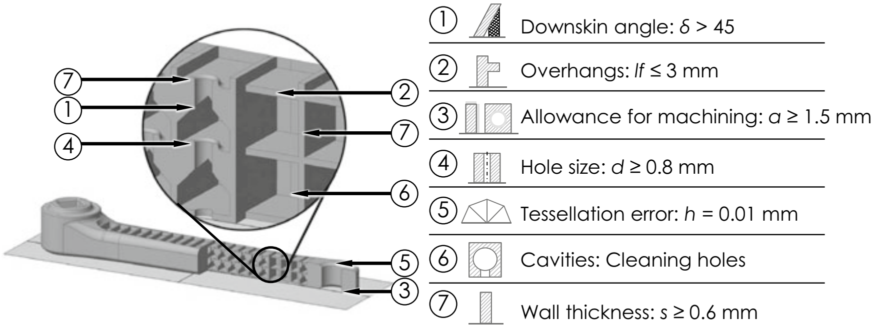

Fig. 9.20 Application of design guidelines to a bicycle pedal crank with internal structures

9.2.3.1 Checklists

A checklist is a simple tool for transferring experience knowledge that is suitable for all phases of the development process. They serve, for example, to query whether constructive freedoms and restrictions have been taken into account or whether nature has been used as a model for the design. Since design rules can be very extensive, KUMKE structures the ten most important design rules for AM in the form of a checklist [Kumk-2018]:

- Accuracy/resolution
- Support structures
- Surface quality
- Anisotropic material properties
- Powder removal from cavities/channels
- Maximum component size
- Minimal wall thickness
- Gap dimensions for joints
- Restricted choice of materials
- Consider post-processing procedures already in product development.[4]

9.2.3.2 Design Guidelines/Rules

During the design process, design guidelines must be continuously reviewed and adhered to. These contribute to a high degree to the faultless production of components. General design guidelines were discussed in detail in Sect. 9.2.2 in the form of a design catalogue. Specific design rules result from the specifically selected process and the machine to be used. Figure 9.20 shows a bicycle pedal crank with internal structures. The concrete manufacturing restrictions are assigned to the corresponding areas of the component.

[4]For example, free-form geometries to be milled cannot always be clamped in the vice, so that separate mounting surfaces must be provided.

9.2.3.3 Classification of Potentials

In order to realize the potentials of and within AM, these must be linked to the design freedoms or levers. Section 9.2.2 can be used as an aid. By defining design goals, the potential of AM is used. At the same time, evaluations must be carried out again and again to narrow the solution space. Specific case bases and collections of lessons learned can be helpful in this respect. However, all otherwise known evaluation methods are also used. In general, the requirements and development goals and, in special cases, the degree of innovation of the solution created by AM, too, serve as criteria for evaluation and selection.

9.2.3.4 Demonstration Objects

Digital and physical demonstration objects are particularly suitable for familiarizing oneself with the design potential and restrictions of a product using concrete examples. Visualization and haptics enable the product developer to gain a good overview in a short time to generate suggestions and ideas for his own development process. Furthermore, the surface properties of physical objects can be better assessed. Mood boards are also suitable for setting new stimuli. Figure 9.21 shows a safety valve as an application example.

Starting from the functional surfaces of the connections, a channel geometry is built up by an iterative process of design and CFD simulation, with the aim of realizing a laminar flow with simultaneous guarantee of the component function. By means of CFD simulation, it was possible to identify the active surfaces shown in Fig. 9.21a. It must be taken into account that due to the curved channel geometries, subsequent mechanical removal of support structures in the channels is not possible.

The optimized active surfaces are then provided with a wall thickness in order to build up the solid model close to the final contour. Furthermore, the design scope of the housing is extended to integrate adjacent components such as the silencer. Furthermore, a grid structure is printed into the outlet of the silencer to reduce the

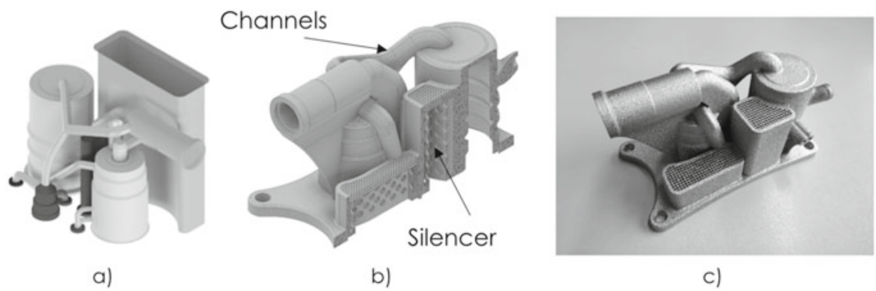

Fig. 9.21 Development of a safety valve [LSLB-2018]

sound radiation and thus the sound volume (see Fig. 9.21b). The printed safety valve is shown in Fig. 9.21c.

9.2.4 Sustainability—Potentials and Possibilities of Additive Manufacturing

Regardless of social, ecological or economic dimensions, the overarching goal of sustainability is to reconcile the lasting stability of all dimensions (see also Chaps. 5 and 12). The concept of efficiency is also important in the context of sustainable development. The striving for efficient processes and productions has increased until today. In principle, the concept of efficiency is closely linked to that of sustainability (see Fig. 9.22). The various dimensions can be assigned different goals, such as increased resource, material or cost efficiency.

Process efficiency as a focus on a positive process-related benefit is shown in AM as a possibility for flexible and always individual production without having to store a large number of standard components [ONHF-2018]. In addition to pure process efficiency, the aim is to increase both material efficiency over a closed value-added chain [Sauer-2017] as well as resource efficiency by means of the various AM processes. This goal is pursued in the approach of "Sustainable Supply-Chain-Management", because through intelligent use of resources, the company can be made both more efficient and more sustainable in all dimensions. In addition, the performance of the technologies implemented in the production process can be improved by minimizing waiting times and downtimes within the supply chain.

The focus of AM area is primarily on the implementation of ecological and economic sustainability goals. The desired goal of increasing resource, energy and material efficiency can be formulated as minimizing the CO_2 footprint. When considering the CO_2 footprint, the product life cycle includes the various process steps from raw material extraction to recycling [LaGL-2015] Fig. 9.23.

In addition to geometry and cutting rate, the type of material has a high impact on the potential for sustainability of the AM. The reason for this is that metals such as aluminium are obtained by an energetically very complex process, which means that any saving in material has a much greater effect on reducing the overall CO_2 footprint than, for example, plastics.

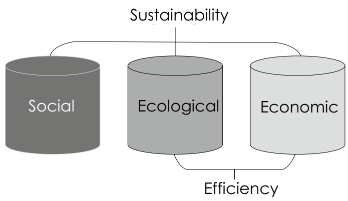

Fig. 9.22 General presentation of efficiency and sustainability

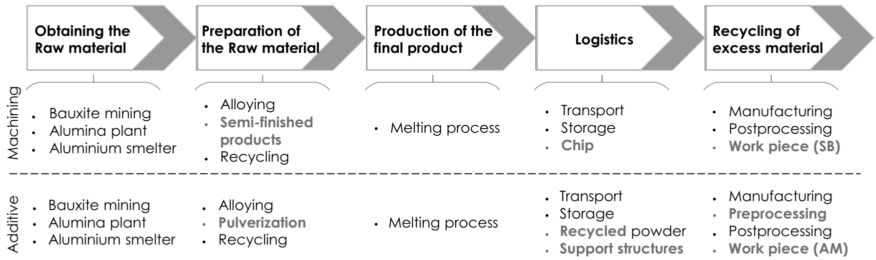

Fig. 9.23 Comparison of additive manufacturing with cutting production [LaGL-2015]

While the energy input for logistics is rather subordinate, a significant difference in the process chain between additive and conventional manufacturing, e.g. turning and milling, lies in the direct recycling of the surplus material.

In the process step of production, it is important to reduce the machine times required for production and the energy consumption of the machines. Regardless of the manufacturing process, the machine times relative to the individual component sizes (e.g. component height or volume) are generally high and the energy requirements of the machines for thermal processes are also [Gebh-2016].

As a result, the following process parameters are decisive for balancing:

- Quantity and type of raw material (in tonnes)
- Production time of the manufacturing machine (in hours)
- Amount of material to be recycled in tonnes and the recycling effort.

9.2.5 *Quality Assurance*

Quality assurance is crucial for the application of AM due to the individual production. For the controls, different test procedures are available according to the process steps, each of which allows the examination of the generated properties or functions. In the following, various test methods are presented in order of their application in AM process chain.

9.2.5.1 Process Simulation

Already in the pre-process, it is possible to predict the quality of the component to be manufactured by simulating the process layer by layer and thereby investigating the thermal load of the component. On the one hand, it is possible to determine the heat distribution and the resulting stress distribution in the component. On the other hand, the thermal state can be changed by the targeted manipulation of the process parameters, which leads to a reduction or complete avoidance of thermal distortion at critical Sections of the component.

9.2.5.2 Material

A major challenge for all processes is the qualification of materials, whereby the quality of the powders, filaments or photosensitive resins must be controlled. But the quality of the material must also be ensured on the printed component, which is not only influenced by the quality of the starting material but also by the individual machine parameters.

9.2.5.3 Destructive Testing

In order to validate the functions of a component and to quantify its lifetime, destructive testing methods are mainly used. For these tests, standardized test specimens are usually manufactured and tested in the associated test benches. For the AM, the main focus is on tests for mechanical load capacity and material composites.

9.2.5.4 Process Monitoring

For process monitoring, measuring methods are used that are applied in the in-process, i.e. during the layered build-up of the component. This in-line process monitoring is particularly relevant in the series production of additively manufactured components, since the quality of the components, but above all their repeatability, must be ensured in order to minimize the reject rate. Monitoring is carried out optically with cameras, currently mainly in selective laser melting and selective laser sintering systems.

9.2.5.5 Non-destructive Testing

Non-destructive testing methods are particularly suitable for the characterization of components. Both the design parameters and the functionality of the component can be investigated. Functional examinations are very individual. The shape can also be examined as with classical methods. As parameters serve:

- Topology (material distribution, density)
- Shape (contour shapes)
- Dimensions (diameter, edge lengths)
- Number (shaping elements, such as number of cooling fins or holes)
- Tolerances
- Material/material composition (interfaces, impurities)
- Surface (roughness, cracks, defects).

Figure 9.24 shows a selection of measurement methods and their respective design parameters.

Design parameters / Measurement procedure	Topology	Form	Dimensions	Quantity	Tolerances	Material	Surface
CT/ µCT	x	x	x	x	x	x	x
OCT	x	x	(x)		x	(x)	x
White light microscopy		x	x	x	x		x
Laser Scanning Microscopy		x	x	(x)	x		x
3D Scanning		x	x	x	x		(x)
Shearography							x
Profilometer		x	x		x		x
Scanning Electron Microscopy		x	x		x	x	x
X-ray absorption spectroscopy						x	
Ultrasound	x	x	x		x		
Noise emission test	x						
Eddy current testing	x					x	

Fig. 9.24 Measuring method and design parameters

9.2.6 Outlook

With the establishment of AM as an equivalent process alongside forming and cutting manufacturing processes, the focus is increasingly shifting to the product development of such components that are to be manufactured with AM from the outset. However, the development of suitable methods and tools for the development process of additively manufactured components is not yet complete. In the future, the economic efficiency of the AM will continue to increase due to the constant progress in production process simulation as well as the continuous improvement of the machine technology, which will also lead to a further reduction of production errors. In addition, machine technology is experiencing rapid development as a result of more efficient processes and cheaper materials, as more and more materials are qualified for AM and ever larger machines are available.

Up to now, AM is used rather for small quantities. For products without the need for weight reduction (e.g. machine tools), there is little potential. In contrast, AM is worthwhile for aircraft components even at low weight reduction due to the increased savings potential in the use phase. In the future, sustainable fields of application will be developed above all. As a result of the associated discussion, for example, the repair of components using additive repair will gain market share. A major research area will be the production of functionally adapted components using multi-materials or functionally graded materials.

9.3 Principles of Material Selection

Thorsten Halle

This section gives a brief insight into the selection of materials and explains the basic procedures for this. A comprehensive overview of all the problems involved in the systematic selection of materials is not given here for reasons of space[5] (but see footnote 3).

Material selection plays a central role in the development of physical products. Today, there are about 80,000 different materials available, from which a sensible selection must be made. This is made even more difficult by a large number of requirements and boundary conditions that must be taken into account when selecting materials. On the one hand, these result from the product attributes (Chap. 3), for example functionality and serviceability (mechanical, corrosive, thermal stress, etc.), producibility (joining, forming, master forms, etc.) and sustainability (re-circulation, environmental compatibility). On the other hand, requirements from the product's environment of usage must be met, for example legislation (end-of-life vehicle directive, ban on knotting, etc.) and market (price, availability, quality).

For a product, the material stress during manufacture and usage plays a decisive role in the selection of a suitable material. The material stress is the sum of all external and internal factors that affect the material during production, use and preparation/depositing. Materials can be subjected to the following stresses:

- Mechanical stress,
- thermal stress,
- biological stress,
- tribological stress,
- corrosive stress (chemical and electrochemical) and
- radiation exposure.

These loads can also occur in combination, for example in a nuclear power plant with simultaneous thermal, mechanical, corrosive and radiation exposure. These stresses influence each other. An example of such a direct interaction is the decrease in strength when using metallic materials at elevated temperatures. It is clear that these partially complex technical requirements alone make the selection of materials very complicated. In addition, the above-mentioned requirements such as prices, availability and manufacturing processes must also be taken into account. This means that material selection is a complex process that requires basic knowledge of

[5] A detailed overview of different materials and their possible applications can be found in [Moel-2014] and in Chap. 6 in [Vajn-2014].

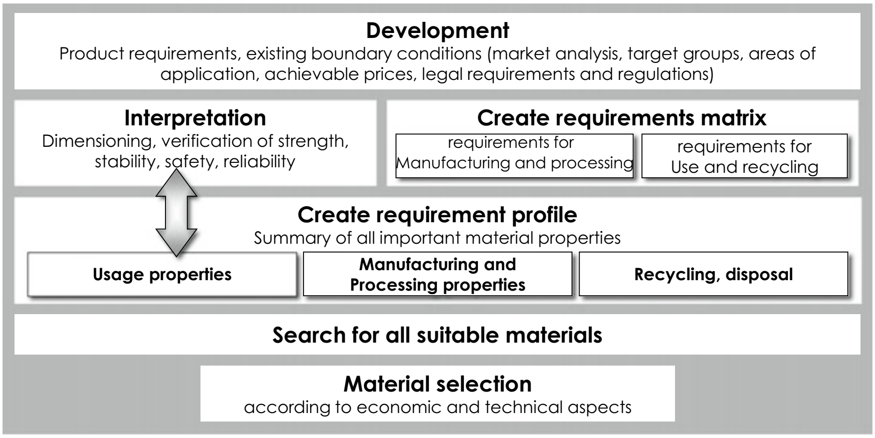

Fig. 9.25 Schematic representation of the procedure for selecting a material

manufacturing technology, technical mechanics of materials engineering and business management expertise. A meaningful material selection is only possible with a structured procedure, which is presented here in an overview.[6]

In principle, each problem of material selection can be divided into several phases. These are the development, the creation of the requirement profile, the search for suitable materials and the selection of a material according to various aspects. Afterwards the results are sorted in a sensible way. The basic procedure for a material selection and the division into different phases is shown in Fig. 9.25.

There is no ideal material, but the decision will always be a compromise. This compromise requires a comprehensive analysis of the problem, assured material characteristics and experience.

9.3.1 Product Development

In product development (see Fig. 2.2 in Sect. 2.2), after project planning, specification and planning, relevant product properties are defined with the help of the attributes and their respective fulfilments (Chap. 3), taking into account material decisions already made (e.g. from legal regulations or market or competitor analyses). The static or dynamic design calculations including strength, stability and safety verifications for component dimensioning are also carried out. Care must be taken to dimension the component for the expected or desired product life (fatigue, wear, corrosion, etc.) and to determine a favourable geometry. At this point, the corrosive properties of the

[6]In industrial practice, knowledge-based systems for material selection are used, which support the process of material selection through structured databases and linked information on producible geometries, applicable processes and material properties.

Processing or manufacturing	Use and recycling
In general: • Number of pieces, dimensions • Production times, assembly possibilities • reparability, etc.	*In general:* • Service life, optics, haptics, surface quality • Medical compatibility, toxic properties • Flammability / fire behaviour, etc.
Manufacturing characteristics: Machinability, formability, joinability, castability, coatability, etc.	*Physical properties:* Density, electrical and magnetic properties, thermal conductivity, heat capacity, optical properties, etc.
Environmental impact during production: Exhaust gases, scrap metal, energy requirements, toxic by-products, overspray, lubricants, binders, occupational safety measures, etc.	*Mechanical properties:* Young's modulus, shear modulus, strengths, fracture toughness, fatigue strength, creep rupture strength, fatigue strength
Intermediate and / or post treatment : • Heat treatment • Hardening / tempering • Case hardening / nitriding • Annealing / intermediate annealing • radiation treatment (polymers), etc.	*Other:* • Operating temperatures, sensitivity to temperature changes • Behavior under radiation (light, UV, infrared, α, γ) • Transparency, damping properties, energy absorption, • Wear properties, corrosion resistance • residual stresses, combined stresses, etc.
Surface treatment / coating: Preparation (pickling, cleaning, blasting) and pretreatment (anodising, phosphating) of surfaces Coatings (lacquers, linings) and metallic coatings (hot-dip, galvanising, plating), etc.	*End of life:* Reusability, recyclability, thermal recovery (reaction products), landfillability Disposal costs, scrap value, laws, regulations, standards for disposal, etc.

Fig. 9.26 Requirements matrix for production, use and re-circulation of the product at the end of its life

materials in question must also be taken into account in the selection of materials (see for example [Wran-1985, Moel-2014]). For a structured approach, it is advisable to draw up a matrix of requirements for the material with regard to processing, usage and recycling or landfilling. The matrices for processing or production and for use or recycling should contain at least the points shown in Fig. 9.26. If possible, quantification should be used to determine the required properties. It is also helpful to determine the weight of individual required properties in relation to the other requirements for a later comparison of different material candidates.

9.3.2 Creating the Requirement Profile

With the aid of the two requirement matrices in Fig. 9.26, all important properties can be combined into a requirement profile, taking into account the development and manufacturing boundary conditions. This is where the real difficulty lies when selecting a material. If essential requirements for the material are not taken into account here, this can under certain circumstances lead to serious problems during production and/or use.

9.3.3 Search for All Suitable Materials

Starting from the requirement profile defined in the previous step, all materials that meet this profile must now be found. Database systems, standards, manufacturer specifications or specialist books are used for this purpose. At the end of this step, depending on the boundary conditions and complexity of the product, 10 to 100 + possible material candidates are determined, which then have to be put into an order. If no suitable materials are found, feedback must be given to the development and, if necessary, other values for individual properties must be defined or an alternative solution must be worked out.

9.3.4 Material Selection According to Technical and Economic Aspects

As mentioned above, price is often the selection criterion used to sort the list of all possible materials for a final selection. The price of a material is always a question of its availability, world market conditions and the quantity purchased. In Fig. 9.27, the price relations for different materials of metallic materials, glasses and ceramics, polymers and natural materials are shown in a comparative way.

Often the aim of a material selection is to choose a material that fulfils all the requirements placed on it at a low price. In some product areas, however, price only plays a subordinate role, especially if higher prices are accepted in a particular market and values such as appearance, haptics or handling are of primary importance. Such a typical market is, for example, the sports equipment industry, where golf clubs

Werkstoff	Preis	Werkstoff	Preis
allgemeine Baustähle	1	Polyvinylchlorid (PVC)	1,7
niedriglegierte Stähle	1 - 1,6	Poöyimide (PI)	24
rostfreie Stähle	5 - 7,5	Polymethylmethacrylat (PMMA)	13
Schnellarbeitsstähle	8 - 12	Polyethylen (PE)	2,9
unlegiertes Gusseisen	0,65	Epoxidharze (P)	3,7
Aluminium-Knetlegierungen	4,5 - 5,5	Naturgummi	3,2
Aluminium - Gusslegierungen	4,6	Schaumstoffe	2,1 - 3,3
Titanlegierungen	22 - 33	Silikatglas	3,2
Kupferlegierungen	6 - 9	GRP composite material	5,2 - 8,5
Messing	4 - 5	CFK-Verbundwerkstoff	430
Wolfram	55 - 65	Bor-Epoxyd-Verbundwerkstoff	730

Fig. 9.27 Prices of various materials per kilogram, standardized to structural steels

made of titanium alloys can be sold despite their multiple price compared to mass materials (steel, aluminium, polymer materials) due to their better usability.

In addition to sorting by price, more complex technical criteria can also be used. This is achieved by using so-called specific material characteristics. A specific material parameter sets two or more material parameters in relation to each other. An example of such a specific material parameter is the strength, which is normalized to the density. Such representations are, for example, the so-called *Ashby diagrams* [AsWF-2006], Fig. 9.28.

If all materials identified as suitable in the previous step are now entered in such a diagram, a sequence of these materials can be created. For products that should have the highest possible strength and at the same time a low weight, materials that are located in the upper left corner of 0 are ideal. This combination of different material characteristics can be extended to any dimensions by combining the characteristics on the axes. In this way, even very complex material selection problems can be clearly illustrated.

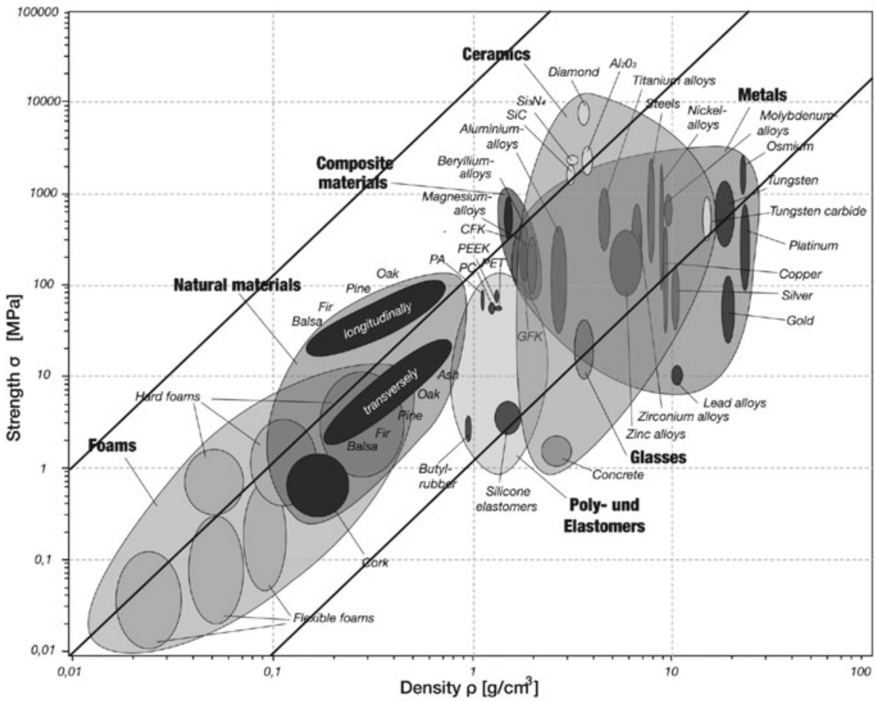

Fig. 9.28 Schematic representation of strength versus density of all material classes according to Ashby [AsWF-2006]

References

[ASTM-52910] Standard Guidelines for Design for Additive Manufacturing, American Society for Testing and Materials (ASTM) ISO/ASTM52910–17. ASTM International West Conshohocken (PA) (2016)

[AsWF-2006] Ashby, M.F., Wanner, A., Fleck, C.: Materials Selection in Mechanical Design: Das Original mit Übersetzungshilfen, Spektrum Akademischer Verlag (2006)

[Buch-2013] Buchbinder, D.: Selective Laser Melting von Aluminiumgusslegierungen. Dissertation RWTH Aachen 2013. Unter gleichem Titel erschienen in der Reihe "Berichte aus der Lasertechnik". Shaker Aachen (2013)

[Gebh-2016] Gebhardt, A.: Additive Fertigungsverfahren: Additive Manufacturing und 3D-Drucken für Prototyping - Tooling - Produktion. 5. Auflage, Hanser München (2016)

[GMWP-2012] Gu, D.D., Meiners, W., Wissenbach, K., Poprawe, R.: Laser additive manufacturing of metallic components: materials, processes and mechanisms. Int. Mater. Rev. **57**(3), 133–164 (2012)

[Hehe-2011] Hehenberger, P.: Computerunterstützte Fertigung – Eine kompakte Einführung. Springer, Heidelberg (2011)

[Hull-1984] Hull C.W.: Apparatus for production of three-dimensional objects by stereolithography. US000004575330A. 08.08.1984.

[Kadd-2010] Kaddar, W.: Die generative Fertigung mittels Laser-Sintern: Scanstrategien, Einflüsse verschiedener Prozessparameter auf die mechanischen und optischen Eigenschaften beim LS von Thermoplasten und deren Nachbearbeitungsmöglichkeiten. Dissertation Universität Duisburg-Essen. 209. (2010)

[Kran-2017] Kranz, J.: Methodik und Richtlinien für die Konstruktion von laseradditiv gefertigten Leichtbaustrukturen. Unter gleichem Titel erschienen in der Reihe "Light Engineering für die Praxis". Springer Vieweg (2017)

[KrLN-1998] Kruth, J.-P., Leu, M.C., Nakagawa, T.: Progress in additive manufacturing and rapid prototyping. CIRP Annals. **47**(2), 525–540 (1998)

[Kumk-2018] Kumke, M.: Methodisches Konstruieren von additiv gefertigten Bauteilen. Unter gleichem Titel erschienen in der Reihe "AutoUni-Schriftenreihe". Springer (2018)

[LaGL-2015] Lachmayer, R., Gottwald, P., Lippert, R.B.: Approach for a comparatively evaluation of the sustainability for additive manufactured aluminum components. In: Weber, C., Husung, S., Cantamessa, M., Cascini, G., Marjanovic, D., Graziosi, S. (eds.) Design for X, Design to X, Glasgow. Design Society, pp. 215–224 (2015)

[LaLi-2017] Lachmayer, R., Lippert, R.B. (eds.): Additive Manufacturing Quantifiziert: Visionäre Anwendungen und Stand der Technik. Springer, Berlin Heidelberg (2017)

[LaLK-2018] Lachmayer, R., Lippert, R.B., Kaierle, S. (eds): Additive Serienfertigung: Erfolgsfaktoren und Handlungsfelder für die Anwendung. Berlin Springer Vieweg (2018)

[Lipp-2018] Lippert, R.B.: Restriktionsgerechtes Gestalten gewichtsoptimierter Strukturbauteile für das Selektive Laserstrahlschmelzen. Dissertation Universität Hannover. Unter gleichem Titel erschienen in der Reihe "Berichte aus dem IPeG". Tewiss Verlag (2018)

[LSLB-2018] Lippert, R.B., Siqueira, R., Lachmayer, R., Baudach, T., Knöß, M.: Additive Fertigung als Bestandteil des industriellen Konstruktionsprozesses. In: Konstruktion Zeitschrift für Produktentwicklung und Ingenieur-Werkstoffe **2018**(5), 46–49 (2018)

[Mich-2014] Michaleris, P.: Modeling metal deposition in heat transfer analyses of additive manufacturing processes. In: Finite Elements in Analysis and Design, vol. 86, pp. 51–60 (2014)

[Moel-2014] Moeller, E.: Handbuch Konstruktionswerkstoffe: Auswahl, Eigenschaften, Anwendung, Carl Hanser-Verlag, 3. Auflage, Hanser München (2014)

[MuAt-2014] Murphy, S.V., Atala, A.: 3D bioprinting of tissues and organs. Nature Biotechnol. **32**(8), 773–785 (2014)

[ONHF-2018] Ostertag, K., Neuhäusler, P., Helmich, P., Frietsch, R., Walz, R., Gehrke, B., Schasse, U.: FUI-Indikatoren zu Nachhaltigkeit und Klimaschutz: Forschung, Entwicklung, Innovationen und Marktergebnisse. In: Studien zum deutschen Innovationssysten. 7 (2018)

[RWES-2009] Roberts, I.A., Wang, C.J., Esterlein, R., Stanford, M., Mynors, D.J.: A three-dimensional finite element analysis of the temperature field during laser melting of metal powders in additive layer manufacturing. Int. J. Mach. Tools Manuf. **49**(12–13), 916–923 (2009)

[Sauer-2017] Sauer, A.: Ressourceneffizienz durch Digitalisierung. Stuttgart. 15.03.2017.

[SDKV-2013] Shahzad, K., Deckers, J. Kruth, J.-P., Vleugels, J.: Additive manufacturing of alumina parts by indirect selective laser sintering and post processing. J. Mater. Process. Technol. **213**(9), 1484–1494 (2013)

[SPZF-2015] Sun, J., Peng, Z.; Zhou, W., Fuh, J.Y.H., Hong, G.S., Chiu, A.: A review on 3D printing for customized food fabrication. Proc. Manuf. **1**, 308–319 (2015)

[TVCV-2010] Thijs, L., Verhaeghe, F., Craeghs, T., van Humbeeck, J.; Kruth, J.-P.: A study of the microstructural evolution during selective laser melting of Ti–6Al–4V. In: Acta Materialia. **58**(9) 3303–3312 (2010)

[Vajn-2014] Vajna, S. (ed.): Integrated Design Engineering. Ein interdisziplinäres Modell für die ganzheitliche Produktentwicklung. Springer, Heidelberg Berlin (2014)

[VaWe-2000] Vajna, S., Weber, C.: Sequenzarme Konstruktion mit Teilmodellen - Ein Beitrag zur Evolution des Konstruktionsprozesses. Konstruktion 52(2000)5, S. 35–38

[VDI-2221/2019] VDI-Richtlinie 2221 Blatt 1: Entwicklung technischer Produkte und Systeme – Modell der Produktentwicklung. VDI, Düsseldorf (2019)

[VDI-3405] VDI-Richtlinie 3405: Additive Fertigungsverfahren - Grundlagen, Begriffe, Verfahrensbeschreibungen. Beuth Berlin (2014)

[VWZH-2018] Vajna, S., Weber, C., Zeman, K., Hehenberger, P. Gerhard, D., Wartzack, S.: CAx für Ingenieure – eine praxisbezogene Einführung. 3. Auflage, Springer (2018)

[Wran-1985] Wranglén, G.: Korrosion und Korrosionsschutz. Springer, Heidelberg Berlin (1985)

[Zgha-2016] Zghair, Y.A.: Rapid Repair hochwertiger Investitionsgüter. In: Lachmayer, R., Lippert, R.B., Fahlbusch, T. (eds.) 3D-Druck beleuchtet: Additive Manufacturing auf dem Weg in die Anwendung. Berlin Heidelberg Springer Vieweg, pp. 57–69 (2016)

[Zgha-2019] Zghair, Y.A.: Additive repair design process for aluminium components. Dissertation Universität Hannover. Unter gleichem Titel erschienen in der Reihe "Berichte aus dem IPeG". Tewiss Verlag (2019)

Chapter 10
Availability

Justus Arne Schwarz

The availability of a product has two dimensions. The first dimension is the continuous readiness of the product to be acquired by a customer on the market during the sales period. It requires that the provider disposes of sufficient capabilities to develop, produce, and deliver the product. It is challenging to ensure the availability of a product due to uncertainty and changes over time in the customer demand, the product development process, the production process, and the delivery process. The second dimension is the availability after the arrival at the customer, i.e., the readiness to be used. This means the product is ready for use in the intended application area, according to the requirements, and during the expected lifetime. In contrast to the fulfillment attribute reliability (see Sect. 13.2), the availability at the customer explicitly considers the time aspect and is not restricted to the time prior to a failure.

10.1 Performance Measures and Service Levels

The readiness to be acquired by the customer can be captured by logistical performance measures. These measures are used to quantify the performance of a company with respect to delivering the product to the user at the right time, in the right quantity, and at the right place. For individual orders, the availability can be measured by the customer's waiting time to receive the product. What the customer perceives as an acceptable waiting time depends on the product type that is influenced by many factors, e.g., the complexity of the product, its degree of customization, or its price.

Often, service levels are used to quantify the availability of mass products, for which the provider faces many orders that arrive over time. In B2B relations, agreements that a certain service level has to be ensured are typically part of purchasing

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contracts. Examples of these service levels are α-, β-, and γ-service levels (see [Temp-2011]).

For a given reference period, the α-service level measures the probability (Prob) that all customer orders will be fulfilled without a delay, i.e., that they can be completely delivered from stock on hand:

$$\alpha = \text{Prob}(\text{Period demand} \leq \text{Inventory on hand at the beginning of a period}).$$

The α-service level measures the complementary probability of stock-out events. Hence, it is an event-based metric. For example, an α-service level of $\alpha = 90\%$ corresponds to a 10% chance to observe a stockout during a reference period.

The β-service level measures the proportion of total demand, which is delivered without delay from stock on hand during a reference period. Thus, it is a quantity-oriented performance measure, which is defined by the share of the demand that is not back ordered. Hence, it can be calculated by 1 minus the share of backordered demand, where the share of backordered demand is given by the expected value of the backorders per period devided by the expected period demand:

$$\beta = 1 - \frac{\text{Expected backorders per period}}{\text{Expected period demand}}.$$

For example, a β-service level of $\beta = 90\%$ corresponds to a 10% chance that an arbitrary demand unit cannot be fulfilled from stock.

$$\beta = 1 - \frac{\text{Expected backlog per period}}{\text{Expected period demand}}.$$

In addition to the quantity, the γ-service level also considers the time that the orders are delayed. The γ-service level, which is a time- and quantity-oriented performance criterion, reflects not only the number of late deliveries but also the waiting times of the back-ordered demands by considering the development of the backlog in the preceding periods. The γ-service level is defined as follows:

$$\gamma = 1 - \frac{\text{Expected backlog per period}}{\text{Expected period demand}}.$$

Other time-based measures for the availability include the expected durations of stock-out situations and performance measures based on the distribution of the customers' waiting time from ordering to receiving a product.

Criteria for selecting the type of service level and the desired value of the chosen type are among others: the customers' preferences, the costs for unavailability, the inventory holding costs, and the demand volume (see [TZA-2009]).

The readiness to be used after the product reached the customer is a time-based measure. It describes the fraction of time in which the product is found in the "ready to use" state. For a finite period of time τ, the availability is defined as

$$A(\tau) = \frac{1}{\tau}\int\limits_{0}^{\tau} R(t)\mathrm{d}t \text{ where } \quad R(t) = \mathrm{Prob}(X(t) = 1) \text{ denotes the reliability}$$

$$\text{of the product with state} X(t) = \begin{cases} 1, \text{product is found in read to use state} \\ 0, \text{otherwise} \end{cases},$$

i.e., the ratio between the time the product is actually ready to be used and the time τ it was planned to be used. Under steady-state conditions and an infinite time period, the availability $\lim\limits_{\tau \to \infty} A(\tau) = A$ can be expressed by the mean time between failures (MTBF) and the mean time to repair (MTTR) as

$$A = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}}.$$

10.2 Relevance of Availability

The availability of a product on the market is relevant for both the provider and the customer. From the customer's point of view, the readiness to be acquired on the market is a necessary condition for the user to experience the benefits of the product. After the product has reached the user, the market availability is typically no longer of interest to the user. Exceptions are products that rely on network effects, for which the utility increases with the number of other users. In this case, the user also cares about the availability for other users because it directly affects his/her own product utility. Consumer goods of this product type are, e.g., gaming consoles like PlayStation or Xbox. These consoles allow the user to access an online gaming platform. The gaming experience on the online platform improves with a larger player base. Hence, a lack of availability harms those who have acquired the product already. They suffer because the lack of availability prevents additional customers from entering the gaming platform which would increase the number of players and thereby their gaming experience. Industrial goods subject to these network effects are, e.g., products that are used to establish Cyber-Physical Systems beyond company boarders.

From the provider's point of view, the availability on the market is relevant over the complete sales period of the product. Nevertheless, it is often at the beginning of the sales period at which it is most relevant. In particular for consumer goods, the availability on the market plays a crucial role in the diffusion of awareness about the product in the market. The word of mouth effect requires the customers to experience the product. Limited availability delays the diffusion of awareness and thereby delays and reduces the occurring demand. In addition, failing to provide the product that has just been launched may also result in loss of goodwill and brand loyalty, which negatively affects future sales.

Similar effects occur if the product does not meet the customer's expectations regarding the readiness to use (see Sect. 13.2).

10.3 Possibilities to Affect Availability

The product attribute availability on the market may only be influenced indirectly via other product attributes during the product development process. The root cause for insufficient availability is that the demand requirements exceed the capabilities of the firm. This mismatch can occur due to uncertainty with respect to both the demand and the development and production capabilities.

For consumer goods, the uncertainty with respect to the demand originates from the characteristic that there is not only a single customer but a market segment with customers that have heterogeneous and partially unknown expectations regarding the developed product. For products that are developed in a B2B relation, a specific customer is known. However, the requirements of this customer often change over time because the needs of the customer change or the improved understanding of the newly developed product yield new requirements. Hence, efforts to better understand customer demands, e.g., via Quality Function Deployment (see Sect. 13.3), and, if possible, establishing contracts with customers can help to reduce uncertainty with respect to demand.

Techniques to increase the innovation ability and the performance of product development processes such as IDE or building up a reliable production process by making it simpler, more flexible, and more efficient (e.g., by converting rather traditional manufacturing technologies into generative manufacturing technologies, see Chap. 9) can help to reduce the uncertainty with respect to the capacity.

Moreover, improvements with respect to the readiness of the product to be acquired on the market can be made by

- decreased demand requirements,
- increased capabilities or more efficient use of available capabilities, or
- decreased capability requirements of the product.

The capability requirements of the product are captured by the product attribute Producibility. The interdependencies between availability on the market and producibility are also discussed in Sect. 10.4. If the product is designed such that the firm can produce it easier, e.g., by increasing the share of equal parts with previous product generation or related products, the capability requirements of the product can be reduced. Similarly, designing the product such that it can be produced with the existing manufacturing technologies leads to a better match between capability requirements and the capabilities of the firm.

The other potential improvements belong to the fields of marketing and operations management. Exemplary approaches are briefly outlined in the following.

Demand requirements can be controlled indirectly by pricing and more directly by revenue management. The demand volume for a product typically decreases with increasing prices. At the same time, it improves the profit margin and helps the firm to exploit the willingness to pay of some customers.

In case a predecessor product exists, not only the absolute price matters but also the relative price compared to the predecessor. The predecessor version may serve as a substitute for the newly developed product. This bears the potential to improve the availability of the new version by offering the old version at a reduced price during the introduction phase of the new product. It improves availability because price-sensitive customers will buy the old product and thereby reduce the demand for the new product. This strategy is known as the dual rollover strategy and turns out to be especially effective if different resources are used to produce the new and old product, or if inventory can be build up prior to the introduction to the market (see [NeSm-2018]).

In case of limited capacity, revenue management aims to improve the profit by making the product available to the right customer segments at the right time via order acceptance decisions that are based on analytical methods. While revenue management was developed in the airline industry, similar concepts have been developed for the semiconductor industry (see [GFMS-2018]). A comprehensive treatment of revenue management problems and solution approaches can be found in [TaVR-2004].

Increasing capabilities refers to both product development capabilities and production capabilities. For a limited budget, there is a trade-off between investing in product development capabilities and investments in production capabilities (see [CaFr-2006]).

If capabilities are limited, it is crucial to make efficient use of them. With respect to product development, this can be achieved by techniques such as Simultaneous Engineering or Concurrent Engineering, which are discussed in Sect. 15.1.

In particular, during the early stage of the product life cycle, the production capabilities are often limited. Even tough production capacities and technologies are available, they cannot be utilized completely as a complete description of the product is often missing. Moreover, learning effects with respect to process improvements have not occurred yet (see [GlGr-2015]). At the same time, market availability is crucial to ensure the diffusion of awareness (see Sect. 10.1). One approach to foster availability at the market introduction is to increase the time to market and build up inventories. The pre-produced products can then be used to improve availability at the market introduction. However, this comes at the price of a delayed introduction, which can make this approach inapplicable for markets in which the time to market is part of the competition. Moreover, Shen et al. [ShDK-2014] show with a mathematical model that the option of adjusting prices is substantially more important than the ability to produce in advance and holding inventory.

Ensuring market availability remains challenging during the complete sales period, if there are no long-term contracts between the provider and the customers of what, when, and how much to deliver, or the contracts allow for short-term changes. For these cases, the availability can be improved by installing safety stocks in the supply chain to hedge against the uncertainty of customer demand. A comprehensive overview of methods to determine the amount and the location of ***safety stocks*** may be found in [Temp-2011].

The availability of the product, while it is in the possession of the user, can be improved either by increasing the MTBF or by decreasing the MTTR.

To increase the MTBF, products that include redundant components can be used. The redundancy of critical components allows the product to remain in the ready-to-use state even if a failure of a critical component occurs as long as there is still a functioning component remaining. This design approach is common in applications for which availability is crucial, such as aircraft or nuclear power plants. Preventive and predictive maintenance actions that replace critical components, which suffer from deterioration, before they actually fail are another lever to increase the MTBF.

An example for a measure to reduce the MTTR is a continuous monitoring system that automatically sends an alert in case of a failure to ensure a repair can start as soon as possible. The MTTR is also closely related to the product attribute maintainability that is described in Chap. 11. A product design that allows the easy replacement of critical parts as a whole can contribute to a reduction in downtime. Instead of searching for the failure reason while the product is not ready for use, the complete component can be replaced quickly by a spare part and the broken component can be reworked off-line.

The availability A is a measure that is based on the expected time to failure and the expected repair time. The actual performance of the product depends of the probability distribution of the times between failures and repair times. From an operations management point of view, a product with shorter but more frequent down times is more desirable than a product with longer but less frequent down times, given that both products have the same availability. This is because the resulting coefficient of variation of the effective usage times that include breakdowns is smaller (see [HoSp-2011]). Hence, preventive maintenance actions that lead to frequent but short downtimes can be beneficial.

10.4 Relations with Other Attributes

The attribute Availability is related to the product attributes Producibility, Product gestalt, Sustainability, and Maintainability.

Availability on the market and Producibility may be regarded as two sides of the same coin, where the customers care for the Availability on the market and the provider cares about the Producibility of the product to ensure the availability for the customer. In a multistage supply chain, a provider may also act as a customer, e.g., the Original Equipment Manufacturer (OEM) is the customer of Tier 1 suppliers (Fig. 10.1). Hence, the provider is concerned with the availability on the market when acquiring raw materials and components. Because the attribute Product Gestalt is a key driver for producibility (Sect. 6.1), the availability is also indirectly related to the product gestalt.

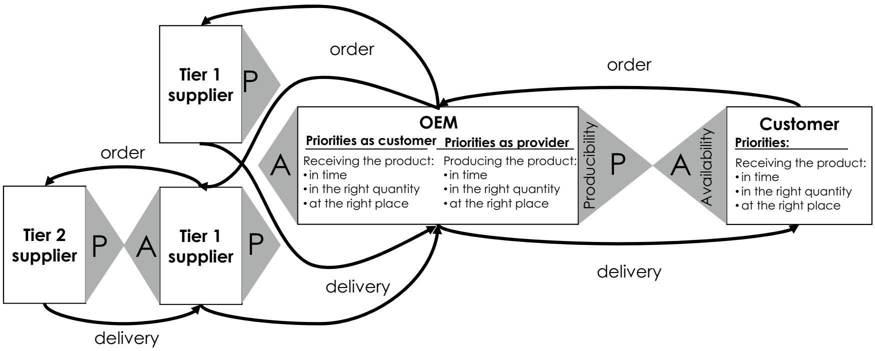

Fig. 10.1 Relation between producibility and availability in a multistage supply chain

High availability on the market and sustainability may be conflicting goals. This is the case if the product includes raw materials or components subject to seasonality. To ensure continuous availability on the market, the provider may be forced to source components from regions with lower ecological standards and will incur energy-intensive transports if the regions are located far away. In addition, building up inventories to improve availability on the market may harm the sustainability of a product, too. This is the case in particular if storing requires energy-intensive cooling of the product. In this situation, customers may be willing to trade-off the temporary unavailability of the product on the market for a more sustainable product.

The readiness to use is closely related to the attribute Maintainability because the maintainability drives the required repair time, in case of a defect. As the product is not ready to use for the customer during a repair, better maintainability can improve the proportion of time the user finds the product in the ready-to-use state.

In summary, the product development phase is crucial for the product attribute availability. Design choices such as the number of equal parts with predecessor generations, modular product design, and the use of components that can be manufactured with existing capabilities contribute to an improved availability on the market. Moreover, the organization of the development process itself and techniques, such as Simultaneous Engineering and Concurrent Engineering, can contribute to a faster time to market and thereby improve the availability of the product. Finally, the product development can also contribute to the readiness to be used while the product is in the possession of the customer via design choices, e.g., redundant critical components and the integration of sensors that support failure diagnosis.

References

[CaFr-2006] Carrillo, J.E., Franza, R.M.: Investing in product development and production capabilities: the crucial linkage between time-to-market and ramp-up time. Eur. J. Oper. Res. **171**(2), 536–556 (2006)

[GlGr-2015] Glock, ChH, Grosse, E.H.: Decision support models for production ramp-up: a systematic literature review. Int. J. Prod. Res. **53**(21), 6637–6651 (2015)

[GFMS-2018] Guhlich, H., Fleischmann, M., Mönch, L., Stolletz, R.: A clearing function based bid-price approach to integrated order acceptance and release decisions. Eur. J. Oper. Res. **268**(1), 243–254 (2018)

[HoSp-2011] Hopp, W.J., Spearman, M.L.: Factory Physics, Waveland Press, (2011)

[NeSm-2018] Negahban, A., Smith, J.S.: Optimal Production-Sales Policies and Entry Time for Successive Generations of New Products. Int. J. Prod. Econ. **199**, 220–232 (2018)

[ShDK-2014] Shen, W., Duenyas, I., Kapuscinski, R.: Optimal pricing, production, and inventory for new product diffusion under supply constraints. Manuf. Serv. Oper. Manage. **16**(1), 28–45 (2014)

[TaVR-2004] Talluri, K.T., Van Ryzin, G.J.: The theory and practice of revenue management. International Series in Operations Research and Management Science (vol. 68). Boston, MA: Springer US 2004

[Temp-2011] Tempelmeier, H.: Inventory Management in Supply Networks. 2nd edn. Books on Demand (2011)

[TZA-2009] Teunter, R.H., Babai, M.Z., Syntetos, A.A.: ABC classification: service levels and inventory costs. Prod. Oper. Manage. **19**(3), 343–352 (2009)

Chapter 11
Maintainability

Frank Müller, Martin Dazer, and Bernd Bertsche

In order to reduce operating costs and downtimes due to unplanned outages, good maintainability of technical products or systems is necessary. The maintainability of of the systems therefore plays an important role, especially for capital goods such as production plants. In qualitative terms, maintainability describes the ease with which maintenance work can be carried out on a plant or a system.

In contrast to the reliability analysis (see Sect. 13.2), which analyses systems up to their first failure, repairable systems are considered over their entire service life. As a rule, this does not end with the first failure. Maintenance, repairs or other maintenance measures are carried out so that the systems are restored to a functional state after a failure. Maintenance or repair is followed by a further utilization phase [BeLe-2004]. Availability is a decisive parameter for describing the long-term behaviour of repairable systems (see Sect. 11.1). This is calculated over the mean time of use as well as the mean downtime of the systems and is thus significantly influenced by the reliability of the systems and their maintainability [Frit-2001].

With an increasing trend towards so-called Total Cost of Ownership contracts [Oest-2004] and operator models [Meie-2004], maintainability and optimized maintenance planning are becoming an additional competitive factor. Only through reliable planning and prediction of the necessary maintenance expenditure of a plant as well as the optimum maintenance times can a plant manufacturer achieve the contractually agreed availability targets and plan economically. Maintainability should therefore be considered early on in the development process so that the subsequent maintenance effort is as low as possible and remains below the planned effort.

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11.1 Basics of Maintainability

The maintenance of a technical product describes all measures and possibilities for the assessment and preservation of the actual condition as well as for the restoration of the useable nominal condition of technical systems, installations or devices [DIN-31051]. It refers to the entire use phase of the product and is largely determined during product development. To ensure easy maintainability, attention must be paid, among other things, to ease of assembly, task-related structuring and good disassembly of the components critical to failure. This provides an easy way to repair or replace components [BeLe-2004].

In addition to high reliability, good maintainability makes a major contribution to achieve high availability (see Sect. 11.2) of the systems. The goal of maintenance work is therefore to achieve or maintain the required operational availability. According to [DIN-31051], the following types of maintenance are distinguished in maintenance, inspection, repair and improvement.

- All measures for maintaining the target condition are summarized under *maintenance*. This includes all preventive measures that help to prevent or delay wear and tear, such as the precautionary replacement of components that are prone to faults or the regular replacement of lubricants.
- *Inspections* include all measures to determine and assess the actual condition as well as the initiation of appropriate countermeasures, e.g., checking for wear, corrosion, leaks, loose connections, etc.
- *Overhaulings*, also known as repairs, include all measures for restoring the target condition and
- *Improvement* covers all activities to increase safety, reliability, availability and maintainability of a product.

Depending on the time at which a maintenance task is performed, a further classification can be created. While scheduled and condition-based maintenance is carried out before a failure, unscheduled maintenance is only carried out after a failure [Biro-2017, BeLe-2004, Vajn-2014].

- Planned maintenance is carried out at predetermined times or periodically after a certain number of operating hours. They include maintenance and inspection as well as overhaul work. During an *overhaul,* the product is disassembled to such an extent that certain parts, assemblies or components are accessible and can be replaced if necessary.
- Condition-oriented maintenance measures are carried out in the same way as scheduled maintenance before a breakdown, but avoid fixed or pre-defined time intervals. The aim is to reduce the maintenance effort without compromising the reliability or safety of the systems. It must be possible to detect and monitor the damage characteristics or the condition of the systems by means of suitable monitoring techniques such as oil or vibration analyses, thermographic monitoring or by means of sensors. The replacement of components or repair is carried out as soon as a critical condition of the components, e.g. a certain degree of wear,

has been reached. This prevents fully functional components from being replaced too early [VDI-2888].

In contrast to planned and condition-based maintenance, unscheduled maintenance (corrective maintenance) is only carried out after a partial or total failure and restores the target condition of the systems, devices or components. Corrective maintenance is therefore often referred to as *repair* [Biro-1991].

Often there are several maintenance levels, i.e. the faulty component is replaced by another, functional component and the faulty component are fed into a maintenance cycle within which all subsequent work to restore the functionality of the component is performed. The exchange of the component forms the first maintenance level, the maintenance cycle of the faulty component forms the second maintenance level. This reduces the downtime and the repair time of the system until it is put back into operation. However, the total maintenance effort remains unchanged. If there is only one maintenance level, corrective maintenance measures are divided into the following individual measures [BeLe-2004]:

- Detection of the fault or failure
- Notification of the fault or failure to responsible maintenance personnel
- Travel of maintenance personnel to the location of the malfunction or failure
- Provision of tools and test equipment
- Localization at component level of the fault or the failure
- Removal of the faulty component
- Provision of the required spare parts
- Elimination of the fault or failure by replacing the faulty parts or components
- Adjustment, calibration and testing of the repaired component
- Installation of the repaired component in the system
- Functional test of the complete system.

The sum of all time expenditure assigned to these individual measures results in the total downtime or the total maintenance duration. Whether a separate maintenance cycle introduced depends, for example, on whether the problem can be repaired on site [Bitt-1986].

In practice, repair or maintenance priorities are often set. This is useful if one component is more important for the functionality of the system than another, e.g. a serially connected component as opposed to a component with additional redundancy connected in parallel (see Sect. 11.2). From an economic point of view, the component with the highest failure costs is the most important [BeLe-2004].

In addition to the maintenance task itself, the associated maintenance capacities must also be planned. Thus, it is usually not possible to carry out maintenance work without delay because necessary resources are not immediately available. For the calculation of the maintenance capacities, an economic compromise between the provision of the capacities (e.g. the number of spare parts in the warehouse) and the waiting times caused by the unavailability of the maintenance capacities (e.g. necessary delivery time of the spare parts if the warehouse is too small) must be found [BeLe-2004, Frit-2001, Pozs-2006]. Maintenance capacities include all boundary conditions that are necessary for the maintenance work, such as the maintenance infrastructure, personnel, tools and equipment or exchange and spare parts.

The number of repair teams is usually limited. It can be estimated by the type and duration of the maintenance work or predicted in advance using suitable models and simulation algorithms (e.g. Petri nets, renewal processes, Markov processes, etc.) Spare parts, on the other hand, are usually kept in warehouses. According to PFOHL, inventories are "buffers between input and output flows of goods" [Pfoh-2018]. In maintenance management, these goods are spare parts that are required for maintenance work. By stocking spare parts in warehouses, waiting times and thus extended maintenance periods can be avoided and economies of scale, e.g. quantity discounts when ordering, can be used. A warehouse also serves as a protection against uncertainties with regard to the predicted scope of maintenance or the predicted demand for spare parts and to ensure long-term availability of spare parts. Bearings that are too large lead to avoidable storage costs, bearings that are too small lead to an extension of the downtime of the plants and thus to economic losses. The aim is to establish an optimal inventory management system for the needs of maintenance. Figure 11.1 shows a typical inventory development and gives the basic terms in connection with inventory [Pfoh-2018]. An order cycle covers the time between two orders.

Maintenance tasks include coordination with the company goals and the definition of a maintenance strategy [DIN-31051]. In this context, the maintenance strategy defines the following topics for the system and its components [BeLe-2004]:

- Type and frequency of maintenance measures (e.g. inspection intervals, scope of maintenance, etc.)
- Strategy of warehousing
- Number and qualification of repair teams
- Repair priorities
- Maintenance levels
- Maintenance capacities (spare parts, personnel).

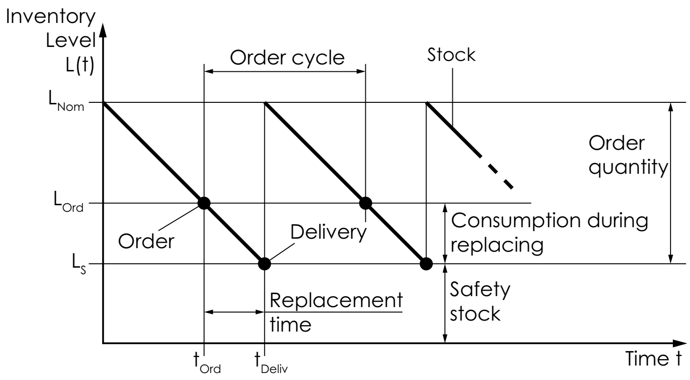

Fig. 11.1 Development of the stock level [BeLe-2004]

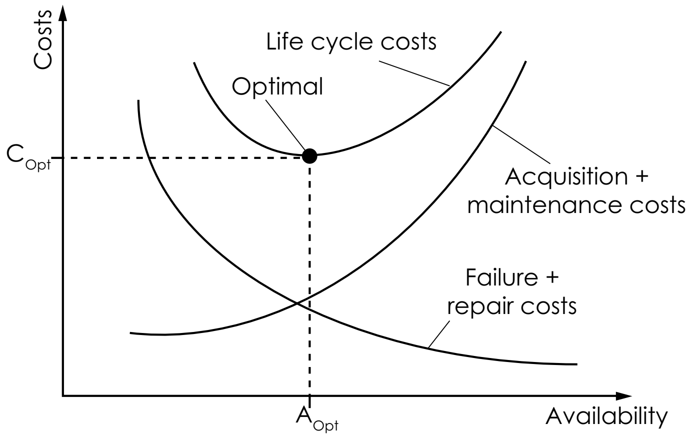

Fig. 11.2 Schematic relationship between availability and life cycle costs [BeLe-2004]

The optimal maintenance strategy is derived from the conflict of objectives between the achieved availability of a plant and the maintenance costs to be incurred. In addition to reliability, maintainability and availability have a major influence on the so-called life cycle costs (LCC), i.e. the costs incurred during product use. These consist of the purchase costs (purchase price), one-time costs, operating costs, maintenance costs and other costs. Figure 11.2 shows the relationship between availability and life cycle costs. Greater reliability and rapid maintainability lead to higher purchase costs. Due to a well-trained maintenance organization and high stock levels, maintenance costs are increasing. High investments in these two cost types result in increasing availability. At the same time, the costs arising from downtimes decrease with increasing availability.

The sum of purchase costs, maintenance costs and downtime costs (breakdown and repair costs) for a certain availability has A_{Opt} a minimum with which the lowest life cycle costs are achieved with optimum availability.

The durations of the activities and the waiting times for maintenance are usually not deterministic, but stochastic, that is, they can vary. In analogy to the context of reliability (Sect. 13.2), they are understood as random variables. The maintainability describes the probability that the time required for a maintenance task is less than a specified interval if the maintenance is carried out under defined material and personnel conditions [BeLe-2004, Biro-1991]. The random variable τ_{M} is the duration of the maintenance task. Maintainability covers the entire period between failure detection and re-commissioning, including the time needed to procure spare parts and other waiting, delivery or logistics times. Table 11.1 gives an overview of the characteristics of maintainability in analogy to reliability.

To distinguish between preventive and unplanned (corrective) maintenance, their parameters are often indicated differently (PM for preventive maintenance, R for repair), which is why, depending on the type of maintenance measure τ_{PM} or rather τ_{R} is used as a random size. The terms *MTTPM* (Mean Time To Preventive Maintenance)

Table 11.1 Overview of the maintenance parameters

Term	Formula symbol	Declaration
Maintainability	$G(t)$	Distribution of maintenance duration τ_M describes the probability that the maintenance duration is less than a specified period t where $G(t) = P(\tau_M \leq t)$
Maintenance density	$g(t)$	Derivation of maintainability describes the corresponding number of maintenance operations with a corresponding duration
Maintenance rate	$\mu(t)$	Probability that a maintenance task is finished in the next time interval dt
Expected value of the maintenance duration	$MTTM$	Mean time to maintenance corresponds to the mean value of the maintenance duration

for the mean value of the maintenance duration and *MTTR* (Mean Time To Repair) for the mean value of the repair duration are then commonly used to characterize the maintenance and repair duration [Biro-1991]. Table 11.2 summarizes the survival and maintenance parameters [BeLe-2004].

Maintainability directly influences the availability and economic operation of a plant, which is why it is becoming increasingly important. New approaches such as predictive maintenance or approaches of Prognostic and Health Management offer great potential within maintenance work. The aim is to make maximum use of the remaining service life of the systems so that maintenance measures are only carried out shortly before an actual failure. For example, operating strategies are adapted in such a way that a breakdown is avoided until the next maintenance interval. This promises further cost savings compared to conventional maintenance strategies.

Table 11.2 Survival and maintenance parameters [BeLe-2004]

Key figure	Random size			
	Lifetime	Maintenance duration	Maintenance duration	Repair duration
Random size symbol	τ_L	τ_M	τ_{PM}	τ_R
Distribution function	$F(t)$	$G(t)$	$G_{PM}(t)$	$G_R(t)$
Probability of survival	$R(t)$	–	–	–
Density function	$f(t)$	$g(t)$	$g_{PM}(t)$	$g_R(t)$
Performance risk	$\lambda(t)$	$\mu(t)$	$\mu_{PM}(t)$	$\mu_R(t)$
Expected value	$MTTF$	$MTTM$	$MTTPM$	$MTTR$

11.2 Maintenance-Friendly Design of Products

The maintainability of a product is already determined during product development. If care is taken to ensure that the components are easy to assemble, task-related structuring and good disassembly of the components, as well as the possibility of easy repair or replacement of the components, the time required to detect and rectify a fault or the subsequent time required to carry out a maintenance measure can be reduced. As described in Sect. 11.1, there are numerous measures that can be taken to develop a product that is suitable for maintenance. Figure 11.3 shows an overview of the relevant control variables for the good maintainability of a product [Ebel-1997, BeLe-2004, Vajn-2014].

If a product fully complies with agreed standards such as norms or guidelines, and if it is also implemented as uniformly as possible beyond these standards, this leads to better traceability of the product, which eliminates or significantly reduces training times of maintenance personnel in the product structure. A high degree of modularity and good exchangeability or compatibility can additionally shorten repair times, since, for example, individual modules can be replaced quickly and easily. The faulty modules can then be repaired in a downstream maintenance cycle while the product is already being used again. If different product or machine types use the same assemblies, modules or identical parts, the spare parts stocking can be simplified or the stock size reduced. A spare part can then be used for repairs in different product or machine types.

A good documentation together with a comprehensible and intuitive labelling or coding of the parts or components further reduce repair or maintenance times, as a tedious search for suitable spare parts is no longer necessary. Faulty components can be detected directly and replaced by a suitable new (or refurbished) component. Fault codes issued by the system or other indicators can also simplify fault localization or troubleshooting, thus reducing repair or maintenance time. The same is

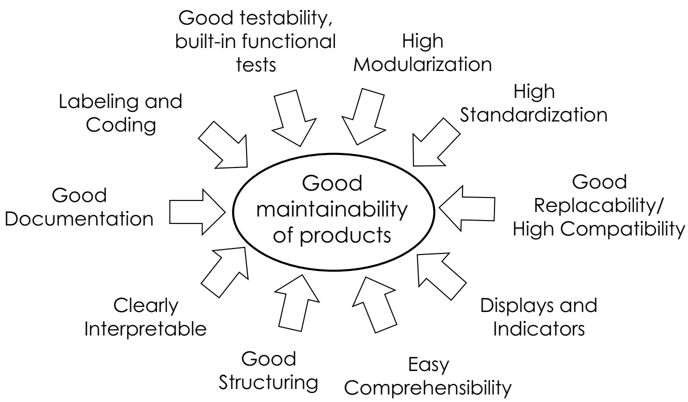

Fig. 11.3 Good maintainability of products

achieved through simple functional tests and simple relationships between product components.

Better maintainability is also achieved by making the systems or products easy to understand and appropriately structured. If, in the best case, a system can also be maintained or repaired by non-specialist personnel, waiting times for specially trained personnel are eliminated. In addition, troubleshooting is simplified. A product that can be maintained in good condition can be clearly interpreted and the intermediate products can be mapped to their predecessors and vice versa.

References

[BeLe-2004] Bertsche, B., Lechner, G.: Zuverlässigkeit im Fahrzeug—und Maschinenbau, 3rd edn. Springer, Heidelberg (2004)

[Biro-1991] Birolini, A.: Qualität und Zuverlässigkeit Technischer Systeme, 3rd edn. Springer, Berlin (1991)

[Biro-2017] Birolini, A.: Reliability Engineering, Theory and Practice, 8th edn. Springer, Berlin (2017)

[Bitt-1986] Bitter, P., Groß, H., Hillebrand, H., Trötsch, E., Weihe, A.: Technische Zuverlässigkeit. Problematik, Mathematische Grundlagen, Untersuchungsmethoden, Anwendungen. 3., neubearbeitete und erweiterte Auflage, Berlin, Heidelberg, New York, London, Paris, Tokyo: Springer (1986)

[DIN-31051] Deutsches Institut für Normung (DIN): DIN 31051—Grundlagen der Instandhaltung. Beuth, Berlin (2012)

[Ebel-1997] Ebeling, C.E.: An Introduction to Reliability and Maintainability Engineering. McGraw-Hill Verlag, Singapur (1997)

[Frit-2001] Fritz, A.: Berechnung und Monte-Carlo Simulation der Zuverlässigkeit und Verfügbarkeit technischer Systeme. Dissertation, Stuttgart: Berichte aus dem Institut für Maschinenelemente (2001)

[Meie-2004] Meier, H. (Hrsg.): Dienstleistungsorientierte Geschäftsmodelle im Maschinen- und Anlagenbau. Vom Basisangebot bis zum Betreibermodell. Springer, Berlin, Heidelberg (2004)

[Oest-2004] Oesterlin, T.: Gesamtkostenoptimierung durch Lebenszeitbetrachtung (TCO). In: VDI-Berichte 1826, Instandhaltung und Produktion—Integriert in die Zukunft. Düsseldorf: VDI Verlag, 2004, S. 265-286

[Pfoh-2018] Pfohl, H.-C.: Logistiksysteme. Betriebswirtschaftliche Grundlagen. 9. Auflage. Springer-Vieweg, Berlin (2018)

[Pozs-2006] Pozsgai, P.: Realitätsnahe Modellierung und Analyse der operativen Zuverlässigkeitskennwerte technischer Systeme. Dissertation, Stuttgart: Berichte aus dem Institut für Maschinenelemente (2006)

[Vajn-2014] Vajna, S. (Hrsg.): Integrated Design Engineering. Ein interdisziplinäres Modell für die ganzheitliche Produktentwicklung. Springer, Berlin, Heidelberg (2014)

[VDI-2888] Verein Deutscher Ingenieure (VDI): VDI-Richtlinie 2888—Zustandsorientierte Instandhaltung. Düsseldorf: VDI-Verlage (1999)

Chapter 12
Sustainable Product Development

Martin Wiesner

Sustainability is a strategy for the mutual interlocking of society, ecology and economy with the aim of promoting development that meets the needs of the present generation without limiting the opportunities of future generations [Beys-2012]. In a supplementary definition of sustainability, which is the intra-generational justice, attention is also paid to socially just development in the present generation (see [LSRH-2012, UnNa-1992]), especially with regard to disadvantaged groups and the inhabitants of the world's poor countries (see also [Prah-2002]).

Within IDE, sustainability is imperative because all the prerequisites for a sustainable product are already created in the product development phase. This chapter describes sustainability and the consequentially resulting properties and procedures. These serve to formulate the product attribute Sustainability, whose influence and effectiveness run parallel to the entire product life cycle (Fig. 3.5). Even in earlier design methods, it has been recognized that a product cannot be viewed in isolation from its environment and its effects. For example, as early as 1976, HUBKA attributed an ethical sense of responsibility for society and the economy to the designer of the product to be developed [Hubk-1976].

The basic principles and starting conditions of sustainability described in Chap. 5 place new demands on product development, which are increasingly being required by consumers (see for example [Oerk-2015]). Basically, these demands resulting from sustainability aspects can be summarized in two categories, whereby it should be noted that the entire life cycle of the product must always be considered because about 75% of the effects are determined during product development (Fig. 1.1 [Wien-1970]).

1. **Conservation of resources**: During development, the use of resources (energy sources and other raw materials) for the manufacture and use of the product must

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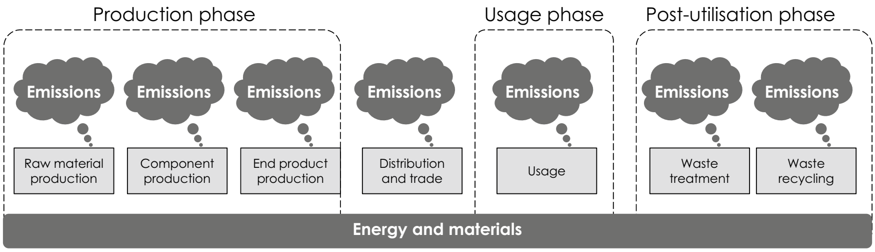

Fig. 12.1 Environmental impacts over the product life cycle

be reduced to a necessary minimum, whereby non-renewable resources must be substituted or used in the product conceptually in such a way that loss-free (quantitative and qualitative) recovery and further use is possible.

2. **Environmental effects due to emissions**: During production, use and disposal of the product, emissions harmful to the environment and health must be avoided. Not only the air path (e.g. the emission of greenhouse gases such as CO_2 and methane), emissions in water and soil as well as the generation of waste (primarily in the production and disposal phase) and noise (primarily in the use phase) must also be taken into account.

Figure 12.1 shows these relationships.

In addition, social aspects have to be taken into account, which essentially result from working conditions (e.g. health and safety at work), fair pay, equal treatment and the prohibition of child labour. In many cases, the influence of product development can only be seen peripherally and to a limited extent, but social aspects must nevertheless be taken into account, especially in product planning, in design and in determining suppliers and production conditions. In some cases, it is still necessary to examine what social impacts a product has in terms of technology impact assessment[1], and it must be checked whether a product range and the production approaches required for it are ethically justifiable (see for example VDI guideline 3780 [VDI-3780, Köni-2013]). In terms of sustainability, product development must therefore lie between planetary and social limits (see Chap. 5) take place (Fig. 12.2). This means that negative effects on the environment must be excluded or remain within tolerable limits (or minimum standards).

The planetary boundaries (shown in Fig. 12.2 left) include climate change, extinction of species, ocean poisoning, chemical pollution, oxygen and phosphorus cycles, ocean acidification, land use, particle pollution of the atmosphere and freshwater use [Rock-2009]. These individual boundaries are also called impact categories. They are important for assessing the effects and consequences of a product. From the point of view of social sustainability, important impact categories are a fair income, social equality, gender justice, co-determination, access to education, energy, food

[1]Technology assessment aims to anticipate possible positive and negative technology impacts and consequences, to recognize technology conflicts at an early stage and to show ways to solve them [Duss-2013].

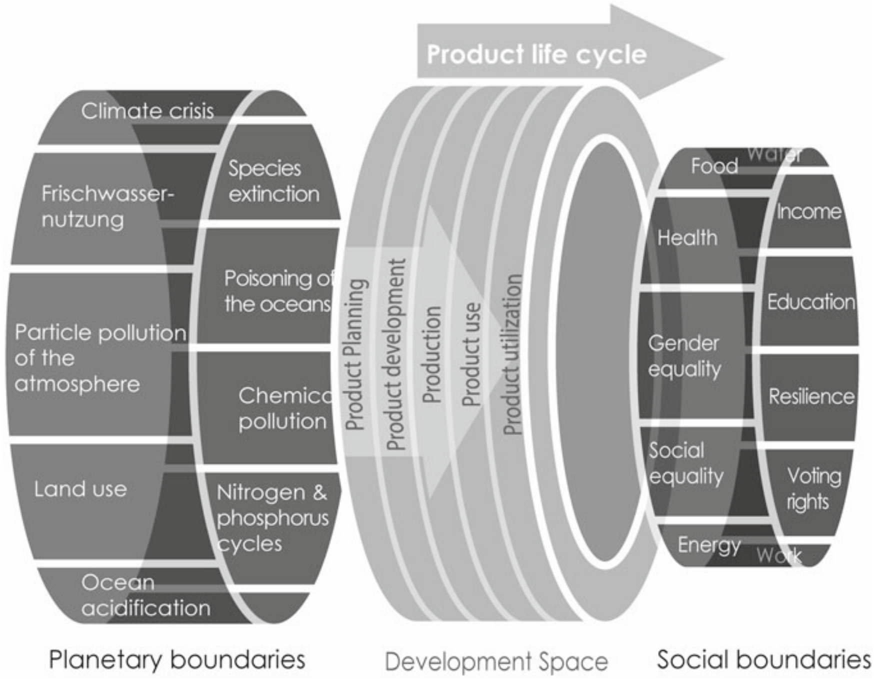

Fig. 12.2 Product development within a development space between planetary and social boundaries

and health care (in Fig. 12.2 shown on the right) [Vinc-2012]. Only within these limits may a product be developed and produced (shown in the middle of Fig. 12.2) in order to achieve sustainable value creation to be generated.

12.1 Actors with Regard to Sustainable Product Development

A change of direction towards more sustainability can only succeed with the involvement of the various actors in politics, business and society [BMU-2020]. The population supports the basic principles of sustainable development to a high degree. The business community is also committed to sustainable development and makes this commitment through various corporate responsibility activities which is also known as Corporate Social Responsibility (CSR) is clearly marked [BMU-2020]. Sustainability as a quality feature of products must become a self-evident guiding principle for users in the capital and consumer goods sector, but it must also be equally valid for the economy and public administration.

12.1.1 *Changing Requirements of Users and New Forms of Usage*

Among product users (especially those in the consumer goods industry), awareness of the need for sustainable lifestyles and alternative consumption patterns is higher than ever before: 63% say that sufficient environmental protection and climate protection are the basic conditions for coping with future tasks [SGHS-2016]. The decisions of this group of people are of great importance. It is estimated that between 30 and 50% of environmental pollution caused by household consumption activities [KnRe-1998], and also, more than 70% of greenhouse gases in Europe are directly or indirectly caused by consumption decisions [Grög-2017].

For this reason, it is important to show that product users can contribute to the realization of sustainable development and the reduction of pollution by consuming sustainable or ecological products [Pufé-2014, Grög-2017].

The ideal picture for sustainable development is that of mature product users, who make competent and informed purchasing decisions and thus have considerable influence on political decisions and corporate strategies as a result of changing wishes and requirements [HeSc-2011]. More realistic than mature product users, however, seem to be the image of a type of user who is not always disciplined, who tends to be overburdened, conditionally interested and under time pressure [MOPL-2010]. There is therefore a certain discrepancy between the existing environmental awareness and attitudes of the users and their observed behaviour. This discrepancy is called the *attitude-behaviour gap* [HeSc-2011, TeHi-2015], which means that existing attitudes are by no means always reflected in concrete actions (behaviour), and there is therefore a gap. The reasons for this gap have a great influence on all projects that [2]include sustainable product development in a narrow or broader sense. These will therefore be examined in more detail below.

12.1.1.1 What Inhibits and What Promotes Sustainable Consumption

Enforcement barriers to sustainable consumption are factors that promote the purchase of conventional products or restrict the use of sustainable consumption alternatives, even though there is an ecological intention to purchase [Berg-1994, Glei-2013]. Traditionally, authors cite factors or characteristics such as the relatively high price, poor quality, low availability, but also the lack of information as barriers to purchase [BuFH-2014, Falt-2010]. These barriers are in line with a

[2]Sustainability in a broader and narrower sense: BELZ and BILHARZ [BeBi-2007] distinguish two levels of sustainable consumption. The first level (sustainable consumption in the broader sense) includes consumption activities that have a lower socio-ecological impact than conventional consumption (e.g. organic food), i.e. a relative improvement over previous consumption. The second level of sustainable consumption (sustainable consumption in the narrower sense) refers to a consumption pattern that is inter- and intra-generationally just, i.e. the ideal of a consumption style that is sustainable in all aspects.

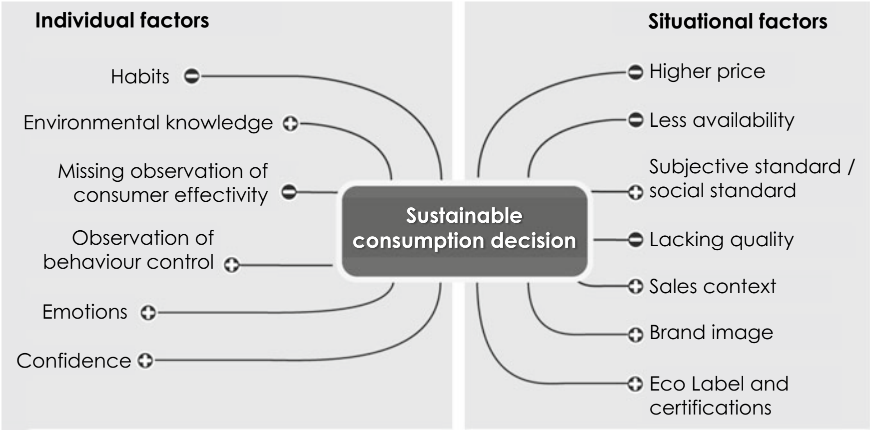

Fig. 12.3 Factors influencing sustainable consumption decisions, based on data from [JoRa-2015]

meta-study by JOSHI and RAHMAN, in which the influence of existing habits, lack of perceived consumer effectiveness and lack of trust are also named as buying barriers [JoRa-2015].

The barriers to sustainable consumption are counterbalanced by a number of beneficial properties, which are unanimously mentioned by others authors: Trust in the product, environmental knowledge, subjective and social standards, brand image, availability, positive emotions, positive aspects of the sales context at the point of sale (POS), perceived behavioural control, high product quality, brand image and independent eco-labels and certificates [JoRa-2015]. Figure 12.3 shows inhibiting and promoting factors, which are divided into situational factors and individual factors of the consumers.

For product development, these findings mean that

- the sustainable product alternative should not break too much with existing consumer habits, or that the additional behavioural effort should be minimal,
- consumers should be made aware that this product alternative has positive effects in terms of sustainability (i.e. that it is efficient to choose it),
- sustainable behaviour is all the more likely if it is considered easy to implement, i.e. the greater the subjective conviction that one's own behaviour is under control[3],
- it is worthwhile to build trust with consumers in the sense of CSR,
- independent eco-labels and certificates are important,
- sustainable product alternatives are preferred when they have become the social norm or as soon as a high proportion of the social environment uses them,
- sustainability in itself is not sufficient for a purchase decision, but that the consumer must also be convinced by emotions, product quality and brand image as well as the design of the selling point and that the price must not be too high.

[3]This means that one assumes, for example, that one has enough abilities, skills or even resources to realize the behaviour.

12.1.1.2 Changed Business Models Through Collaborative Consumption

In addition to consumption in the sense of physical possession, a focus on new forms of use should be placed, which can make the physical possession of a product obsolete in some areas. This strategy is known under the keywords “use instead of owning”, “sharing economy” or as collaborative consumption [LSRH-2012, Ston-2017]. The differences and possible advantages to previous behaviours are described below in Fig. 12.5 (left and right side).

According to the model of collaborative consumption, from the manufacturers’ (or providers’) point of view, new service systems and from the users’ point of view changed attitudes contribute to reducing both the intention to buy and, in particular, the realized physical purchase of conventional products. On the other hand, possession is replaced by collaborative consumption or, according to sufficiency considerations of the consumers, does not exist any more (sustainability in the narrower sense, right side of Fig. 12.4). In addition, there is still the possibility of buying more sustainable products (sustainability in the broader sense). All these options reduce conventional consumption to a much lower level.

The causes of consumption are, on the one hand, in addition to pure need, also social norms (i.e. adaptation to the current social normality) and participation (e.g. adaptation to the lifestyle of others in order to get a sense of belonging), but on the other hand also demarcation from others and the presentation of one’s own status. Considerations of alternative ways of satisfying needs, of using what is already there or repairing it and, of course, of conscious renunciation should be imitative factors in the emergence of an intention to buy with regard to sustainable consumption.

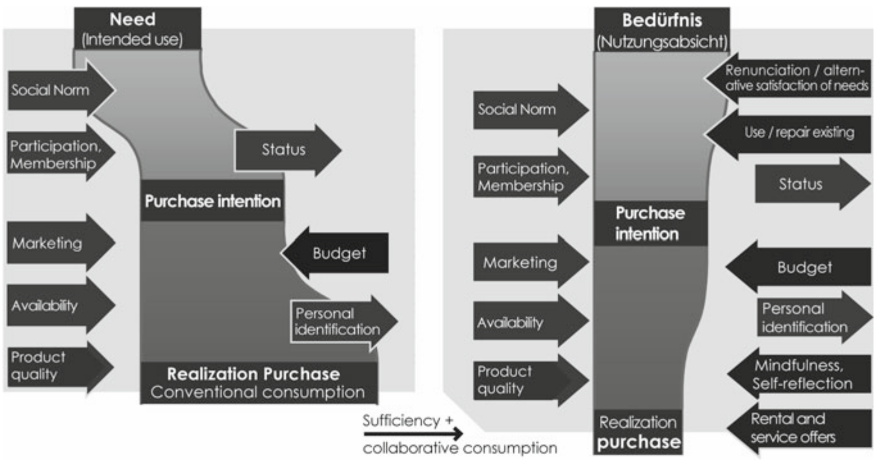

Fig. 12.4 Influences on purchasing decisions in conventional consumption and mindful consumption, which includes sufficiency considerations and collaborative consumption

As soon as the intention to buy is there, product quality, marketing, availability and sometimes also personal commitment to the product play a decisive role. On the other hand, limiting factors are the available budget and, in the sense of sustainable consumption, mindfulness and self-reflection.

12.1.2 Sustainable Product Development from the Perspective of Politics and Society

In addition to the behaviour of users, basic social and legal conditions in particular have a major influence on sustainability-oriented product improvements. This requires a long-term vision for the implementation of sustainable development. Such a vision can be found in the Paris Climate Agreement [UnNa-2015] and (to some extent) also in the German Climate Protection Plan [BMU-2019]. In the German Climate Protection Plan, both long-term and medium-term goals are specified in accordance with the European Union. Germany has committed itself to reducing greenhouse gas emissions by 80–95% by 2050 and by 40% until 2030 compared to 1990 levels [BMU-2019]. A long-term vision can also be seen in the European "Green Deal", which sets out the vision of becoming the first climate-neutral continent by 2050 [EU-2019]. In addition to the long-term vision, it goes without saying that instruments are needed to promote this behaviour. Effective instruments for this are regulations in the areas of tax law, product responsibility, legislation, prohibitions (e.g. the prohibition of harmful substances, see the European act REACH[4]) and emissions trading [Berg-1994].

The current use and design of instruments to promote sustainable consumption, which starts with the consumer, have so far been inadequate and do not go beyond the first meritorious approaches [ScSG-2012]. It should be noted that according to REHBINDER [Rehb-2002], there is not an instrumental panacea in the form of a single sustainability instrument [ScSG-2012]. According to the expert opinion of the German Federal Environment Agency, conceivable future instruments are taxes on product resources, deposits on electrical appliances, privileges for sharing products and, as a last resort, bans on product use [ScSG-2012]. The effectiveness of the legal framework can be seen, for example, in the ban on the greenhouse gas CFC. Strict guidelines and determined action by the international community have ensured that the ozone hole is gradually closing again [Zeibi-2014]. [Knau-2015]. For companies and for product development, legal frameworks are not only an obstacle but also provide a certain planning security and furnish defined requirements that can be integrated into product development.

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[4]REACH: EU regulation for the **R**egistration, **E**valuation, **A**uthorization and Restriction of **Ch**emicals. This regulation bans and restricts certain hazardous substances and introduces an authorization procedure for particularly hazardous substances [Wint-2018].

12.1.3 *Sustainable Product Development from a Corporate Perspective*

Not only the rising expectations of environmentally conscious customers, but also additional requirements from legislators and increasingly sustainability demands from investors are important impulses for companies to make product changes. In addition to product liability, the impact of products on the environment and sustainable management plays an increasingly important role. Accordingly, producers must assume more responsibility not only in the area of customer safety, but also in other areas (such as recycling or the CO_2 balance). From the point of view of companies, it is therefore important to consider these aspects at an early stage in product development in order to keep possible costs resulting from legal obligations as low as possible. In addition to considering the risks that can arise from neglecting environmentally oriented product development, it is also necessary to consider the opportunities that arise from ecological management and product design. KREIBICH [Krei-1991] summarizes these as follows [HoJa-1995]:

- As a result of increasing environmental awareness, any company that strategically responds to such developments at an early stage will have competitive advantages.
- Companies that embrace advanced product developments, production processes and ecologically oriented services will have competitive advantages at least in the medium and long term.
- Consumers and retailers are attaching ever greater importance to the environmental quality criterion in purchasing decisions for products.
- Scientific studies show that companies that take the initiative and innovate in tackling environmental problems are generally more innovative overall and perform particularly well in the market.
- Both creativity and motivation of employees as well as product quality increase with the degree of ecological commitment of the respective company.
- Cost advantages for the companies are associated with the saving of raw materials and energy. Transport and storage cost advantages can also be integrated here.
- Disposal costs are rising and becoming more and more important. In view of the scarcity of landfill space as well as the fundamental problems of waste incineration and hazardous waste treatment, disposal and disposal costs will in future be central corporate problems not only for production residues but also for old products.
- Ecological products also open up new customer groups.
- A positive corporate image can be built up with an ecological corporate culture, a correspondingly aligned corporate policy and environmentally oriented management.

In order to implement sustainability in daily practice and make environmental aspects tangible in companies and organizations, the DIN EN ISO 14031 standard formulates numerous environmental indicators and environmental status indicators [DIN-14031], which are based on the factors influencing sustainability. This standard describes the social component in terms of quality of life, the economic component in terms of costs and the ecological component in terms of resources. In addition to a large number of indicators, the following management requirements are mentioned:

- Commitment of the company management to sustainable corporate management. This includes building long-term partnerships and networks with customers, partners, suppliers, competitors, administration and authorities, as well as accepting and living corporate social responsibility (CSR [Pram-2010]).
- Implementing environmental management at management level as one of the distinguishing and performance features for a holistic and sustainable approach.
- Resource-oriented action as the nucleus of environmental strategies or programmes in terms of the full exploitation of raw materials. This requires the replacement of non-renewable raw materials by renewable raw materials. This also includes the tendency to close material cycles in order to avoid waste and emissions and the use of clean and efficient technologies. Long-term goals are climate neutrality and recycling management.

In principle, if companies want to make a credible and long-term commitment to sustainable development, requirements must become the core of the corporate strategy instead of considering sustainability only defensively, partially and only in individual departments [Dyll-2006]. This can mean that business models must be fundamentally questioned and possibly turned upside down. A strategically interesting approach for companies may be to develop business models based on collaborative consumption. Stahel describes the upheavals that such a model would have to undergo as follows:

> When a product is no longer possessed, but only the benefit is bought, everything changes. The product remains the property of the producer. He can maximize his profit by selling the benefit of his product for as long as possible. And thus he automatically has an interest in the things that make up sustainable business: Durability, modular replacement of components, reuse of individual components after the end of the life of the whole product. [Stah-2000]

Figure 12.5 shows these upheavals from the company's perspective. In particular, the advantages of such a system in terms of recycling management can be seen

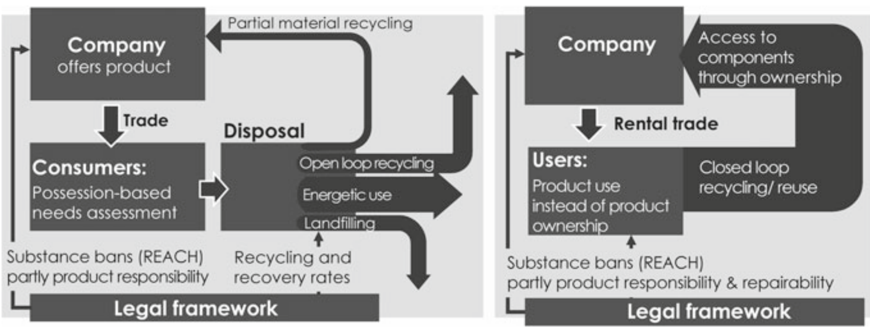

Fig. 12.5 Current and collaborative consumption, taking into account reuse and recycling cycles from a business perspective

along the broadly depicted cycle (see also [MDBr-2009]. A certain flip side of such property-consuming consumption patterns is that potentially excessive product wear and tear can reduce the ecological benefits, especially if users are negligent with the products [SSSO-2010]. However, product developers can counter this flip side by designing products with a long service life.

12.2 Integration of Sustainability in Product Planning and Product Development

In the following, individual approaches to integration in product planning and product development, i.e. in the strategic definition processes upstream of production and usage, will be discussed on the basis of the previous comments. It should be noted that there is still a lack of concrete approaches and methodologies that would enable accelerated and optimized application by industry [PiRA-2015].

12.2.1 The Path to a Sustainable Product Range

In the narrower sense of sustainable products, it is basically a question of questioning the existing product range and also the inclusion of new products in the product range [HoJa-1995]. This means that the right decisions on sustainability in its broadest sense must be made, especially in product planning. Unfortunately, there is little literature on the criteria that should be used to make these decisions or which process steps need to be thought through. One of the few exceptions is a flow chart by BERGMANN, which is used in the following [Berg-1994]. The first two steps are a thorough needs analysis (number 1 of the flow chart in Fig. 12.6) and an examination of possible immaterialization strategies[5] (number 2 in Fig. 12.6). In these two steps, it is examined whether a physical product is needed at all, whether it can be immaterialized as an alternative and whether this is justifiable from a sustainability perspective. Only in the third step (number 3 in Fig. 12.6) begins the actual programme policy, product conception and product development. A sustainable product range can then be created on the basis of the steps contained therein (Fig. 12.7).

It should be emphasized here that, in addition to classical aspects of product development such as program policy, product concept, material, procurement, marketing and production analysis in the illustrated flow chart according to BERGMANN [Berg-1994] also aspects of technology ethics in the form of the analysis of consequences and side effects are integrated.

[5] Immaterialization in this context means that tangible goods are substituted by intangible goods and/or services.

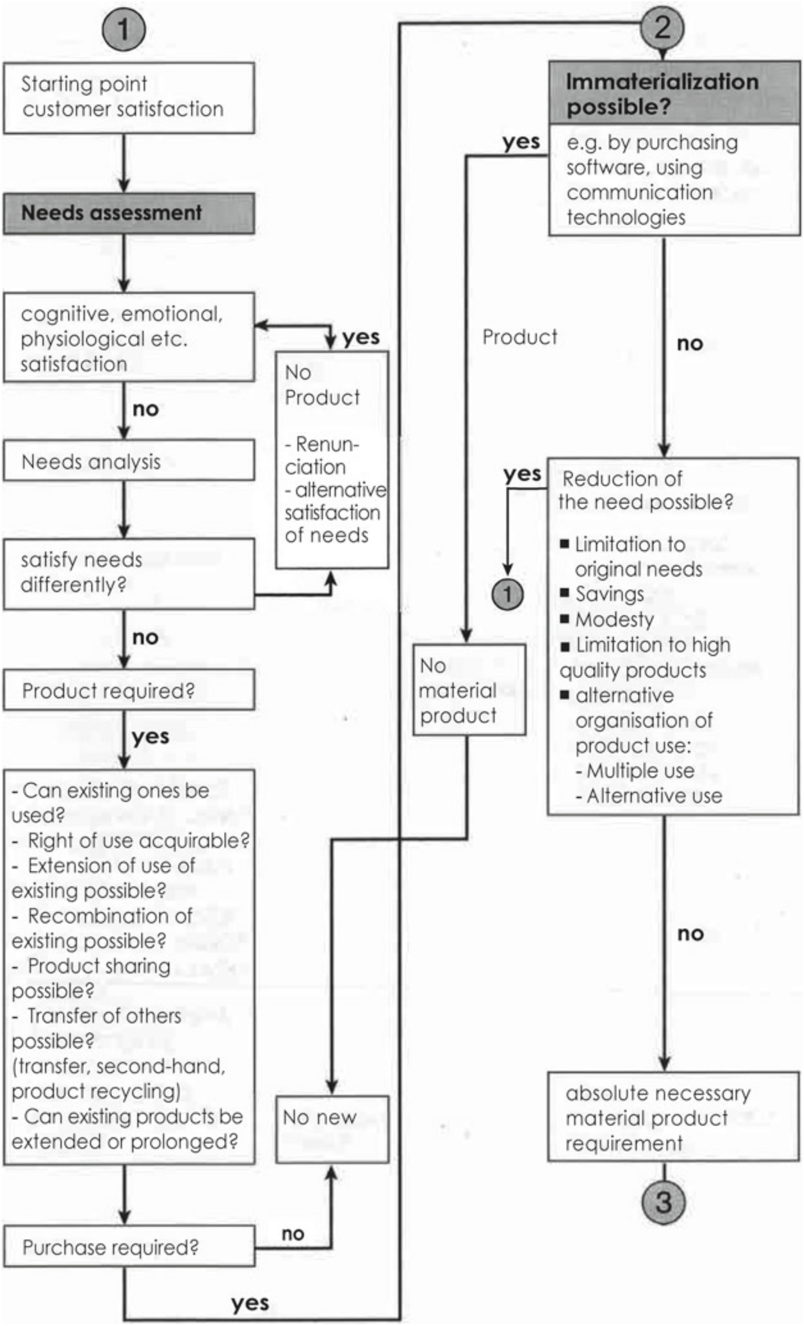

Fig. 12.6 Way to an ecological product range, part 1 of 2 [Berg-1994]. Figure taken from [HoJa-1995]

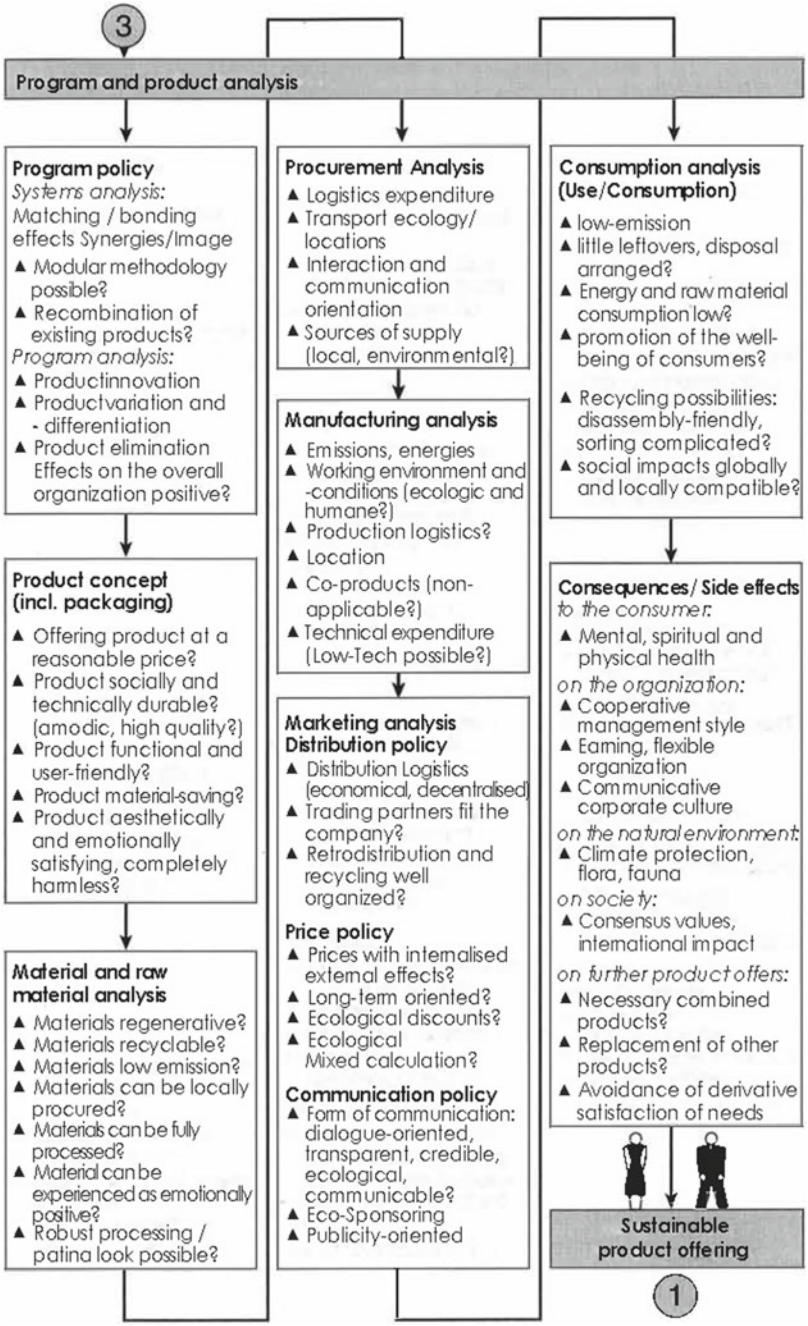

Fig. 12.7 Way to an ecological product range, part 2 of 2 [Berg-1994]. Figure taken from [HoJa-1995]

12.2.2 Sustainability Concepts and Strategies

There are numerous ways to develop a product in a sustainable manner. As it is well known, the relevant decisions on product performance capabilities and product behaviour are made within the IDE phases (Sect. 3.2). These contribute significantly to sustainability. Of the numerous existing concepts for sustainable development (a compilation of which can be found, e.g. in [Rutt-2012]), the concept of eco-efficiency and the cradle-to-cradle (C2C) concept are described below. The sufficiency strategy has already been described in Sect. 5.4.2. To summarize all three strategies, i.e. eco-efficiency, cradle-to-cradle (as a concept of consistency) and sufficiency, a collection of sustainability strategies for the implementation of these three concepts follows.

12.2.2.1 Eco-Efficiency

Eco-efficiency is a basic concept to promote the change from non-sustainable to sustainable development. It has become increasingly established in industry since the mid-1980s years. This efficiency concept is interesting from a company's point of view because the conflict between economy and ecology seems to have been resolved to some extent in the rationalization of material turnover [Hube-2003]. This efficiency is measured as the relationship between the benefit or value of what has been produced and the resulting environmental impact of a product (in its broadest sense, c.f. Sect. 2.1) [YCZS-2013]. The aim is to achieve higher results with less use of resources and to reduce the environmental impact by reducing emissions and pollutants. The World Business Council for Sustainable Development (WBCSD) coined the term eco-efficiency in its 1992 publication "Changing Course" [Schm-1992]. At the Earth Summit in 1992, eco-efficiency was endorsed as a new business concept and means for companies to implement sustainable development in order to achieve a decoupling of environmental impacts and economic growth [OECD-2002].

The eco-efficiency strategy is in some cases an effective tool, as can be seen, for example, in the energy-efficient design of buildings, which can achieve above-average savings based on different building materials and construction principles [Hube-2003]. However, such savings are not possible everywhere, and it must also be fundamentally asked whether the technology itself is the problem (as for example with petrol and diesel engines) and therefore needs to be replaced in the long term [Hube-2003]. There is also a risk that efficiency gains achieved will be neutralized by the rebound effect (Sect. 5.4).

12.2.2.2 Cradle-to-Cradle

If sustainability is not the focus of product development, products are developed according to the "cradle to grave" scheme, as is the case today. In detail, this approach means that

- at the beginning of the product life cycle, mainly new raw materials are used, because on the one hand, this is often financially more favourable, and on the other hand, not all materials used can be recycled to the same quality level as before.
- during and at the end of the life cycle, some of the substances used in and for the product are returned to the process.
- however, a high proportion of the substances (“residual materials”) is disposed of so that there is a continuous consumption of resources.

If, on the other hand, it were possible for all energy and material flows occurring during the development, production, use and recycling of a product to compensate each other so that their overall balance would be zero or at least close to zero, then this sustainability-oriented approach would not have to fundamentally change the nature and manner of development, production, use and re-circulation.

One such approach is the *cradle-to-cradle* concept developed by McDonough and Braungart, C2C) [MDBr-2009]. The substances and products considered in C2C can be classified as biological or technical “nutrients” in a biological and technical cycle, in which they circulate in such a way that their respective quality is maintained in the long term, so that they can be used again completely and as far as possible without loss for a new development each time.

- The biological cycle includes all substances and products that originate directly from nature, can be returned to it and can be recycled without endangering flora and fauna, for example, packaging materials that are completely biodegradable, as the use of toxic and non-biodegradable additives has been avoided.
- The technical cycle includes all substances and products resulting from technical and industrial processes (such as mining, smelting or refining). These may only be used in such a way that their end products can be fully returned to the technical cycle and reused without any loss of quality.

Both biological and technical nutrients can be used in the development and manufacture of a product. In both cycles, waste or the end products of the materials used (from the point of view of the product at the end of its life) should be used to produce raw materials of unchanged quality for such a product that is at the beginning of its life.

In C2C, products must first be designed so that they can be dismantled without difficulty (design for disassembly[6]). It must also be ensured that product components and the substances used in them that belong to different cycles cannot mix during production, use or recycling, so that they can return to their respective cycles in a single type of product. It must also be possible to separate materials in such a way that no new, unpredictable or hybrid objects (materials belonging to both cycles) can be created.

[6]For a basic description of the so-called *suitability* see Chap. 14. “Design for X” can be described as a design that is suitable for a certain approach or procedure. In this context, design for disassembly means that the product in question is suitable for being disassembled at the end of its life time by the (then) existing and available situations and means at the company that performs the disassembly.

An energetic cycle is not explicitly addressed in C2C. On the one hand, there is a constant supply of energy from the sun, which must be used sensibly. On the other hand, all substances in the two cycles contain their respective energy balance during extraction, use and recycling. After all, the product itself can generate energy directly or indirectly during its product life. All of this becomes part of the overall balance of the energy cycle.

C2C builds on the following steps:

- Development of pollutant-free products. The aim is to use only such substances and materials with which, in terms of the attributes safety and sustainability, neither the users of the product nor the environment and the environment in which the product is used nor uninvolved third parties can be harmed, even if the product is no longer used.
- Developing such products that can be easily taken back, dismantled and recycled at the end of their useful life without any loss of quality of materials and substances.
- Preparation of a material balance, with which all substances of a product can be quantified and evaluated, whereupon this balance is based on the one hand on the entire life cycle and on the other hand on a detailed inventory of all substances that can be used in the manufacture and released during the use phase.
- Development of such products, which, with the ingredients used in these products, can be easily integrated into both the biological cycle and the technical cycle.

If, however, the four steps cannot be implemented within the existing capabilities of a company, it is better to develop a completely new product within IDE, preferably using unconventional development methods such as the *Contradiction-oriented Innovation Strategy* [LiHi-1993] or the *Autogenetic Design Theory*[7] (Sect. 1.7, [VaKB-2011]), so that the development and implementation can operate as close as possible to the goals of C2C.

12.2.2.3 Sustainability Strategies for IDE

Whereas in previous sections, fundamental concepts and approaches to sustainability were discussed, this section presents a more pragmatic presentation of possible strategies. The two concepts of eco-efficiency and cradle-to-cradle and the sufficiency presented in Sect. 5.4.2 are not mutually exclusive but can be combined pragmatically to a certain extent [Hube-2003]. In the sense of C2C, all products should be conceived and developed by taking into account the two C2C cycles. This leads to a disruptive innovation in terms of sustainability. In addition, increases in efficiency can lead to successive evolutionary improvements of the products over evolving product generations.

All three basic concepts are addressed in the following sustainability strategies of IDE. These strategies are based on the principles of the sustainability strategies

[7] Autogenetic Design Theory (ADT) uses the procedures of biological evolution to generate products.

described in this section. In the following, a compact list of sustainability strategies of IDE is presented, which extends well-known ecodesign principles (see for example [LuLa-2006, WhPB-2015, BrHe-1997]) or represents a synthesis of several such design principles. These strategies are presented below in the order of the product life cycle.

From this list, it is clear that the strategies definitively can (and must) influence each other. However, they clearly show the basic approach of sustainability that each decision within IDE must not only take into account the associated specifications and effects on the environment, economy and social issues, but also the achievement of the lowest energy input during production, the use of single-variety materials, easy dismantling and reuse of materials and energy.

12.3 Overview on Methods for Determining the Environmental Impact

After the presentation of the different actors and their motivations as well as strategies to achieve sustainability, this Section presents concrete methods and tools that can be used to determine the environmental impacts of products. In the literature, there are quantitative and qualitative methods as fundamentally different approaches to determine the environmental impact or to evaluate sustainability [ViFM-2011]. In the following, the methods relevant for product developers within IDE will be briefly outlined.

12.3.1 Quantitative Methods

12.3.1.1 Life Cycle Assessment LCA)

According to ISO 14040, the life cycle assessment is a tool for assessing the environmental aspects and impacts of a product from cradle to grave through a four-step approach: (1) definition of purpose and scope, (2) preparation of the life cycle inventory (inventory analysis), (3) impact assessment and (4) interpretation [ViFM-2011]. Within life cycle assessment, the environmental impacts associated with the product are identified, quantified and weighted [Tisc-2000]. All emissions caused, the resources consumed and all relevant environmental and health impacts associated with a manufactured product or service are taken into account.

12.3.1.2 Simplified Life Cycle Assessments, the Fast Track to a Life Cycle Assessment

Based on the LCA method, there are several simplified variations, which can often be carried out directly online. Their main aim is to simplify the process and make the method more accessible to product developers and companies, especially small and medium sized enterprises [ViFM-2011]. As a recommendation in the context of IDE, the following tools should be mentioned here:

- Ecolizer[8],
- Ecodesign Pilot[9]
- IdematLightLCA app[10]

All these tools allow a fast life cycle-based analysis even for non-experts, and they support decision-making that is quantitatively based. For a publication of LCAs, however, the execution of a LCA according to the standard is inevitable.

12.3.1.3 Material Input Per Service Unit (MIPS)—Resource Productivity of Products

The method of material input per service unit (MIPS) was already presented in Sect. 5.4. This method records environmental impacts in terms of material and energy input over the entire life cycle of the product. It gives a statement about how much benefit a certain amount of "nature" can donate. For product developers, MIPS can be used as a tool to simplify the assessment of environmental impacts. No special software is required. The tables on which the method is based can be obtained from the Wuppertal Institute (see [Wupp-2014]), and the calculation is carried out in standard spreadsheet programs.

12.3.1.4 LCA-Based Assessment of Sustainability Based on the EcoCosting Approach

The EcoCosting approach of the Technical University Delft (NL) according to VOGTLANDER [Vogt-2009] uses as an indicator for a simplified life cycle assessment the more tangible ecological costs, which are costs that should be made in order to reduce pollution and material degradation in the economy to a level that corresponds to the carrying capacity of our earth. The relevance for companies or product development is that the environmental impact of government regulations[11] is gradually becoming an internal cost. This very concrete, tangible and in the future

[8] http://www.ecolizer.be

[9] http://pilot.ecodesign.at

[10] http://idematapp.com/coll-page-Section/lightlca/

[11] For example, through emissions trading, special eco-taxes, such as C02 taxes

important indicator of eco-costs gives an advantage over other LCA approaches with damage-based point indicator systems that are difficult to interpret. Another advantage is that some steps of the LCA can potentially be shortened, for example, by having these eco-costs for individual materials already pre-calculated in databases or simple spreadsheet files. With this approach, LCA calculations can therefore be carried out in many cases with standard spreadsheet programs or even smartphone apps (IDEMAT app[12], IdematLightLCA app). The only restrictions for this type of simplified calculation are the variety of materials and production processes, since not all conceivable materials and processes are pre-calculated.

Similar to the MIPS approach, a further measure, the EcoCost/Value Ratio (EVR) within this approach allows the possibility to relate the environmental measure of EcoCosts to the value of the product, which together form a relationship to the assessment of sustainability [Vogt-2010]. The EVR is a so-called E/E indicator ("Ecology/Economy Indicator"), which can be applied in cases where a product developer is asked to offer a product within a certain price (budget) [Vogt-2010].

12.3.1.5 Indicator Systems—Continuous Monitoring of Ongoing Production Processes

Indicator systems are suitable for monitoring ongoing processes. On the one hand, they document the current status of resource consumption and emissions, but they are primarily used to monitor the progress of ongoing processes within the framework of sustainability strategies and sustainability management systems. Sustainability strategies can be developed for companies, regions and nation states.

In the following, there is a limitation to an indicator system that is used within the voluntary European environmental management system, "Eco-Management and Audit Scheme" (EMAS) of the European Union [EMAS-2010]. Within six key areas, nine indicators will be collected under this scheme (see Table 12.1). The aim is to present the environmental performance of organizations in a clear and consistent manner within environmental statements to be produced. Furthermore, this system offers the possibility to analyse weak points and thus to optimize ongoing processes (Table 12.2).

12.3.2 Qualitative Methods

In the large group of qualitative methods, four types of tools can be identified [ViFM-2011]: (1) Matrices, (2) checklists, (3) spider web diagrams and (4) lists of strategies and principles. Not always all of these methods are purely qualitative, and therefore, semi-quantitative methods are also included.

[12] http://idematapp.com

Table 12.1 Sustainability strategies for IDE

Collaborative consumption **Objective**: Reduction of physical possessions in order to conserve resources and avoid emissions and to enable integration into cycles. As a result, there is a tendency to consume without ownership, with product benefit taking precedence over product ownership **Description**: Services that promote "use rather than ownership" or collaborative consumption have the potential to use resources fairly and intensively and to avoid emissions. The basis of this strategy is to radically question the way in which a benefit can be offered **Notes to be observed** • For collaborative consumption, it is useful to think in terms of (problem) solutions rather than in terms of products • First of all, the needs must be recorded, and the question of sufficiency must be: Is a product necessary to meet these needs? • Could it be possible, for example, to extend the use of existing products (e.g. by immaterializing, the product with a corresponding app on the smartphone)? • Could production be decentralized by, for example, instead of selling the product, issuing only licenses or information (e.g. production documents) or making it freely available to everyone as open hardware? • Is product sharing in the sense of promoting user communities through joint use (sharing, second-hand, up-cycling) possible? • Could the product performance not be sold as a tangible product, but as a performance or service (product as a service), i.e. could the benefit be offered directly as a service (e.g. by selling the function "light" instead of selling lamps)?	**Material efficiency** **Objective**: Material efficiency includes suggestions for achieving maximum product benefit with minimum resource consumption and waste **Description**: Material efficiency describes the ratio of material used (input) and product benefit obtained (output) **Notes to be observed** • Immaterialization or at least dematerialization of[a] the product (e.g. replacing analogue answering machines with digital voicemails) • Restriction to essential functions Alternatively an integration of further products through multi-functionality (conflict of objectives reparability) • Use of substitutes (e.g. a cargo bike instead of vans) • Reduction of the quantity required to fulfil the function (e.g. better utilization of the means of transport via a carpool) • Optimal technical design through careful simulations, calculations and optimizations (e.g. FEM, topology optimization) • Preference for production processes with few by-products and waste materials and products or corresponding conceptual design (e.g. shaping suitable for cutting) • Minimize the consumption of auxiliary materials even in the use phase (e.g. efficient use of detergent in the appliance)

(continued)

Table 12.1 (continued)

Renewable materials	**Recycled materials**
Objective: Use renewable resources instead of finite resources and avoid emissions **Description**:[b] Renewable raw materials used for material purposes include wood, natural fibres, materials based on vegetable oils (e.g. varnishes), substances based on starch and sugar (e.g. certain bio-plastics) and raw materials of animal origin. Renewable resources have a largely neutral CO_2 balance, are biodegradable in a not too strongly modified state and create an independence from finite resources **Notes to be observed**: Plastics can also be based on renewable raw materials, although in many cases, they are no longer compostable and the life cycle assessment is not better than that of conventional raw materials in all impact categories. A reduction can be seen in the impact category CO_2 emissions. However, there is no functioning system for recycling or composting in current public systems to date Renewable raw materials must be cultivated sustainably (see for example the FSC seal), and monocultures must be avoided. However, these must not compete with food production on arable land Raw materials of animal origin are also considered renewable, for example, wool, leather, milk fibre (Qmilk). Animal welfare must always be taken into consideration, and only materials from responsible sources should be used	**Objective**: To save finite resources by using recycled raw materials **Description**: Besides the use of renewable raw materials, the use of recycled raw materials represents the second possibility to keep resources within cycles and thus save finite resources. Furthermore, recycled materials are in some cases (e.g. metals such as aluminium) less energy-intensive and also associated with fewer emissions than is the case with primarily extracted materials **Notes to be observed**: Materials can come from two fundamentally different recycling cycles, namely open loop recycling and closed loop recycling. Recycled materials from a closed cycle (closed loop) are preferable in most cases due to their higher purity and higher achievable recycling rates. In order to guarantee this purity, the companies themselves or their partners must ensure that the materials are taken back. With open systems, the purity and the recycling quota are usually lower, but existing systems can be used. Furthermore, the shorter the cycles, i.e. the less the material had to be converted, the better the sustainability balance. In addition to recycling, the aim should therefore be to process (remanufacturing or refurbishing) or reuse the product. Reuse can take the form of collaborative consumption, for example, by making the product available to other people for further use after it has been used[c]. Reuse without costly conversion or down-cycling can alternatively in some cases take the form of up-cycling, i.e. the conversion of some components of an existing product at a higher level instead of converting them into inferior material (e.g. using used truck tarpaulins as material for handbags)

(continued)

Table 12.1 (continued)

Pollutant-free materials **Goal**: Achieving freedom from pollutants throughout the entire product life cycle **Description**: Only the absence of pollutants can ensure beyond doubt that human health, biodiversity and water and soil quality do not suffer from the production, use and recycling of products. This strategy is particularly essential for recycling, as this is the only way to establish a closed loop economy that does not continue to accumulate pollutants [MDBr-2009] **Notes to be observed**: In concrete terms, this sustainability strategy means that materials with toxic ingredients or additives for material optimization and auxiliary materials in production are substituted by non-toxic substances. In particular, substances on the "REACH Candidate List[d]" [EuCA-2020] and also the "Priority List" of the EPA [USEP-2014] are to be avoided. However, the company's own standards should be even higher than the legal obligations. If pollutants cannot be avoided (e.g. in the case of special electrical appliances), it must be ensured that they are recycled within cycles and do not come into direct contact with customers. In the case of renewable raw materials, ecological cultivation methods are to be used. When designing and selecting metal alloys, care must be taken to reduce unnecessary alloying elements, for example, in the case of steel, reducing the addition of chromium, tin, lead and copper. For plastics, too, it is necessary to check very carefully during selection and design whether harmful plastic additives are present and whether they can be substituted or omitted	**Energy efficiency** **Objective**: To save energy resources and, as a result, to reduce emissions, in particular CO_2 **Description**: The use of renewable energy sources in all areas of the product life cycle is fundamental for sustainable products. Since this goal seems to be unattainable in the short term and energy waste can be considered unsustainable overall, the following approaches to energy efficiency are summarized here **Notes to be observed**: Energy consumption must be reduced at all stages of the product's life. This means optimizing production processes so that less energy-intensive materials and manufacturing processes are used or can be substituted. One part of the strategy may also be to store energy intelligently and use waste heat. For the use phase, it is relevant to achieve a high degree of efficiency of the product, which means, among other things, that less energy has to be applied for the same benefit (e.g. removal of a defined amount of dust). Buildings can also be made energy efficient by using alternative building materials and principles

(continued)

Table 12.1 (continued)

Water conservation **Goal**: Careful and the locally scarce resource water. This includes the reduction of water consumption and the avoidance of water grabbing[e] and water stress[f] **Description**: This strategy is divided into resource component, which is about the efficient use of water and the condemnation of water grabbing, and the emission component, which is characterized by the avoidance of water stress, i.e. the input of pollutants, heat, germs, drugs and hormones. In addition to avoiding the above-mentioned points, water conservation can also be achieved by recycling water in production or in sewage systems, as well as by using grey water and biological cultivation, which also conserves water **Notes to be observed**: The place of production and the total amount of water consumed or contaminated over the product life cycle are of central importance. When determining production sites and in particular also agriculturally produced raw materials that are water-intensive, no production site may be chosen where water is a locally scarce resource. Water scarcity can be determined using the indicator Avlailable Water Remaining (AWaRe) [BBBB-2018]. Virtual water consumption[g], i.e. the total water consumption along the product life cycle, can be used to analyse the water requirements of individual products or materials. Materials and production processes that require a lot of water or contaminate it should be avoided and substituted by alternatives, especially if the product or materials are manufactured in a place where water is scarce	**Nature conservation**: **Objective**: Use of as little land area as possible for the production of products and careful handling of the soils in this areas, i.e. avoiding the introduction of pollutants (e.g. nitrate) and sealing in order to preserve natural areas and thus biodiversity **Description**: Important soil functions and habitats are lost through land use. Intensive agriculture causes soil degradation **Notes to be observed**: These challenges can be met with the following approaches: First, materials and processing methods with low land use must be selected or substituted. When designing the end-of-life scenario, care must be taken to ensure that landfilling cannot occur, since landfilling also results in high land consumption or pollutant inputs into the soil. Part of the strategy can also be to cultivate renewable resources organically, to avoid monocultures, to create ecological compensation areas and to re-cultivate habitats after intensive land use. In addition, care must be taken to ensure that pollutants cannot enter the soil. If unavoidable, these must circulate in closed cycles. In addition, all built-up areas should also be kept as low as possible, and the degree of sealing should be kept as low as possible. In order to provide a minimum of living space, vertical gardens or green roofs can also be created

(continued)

Table 12.1 (continued)

Fair production **Goal**: *Fair production* Compliance with social and safety standards for all persons involved in the product life cycle and enabling a fair income **Description**: In addition to compliance with social standards, the avoidance of dangers as well as the observance of standards in co-determination and remuneration is part of fair production **Notes to be observed**: An established fair production standard that can be used to implement minimum fair production requirements, SA8000 [SoAc-2014]. This contains the following specifications: No child labour, no forced labour, minimum standards of health and safety at work, admission of trade unions, prohibition of discrimination, no physical or mental disciplinary measures, restrictions on working hours, adequate and secure remuneration. Furthermore, working conditions must be checked on site. All suppliers and partner companies have to sign the compliance with SA 8000 before the start of the cooperation	**Distribution efficiency** **Goal**: Reduce resource use and emissions in distribution and trade **Description**: Efficient distribution describes the movement of a product between locations along the supply chain or the individual phases of the product life cycle, which should be carried out according to this principle with as little use of resources and emissions as possible **Notes to be observed**: In order to comply with this strategy, it is ideal to keep both product volume and product weight as low as possible in transport condition (e.g. through stacking ability). It is also essential to omit packaging or, as far as possible, to reduce its weight and volume. Reusable packaging is in most cases the more sustainable option. Recycled packaging materials also reduce packaging waste. When selecting product materials and auxiliary materials, attention should be paid to regionality of the target market, and means of transport should be selected according to their CO_2 efficiency

(continued)

Table 12.1 (continued)

Longevity	Change of behaviour
Goal: To enable a longer life of the product (primarily the available service life benefit) than in the past. As a result, resources are used more efficiently (both energy and material resources), and emissions can be avoided **Description**: The longevity strategy includes individual measures to extend the life of a product. In order to design long-lasting products, it is worth taking a closer look at the types of obsolescence. These are absolute obsolescence (product is defective), relative obsolescence (functioning product becomes obsolete) and legal obsolescence (product may not be used any further) **Notes to be observed**: Material obsolescence is countered with technical strategies. In the case of other [h]types of obsolescence, this is possible through upgradeability, timeless design and internal company moral principles and standards. From a technical point of view, high-quality materials, stable design principles and replaceable wear parts should be provided. In addition, corrosion risks must be avoided through material selection and design (e.g. by preventing water from entering the component). Furthermore, the durability can be improved by specific operational strength optimizations with FEM and shape optimizations, for example, computer aided optimization (CAO, see Sect. 18.1.3). Components that wear easily should be avoided. If this is not possible, simple possibilities for replacement must be provided. Abrasion on surfaces must be counteracted by appropriate shaping (among other things, by specifically wearing shaping elements, for example, on the underside of a product, which protect the rest of the product). Lubrication can also increase the service life of frequently moving parts (e.g. gears). The relative obsolescence, especially the psychological obsolescence, must be countered by timeless design while avoiding fashionable trends. Furthermore, upgrades and a modular design can keep the product technically up-to-date for a long time	**Objective**: Motivate users to behave a more sustainable way or the creation of the necessary framework conditions **Description**: Product developers can be an important driver for behavioural change towards more sustainability of individuals and society. They can contribute to the public discourse by providing appropriate product design and other information on sustainable behaviour (e.g. transparent presentation of the effects of usage behaviour on the environment) and thus encourage customers and users (e.g. by setting frames[i] or "nudges[j]") to change their usage behaviour accordingly and much more **Notes to be observed**: First of all, the question must be asked whether the product is designed in such a way that it can create incentives to change behaviour and whether this has a positive effect on the sustainability and personal well-being of the perceiving people. To this end, the product can, for example, have an emotional effect, linking sustainable behaviour with a new perspective (framing). Individual interactions with the product can be redesigned (specific user–product interactions such as double flush toilet buttons) or provide food for thought (e.g. information on the result of one's own behaviour). In order to achieve maximum impact, such effects should have a long-term effect and, if possible, help to motivate the social environment. It should be noted, however, that a product should never patronize, monitor or stigmatize Behavioural change can also be achieved by making the opportunity for collaborative consumption available and by doing this in a way that is not elaborate and is at best fun. Convenience is an important factor in changing behaviour in general. For example, sustainable behaviour can also be promoted by making sustainable behaviour the default option, for example, the most energy-efficient dishwasher programme

(continued)

Table 12.1 (continued)

Compostability **Objective**: To return to the biological cycle while maintaining or improving soil quality **Description**: Material is considered compostable if 90% of it is biodegradable within six months in laboratory tests. Additives, which may contain a maximum of 1%, must be harmless for composting. If possible, the material should in any case improve the soil, for example, by adding nutrients **Notes to be observed**: Replace conventional materials with biodegradable or more compostable materials Realize the separability to non-compostable materials	**Reparability** **Objective**: **E**nabling the usage of the product for a longer period of time by means of appropriate (preventive) maintenance and repair measures (Sect. 12.2). An overarching vision is to overcome the current throwaway society and establish a repair society (see also [Batra-1987]) **Description**: A repair is a "measure on a defective product to make it acceptable for its intended use" DIN ISO 9000 (Chap. 11) **Notes to be observed**: In order to enable a repair, the manufacturer must provide the following items: Tools and appropriate knowledge to carry out the repair as well as spare parts, if necessary. All these components must be made available to users. Furthermore, attention has to be paid to a disassembly-friendly design, existing maintenance concept, easy cleaning, accessibility and visual affordances for frequent maintenance procedures. A component should be easy to mount and dismount. Used parts should be easily and cost-effectively reconditioned
Recyclability **Objective**: Return to the technical cycle in order to be able to use the resources again, in the shortest possible cycles **Description**: A central prerequisite for recycling is the functioning collection of the products at the end of the product life cycle. Open and closed circuits are used for this purpose **Notes to be observed**: Attention must be paid to varietal purity[k]. Composite materials should be avoided. If this is not feasible, separability and dismantling of the materials must be made possible, and materials must be labelled. Parts made of different materials may only be combined in such a way that they can be easily separated from each other again, e.g. with magnetic separation methods. If complete separation is not possible, the risk of mutual contamination must be reduced by appropriate measures. Only those materials should be used which have a broad raw material base, whose recycling process is known and which allow an equivalent further use, i.e. which do not require down-cycling. In order to create a return motivation, a take-back concept (e.g. in own shops or with partners) should be developed	

Table 12.1 (continued)

[a]Dematerialization, in contrast to collaborative consumption or immaterialization, does not essentially question the number of goods but focuses on improved material productivity
[b]In the use of renewable raw materials, a distinction is made between energetic and material use. From a product point of view, the material use is mainly of interest for product development
[c]This is also the basic principle of a "reader circle". In such a subscription, a journal is not purchased but is made available for a certain period of time and after its expiry is made available to the next user. The less current the journal becomes the lower the cost of the subscription
[d]REACH candidate list: Under REACH, substances of very high concern (SVHCs) are identified and included in the so-called candidate list. If more than 0.1% by mass of these SVHCs is used in articles (e.g. a dye in a plastic product), the REACH information obligations apply to companies. The list can be viewed at https://echa.europa.eu/de/candidate-list-table. Consumers can obtain information on pollutants in products, for example, via the ToxFox app of BUND (see also footnote 4)
[e]Water grabbing: Unjustified access and unfair distribution of water resources. This refers to situations in which powerful actors take control of valuable water resources for their own benefit, thereby depriving local communities, whose livelihoods often depend on these resources and ecosystems, of their resources [Hand-2014]
[f]Water stress: If 20% or more of the water supply in a region is used, this is referred to as water stress. Excessive water use can lead to environmental problems [RGKP-1997]
[g]Virtual water consumption: The concept of virtual water refers to the total amount of water used along the product life cycle
[h]Possible types of obsolescence: This term refers to the (natural or artificial) ageing of a product. As a result, the product becomes obsolete, i.e. it can no longer be used for the desired purpose. One can distinguish four types of obsolescence: (1) Material obsolescence (lack of performance or wear and tear), (2) Functional obsolescence (changed technical and functional requirements for a product, for example, interfaces), (3) Psychological obsolescence (premature ageing due to fashions and new technical trends) and (4) Economic obsolescence (new purchase economically better than maintenance)
[i]Frame and framing: "Changing the presentation of a decision problem without changing its content" [Clau-2018]
[j]Nudging is a more or less subtle way of getting someone to do or not to do something specific once or permanently [Bend-2019]
[k]Purity in the sense of the design for recycling means that the product consists of as few different materials as possible and/or can be separated from the different materials without any problems (which, however, is not easily achieved in the case of smartphones, for example, due to the bonded components, or only by using too much chemistry)

12.3.2.1 Matrices for the Systematic Recording of Effects Along the Product Life Cycle

There are a large number of matrices in the literature, which all follow a similar scheme: The header line contains the life cycle phases of a product, and the left column contains a catalogue of criteria on the environmental impact of the product [HoJa-1995].

A frequently used matrix is the MET matrix of Brezet and Hemel [BrHe-1997]. For the product to be analysed, a 3×3 matrix is filled here to identify possible environmental impacts along the product life cycle. MET is an abbreviation of Material, Energy and Toxic, and represents the three rows to be filled in. The three columns represent the phases of the product life cycle, namely production, usage, and disposal.

Table 12.2 EMAS indicators

Key area	Input or effects
Energy efficiency	**Total annual energy consumption** in MWh or GJ **Total consumption of renewable energies** Share of energy from renewable energy sources in total annual consumption (electricity and heat)
Material efficiency	**Annual mass flow of the various input materials** (excluding energy sources and water) in tonnes
Water	**Annual water consumption** in m^3
Waste	**Annual waste generation** by waste type in tonnes **Total annual generation of hazardous waste** in kilograms or tonnes
Biological diversity	**Land consumption** in m^2 built-up area
Emissions	**Total annual emissions of greenhouse gases** at least the emissions of CO_2, CH_4, N_2O, hydrofluorocarbonate, perfluorocarbonate and SF_6 in tonnes CO_2 equivalent **Total annual emissions to air** at least the emissions of SO_2, NO_X and PM, in kilograms or tonnes

The advantage of the MET matrix and also other matrices is that the synthesis of the information can be based on both quantitative information and qualitative information. In addition to the MET Matrix, the following other matrices may be of interest to product developers:

- Sustainable SWOT Analysis [MPPG-2012]
- Leopold Matrix [LCHB-1971]
- MECO Matrix [WeHA-2000]
- iTree Matrix [RuRM-2014].

12.3.2.2 Checklists

The second group of qualitative methods includes checklists that allow an evaluation of each criterion listed. They are arranged in table form and describe different criteria in each category. The variation in content between individual lists may be large, but there are common models for analysis and verification: On the one hand, categorization by alphabetical sorting as in the ABC checklist, by classification with characters (e.g. +, −) or by scoring. Furthermore, the lists differ according to their intended use. For example, there are lists for a specific business context such as the Fast Five Phillips [Mein-1997] or company-specific checklists such as those of Sony [Yana-1995].

Checklists recommended for the use within IDE are listed below, although such a selection can never be considered complete. The decision to select and use a checklist should be adapted from case to case, depending on the organization and the product.

- EcoDesign Checklist [BrHe-1997]
- ABC analysis [Lehm-1993]

- Philips Fast Five [Mein-1997]
- Eco design Pilot [WiZü-2001]
- Product Assessment Check Sheet [Yana-1995].

A very concrete checklist (tailored, however, to the specific business context at Sony) is the product assessment check sheet. This checklist allows a wide range of quantitative and qualitative information on electrical appliances to be queried [Yana-1995], Fig. 12.8. It provides information on the extent to which a newly developed product represents an improvement with respect to the criteria queried and where there is potential for improvement. This checklist may not be suitable for

PRODUCT ASSESSMENT CHECK SHEET

Model: Date: Evaluated by:

Item		Evaluation method	Score	Remarks
Materials with high environ-mental impact	Observes relevant national regulations: Observes higher industry standards: Observes higher Sony standards: High impact materials eliminated:	5 pts ☐ 7 pts ☐ 8 pts ☐ 10 pts ☐		Refer to Sony Specified Environmental Substances
Disassembly time	Reduction in time to dismantle product new model (__min) baseline model (__min)	(1 – new model/baseline model) x 100% = ___ %		60% reduction is 10 pts
Labeling of materials types	No labeling: Observes product assessment standards: All materials labeled:	0 pts ☐ 5 pts ☐ 10 pts ☐		
Recyclability	Recyclability improvement ratio where recyclability is the percentage of materials, by weight, for which recycling is feasible new model recyclability (__%) baseline (__%)	(new model – baseline model)/(100% – baseline model) x 100% = ___ %		60% improve-ment is 10 pts
Recycled resource usage ratio	Recycled glass usage as % of total glass weight	Recycled/total = ___ %		50% is 10 pts 0% is 0 pts
	Recycled plastics usage as % of total plastics weight	Recycled/total = ___ %		
	Recycled paper usage as % of total paper weight	Recycled/total = ___ %		100% is 10 pts
Material resource conservation	Product weight reduction ratio new model (___g) baseline model (___g)	(1 – new model/baseline model) x 100% = ___ %		50% is 10 pts 0% is 0 pts
	Product volume reduction ratio new model (___cm)³ baseline model (___cm)³	(1 – new model/baseline model) x 100% = ___ %		
	Parts count reduction ratio new model parts count (__) baseline model (__)	(1 – new model/baseline model) x 100% = ___ %		20% reduction is 10 pts
Product life	Initial failure rate	___ %		<x% is 10 pts x + % is 0 pts
	Annual failure rate	___ %		<x% is 10 pts x + % is 0 pts
Energy conservation	Energy consumption in standby mode	___ Watts		0 W is 10 pts 2 + W is 0 pts
	Energy consumption during use new model (___W) baseline model (___W)	(1 – new model/baseline model) x 100% = ___ %		60% reduction is 10 pts
Packaging	Polystyrene foam usage reduction new model (___g) baseline model (___g)	(1 – new model/baseline model) x 100% = ___ %		60% reduction is 10 pts
	Packaging weight reduction ratio new model (___g) baseline model (___g)	(1 – new model/baseline model) x 100% = ___ %		
	Recycled resource usage as % of weight	Recycled/total = ___ %		100% is 10 pts

Fig. 12.8 Product assessment check sheet [Yana-1995]

every context, but it is a pragmatic example of how sustainability can be recorded within a company.

The EcoDesign checklist (Table 12.3) is used here as an example of a much broader checklist that can be applied in many contexts. It consists of two columns: The questions to be asked are indicated in the left columns of the tables. In the right-hand columns, some possible improvements or EcoDesign principles are suggested. The checklists refer to the LiDS Wheel, which is presented in the next Section as one of the spider web charts.

12.3.2.3 Spider Web Charts for Analysis and Visualization

Spider web charts (also known as polar charts) are the third type of tools widely used in ecological product development because they are simple and they save time. If they are also supported by a comprehensive analysis of the product life cycle or by comprehensive checklists, they can lead to a longer service life and thus to meaningful results [ViFM-2011]. Graphically, all such diagrams have a very similar structure: They present themselves as a spider's web, in which the various axes (usually between five and eight) serve to evaluate certain criteria or aspects. The combination of the qualitative classification, which is carried out on each axis, enables the visual recognition of the effect of the product. The main differences between the different variants of these diagrams are the criteria defined on each axis. There are versions with the analysis of specific criteria of a company (such as the Sony Polar Diagram [ShYa-2017]) or general diagrams that accompany the entire product life cycle, as is the case with the LiDS Wheel [BrHe-1997] or the Ecocompass [Fuss-1999]. The latter two spider web charts will be dealt with in more detail below, as they are universally applicable.

In his work on eco-innovation [Fuss-1999], FUSSLER presents the *Eco-Compass* method which includes environmental aspects as well as social dimensions for the evaluation and comparison of products and suggestions for the development of new products. The dimensions applied in this chart are energy intensity, potential risks for health and environment, amount of waste (which cannot be recycled eco-efficiently), amount of rare or almost exhausted resources used, expansion of services. They are compared for different products with regard to their specific characteristics, and they are evaluated with points (plus points for improvements and minus points for deterioration), Fig. 12.9.

The Life Cycle Design Strategy Wheel (LiDS Wheel) [BrHe-1997] is an ecodesign tool that is part of almost all ecodesign methods and is frequently used by consultants [WeVo-2021]. It is also called Ecodesign Web [BhLo-2016] and Ecodesign Strategy Wheel [BDZs-2013]. Basically, like the eco-compass, it is a tool that very clearly shows the weak points of a product along the product life cycle. In addition, and this is a central strength of all spider web diagrams, it enables the comparison of product alternatives or concepts (see dark grey area in Fig. 12.10 for the existing product and light grey area for a newly designed product).

Table 12.3 EcoDesign checklist (as shown in [BDZs-2013]) [BrHe-1997]

Needs analysis	
How does the product system actually fulfil social needs? • What are the product's main and auxiliary functions? • Does the product fulfil these functions effectively and efficiently? • What user needs does the product currently meet? • Can the product functions be expanded or improved to fulfil user's needs better? • Will this need change over a period of time? • Can we anticipate this through (radical) product innovation?	**EcoDesign Strategy @ New Concept Development** • Dematerialization • Shared use of the product • Integration of functions • Functional optimization of product (components)
Life cycle stage 1: Production and supply of materials and components	
What problems arise in the production and supply of materials and components? • How much, and what types of plastic and rubber are used? • How much, and what types of additives are used? • How much, and what types of metals are used? • How much, and what other types of materials (glass, ceramics, etc.) are used? • How much, and which type of surface treatment is used? • What is the environmental profile of the components? • How much energy is required to transport the components and materials?	**EcoDesign Strategy 1: Selection of low-impact materials** – Clean materials – Renewable materials • Low energy content materials – Recycled materials – Recyclable materials **EcoDesign Strategy 2: Reduction of material usage** – Reduction in weight – Reduction in (transport) volume
Life cycle stage 2: In-house production	
What problems can arise in the production process in your own company? • How many, and what types of production processes are used? (including connections, surface treatments, printing and labelling) • How much, and what types of auxiliary materials are needed? • How high is the energy consumption? • How much waste is generated? • How many products do not meet the required quality norms?	**EcoDesign Strategy 3: Optimization of production techniques** – alternative production techniques – Fewer production steps • Low/clean energy consumption – Less production waste – Few/clean production consumables

(continued)

Table 12.3 (continued)

Needs analysis	
Life cycle stage 3: Distribution	
What problems can arise in the distribution of the product to the customer? • What kind of transport packaging, bulk packaging, and retail packaging are used (volume, weights, materials, reusability)? • Which means of transport are used? • Is transport efficiently organized?	**EcoDesign Strategy 2: Reduction of material usage** – Reduction in weight – Reduction in (transport) volume **EcoDesign Strategy 4: Optimization of the distribution system** – Less/clean/reusable packaging – Energy-efficient transport mode – Energy-efficient logistics
Life cycle stage 4: Utilization	
What problems arise when using, operating, servicing and repairing the product? • How much, and what type of energy is required, direct or indirect? • How much, and what kind of consumables are needed? • What is the technical lifetime? • How much maintenance and repairs are needed? • What and how much auxiliary materials and energy are required for operating, servicing and repair? • Can the product be disassembled by a layman? • Are those parts often requiring replacement detachable? • What is the aesthetic lifetime of the product?	**EcoDesign Strategy 5: Reduction of impact in the used stage** – Low energy consumption – Clean energy source – Permanent consumables – Clean consumables – No wastage of energy or consumables **EcoDesign Strategy 6: Optimization of initial lifetime** – Reliability and durability – Easy maintenance and repair – Modular product structure – Classic design – Strong product–user relation

(continued)

Table 12.3 (continued)

Needs analysis	
Life cycle stage 5: Recovery and disposal	
What problems arise in the recovery and disposal of the product? • How is the product currently disposed of? • Are components or materials being reused? • What components could be reused? • Can the components be reassembled without damage? • What materials are recyclable? • Are the materials identifiable? • Can they be detached quickly? • Are any incompatible inks, surface treatments or stickers used? • Are any hazardous components easily detachable? • Do problems occur while incinerating non-reusable product parts?	**EcoDesign Strategy 7: Optimization of the end-of-life system** – Reuse of product (components) – Remanufacturing/refurbishing • Recycling of materials • Safe incineration

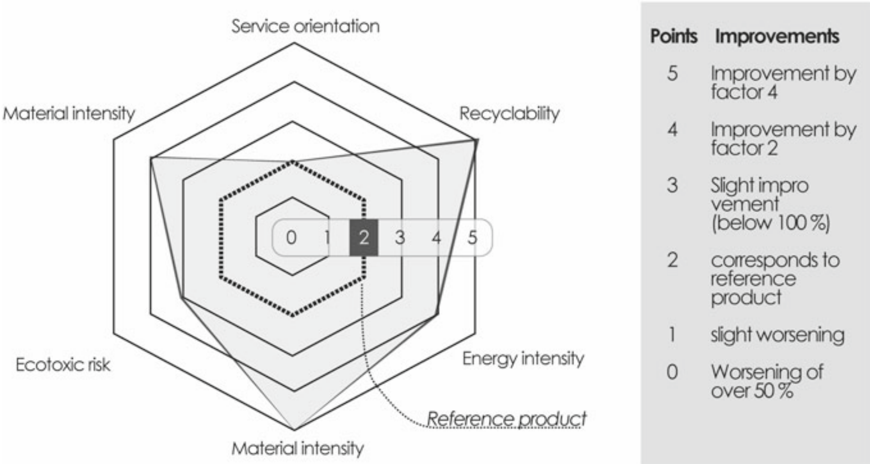

Fig. 12.9 Eco-compass according to FUSSLER [Fuss-1999]

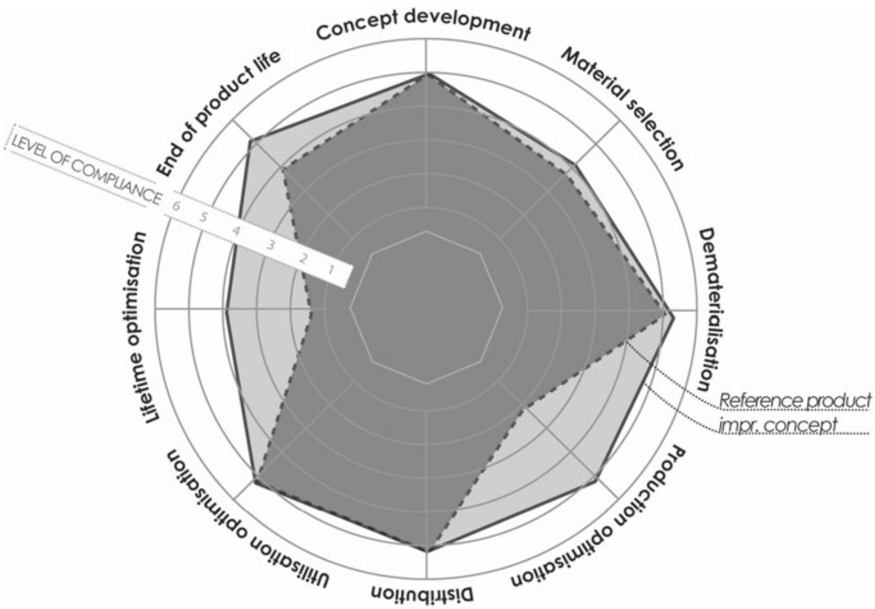

Fig. 12.10 LiDS wheel based on [BrHe-1997]

An advantage over the Eco Compass is that the LiDS wheel can be combined with checklists (such as the Eco Design Checklist) and matrices (such as the MET Matrix). This helps to underpin the basic principles of the diagram and also helps to counteract the disadvantages of the diagram, which may be that the weightings of the individual sustainability aspects are misjudged.

12.3.2.4 Strategies and Ecodesign Principles as Orientation for Product Design

The last group to be mentioned comprises several different approaches, which contain a list of ecodesign strategies that are to be understood as rules of thumb or even recommendations for action for use in product development [ViFM-2011]. In addition to the strategies already described in Sect. 12.2.2.3, the following collection of strategies is a useful source of inspiration for designing sustainable products:

- Ecodesign Principles [BrHe-1997]
- Ten Golden Rules [LuLa-2006]
- Okala Eco Design strategies [WhPB-2015]
- Ecodesign principles [UBA-2015].

12.3.3 Combination of Methods Along Product Development

Based on the overview of methods, this section proposes a combination of methods along the processes of product development that successively builds on each other, Fig. 12.11:

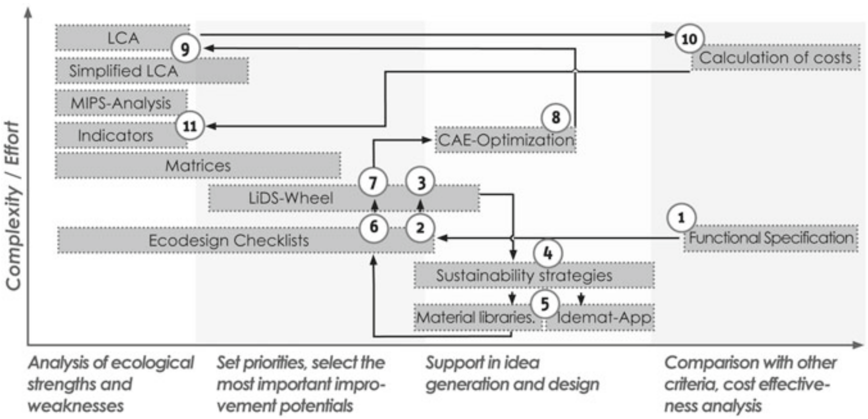

Fig. 12.11 Helpful methods of sustainable product design in the recommended order of application and differentiated in terms of effort and type of support (based on [Tisc-2000])

1. **Functional specification**: Definition of the functional unit based on the needs of customers or (in case of a re-design) based on the predecessor product (adaptation design).
2. **Weak point analysis of the reference product** with the help of checklists and, if necessary, with the help of matrices (i.e.MET and sSWOT).
3. **Visualization of weak points** using the LiDS Wheels and marking of the problematic points where improvements have to be made.
4. S**ustainability strategies** to be applied according to the weak points in order to achieve approaches to sustainability improvements with regard to the problem points identified.
5. **Material selection** based on the IDEMat app, the EcoCost table[13] of the MIT value table or inspired by material libraries.
6. **Verification of** the new product concept being compared to the reference product by means of checklists, matrices, EcoCost life cycle assessments or simplified life cycle assessments.
7. **Visualization of strengths and weaknesses** using the LiDS Wheels.
8. **Detail optimization**: If the critical issues are conceptually resolved, the product design can be detailed, using simulation and optimization to ensure a durable design.
9. **Summative life cycle assessment**: At the latest at this point, an LCA can be drawn up on the basis of the available final data, for example, on the basis of eco-costing according to [Vogt-2009].
10. **Cost calculation**: In order to be able to make a decision as to whether the product in its actual version is in proportion to justifiable costs (including environmental costs), it is advisable to prepare a life cycle cost calculation (see Sect. 25.1.1) and also to integrate the eco-costs into this planning. On the one hand, this is necessary in order to be able to adjust to conceivable costs in terms of environmental impacts and, on the other hand, the ratio of eco-costs to product value (EVR) according to VOGTLANDER is an important indicator of sustainability [Vogt-2009].
11. **Continuous improvement through indicators**: Once production begins, production is monitored in accordance with EMAS indicators and is optimized in line with a continuous improvement system.

12.4 Summary of Sustainable Product Development

Product development aimed at developing products with a lower environmental impact and contributing to sustainable development requires strategies, methods and tools as well as guidance and examples [Loft-2006]. In addition, it must make the assurance of sustainability to become a characteristic part of every decision along the product life cycle, as this cycle always forms the basis for assessing sustainability. Accordingly, the individual phases of the product life cycle also provide

[13] https://www.ecocostsvalue.com/EVR/model/theory/subject/5-data.html

the basis for assessing the IDE attribute Sustainability. Obstacles in the implementation of targeted life cycle-based methods and tools are often effort, complexity and missing data [UBA-2015]. For this reason, this chapter (in addition to elaborate quantitative methods such as life cycle assessment) presents in particular those methods with which it is possible to reduce obstacles in the application. In particular, Fig. 12.11 provides an overview for the selection of suitable procedures. In addition, the importance of product planning was discussed, and a flow chart after Bergmann [Berg-1994] was integrated, which can offer systematic support especially in the early phases of product development.

In addition to the compilation of evaluation methods, the sustainability strategies for IDE offer a comprehensive summary of relevant rules of thumb for the development of sustainable products. These very pragmatic contents have been chosen to convey sustainable product development as clearly as possible without complicating it. Also, the methodological compilation along the product development process should give direct support on how to proceed without forcing the development of sustainable products. The concrete choice of method is always the free decision of each product development team. Sustainable product development is based on common sense, ethical principles, the right advice and methods, fair dealings with all employees and suppliers and the willingness to continually improve.

References

[Batra-1987] Batra, R.: The great depression of 1990. N.Y. Simon & Schuster, New York (1987)

[BBBB-2018] Boulay, A., Bare, J., Benini, L., Berger, M., Lathilière, M., Manzarda, A., Margni. M., Motoshita, M., Nunez, M., Pastor, A., Ridoutt, B., Oki, T., Worbe, S., Pfister, S.: TheWULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). Int J Life Cycle Assess (2018) 23, Seiten 368–378

[BDZS-2013] van Boeijen, A., Daalhuizen, J., Zijlstra, J., van der Schoor, R.: Delft design guide: Design methods (2013)

[BeBi-2007] Belz, F., Bilharz, M.: Nachhaltiger Konsum, geteilte Verantwortung und Verbraucherpolitik: Grundlagen. Nachhaltiger Konsum und Verbraucherpolitik **2**, 21–52 (2007)

[Berg-1994] Bergmann, G.: Umweltgerechtes Produkt-Design: Management und Marketing zwischen Ökonomie und Ökologie, Neuwied. Luchterhand, Berlin (1994)

[BhLo-2016] Bhamra, T., Lofthouse, V.: Design for Sustainability: A Practical Approach, 1. Oxon. Taylor and Francis, Auflage, Abingdon (2016)

[BMU-2019] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit: Klimaschutzplan 2050: Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung, 2019, www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf. Abgerufen am 21 Feb 2020

[BMU-2020] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit: Akteure nachhaltiger Entwicklung. www.bmu.de/themen/nachhaltigkeit-internationales/

nachhaltige-entwicklung/akteure-nachhaltiger-entwicklung/. Abgerufen am 21 Feb 2020

[BrHe-1997] Brezet, H., van Hemel, C. (eds.): Ecodesign: A Promising Approach to Sustainable Production and Consumption, 1. Auflage, The Hague (1997)

[BuFH-2014] Buder, F., Feldmann, C., Hamm, U.: Why regular buyers of organic food still buy many conventional products. Br Food J **116**, 390–404 (2014)

[Clau-2018] Clausen, G., Simon, H., Tacke, G.: Framing, 2018, https://wirtschaftslexikon.gabler.de/definition/framing-53644/version-276716. Abgerufen am 26 Feb 2020

[DIN-14031] DIN EN ISO 14031: DIN EN ISO 14031 Enviromental Performance Evaluation. Berlin (1999)

[Duss-2013] Dusseldorp, M.: Technikfolgenabschätzung. In: Grunwald, A. (ed.) Handbuch Technik-ethik, pp. 394–399. Verlag J.B. Metzler Stuttgart, Weimar (2013)

[Dyll-2006] Dyllick, Thomas, Nachhaltige Innovationen als unternehmerische Chance, Neue Züricher Zeitung (2006) https://www.nzz.ch/articleenfl0-1.76639

[EMAS-2010] UGA: Die neuen Kernindikatoren der EMAS III (2010). www.emas.de/fileadmin/user_upload/4-pub/UGA_Infoblatt-Indikatoren_Mrz_2010.pdf

[EU-2019] Communication from the Comission to the European Parliament, the European Council, the European Economic and Social Committee, and the Committee of the Regions: The European Green Deal, Brüssel (2019) https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf. Abgerufen am 21 Feb 2020

[EuCA-2020] European Chemicals Agency, Liste der für eine Zulassung in Frage kommenden und besonders Besorgnis erregenden Stoffe. Veröffentlicht gemäß Artikel 59 Absatz 10 der REACH-Verordnung, 2020, https://echa.europa.eu/de/candidate-list-table. Abgerufen am 26 Feb 2020

[Falt-2010] Faltins, R.: Bio-Lebensmittel in Deutschland: Kaufbarrieren und Vermarktung, 1st edn. Diplomica Verlag, Hamburg (2010)

[Fuss-1999] Fussler, C., James, P.: Die Öko-Innovation: Wie Unternehmen profitabel und umwelt-freundlich sein können. Hirzel, Stuttgart (1999)

[Glei-2013] Gleim, M., Smith, J., Andrews, D., Cronin, J.: Against the green: a multi-method examination of the barriers to green consumption. J Retail 89 S. 44–61 (2013)

[Grög-2017] Gröger, M.: Unbewusstes beim Entscheiden in ökonomischen Kontexten am Beispiel von Framing im Nachhaltigkeitsbereich, in: Betriebliche Umweltökonomie (2017)

[Hand-2014] The global water grab. Hands off the land alliance (https://handsontheland.net/) (2014)

[HeSc-2011] Heidbrink, L., Schmidt, I.: Mehr Verantwortung für den Konsumenten: Vom passiven zum aktiven Konsum. Ökologisches Wirtschaften, S. 35–38 (2011)

[HoJa-1995] Hopfenbeck, W., Jasch, Chr.: Öko-Design: Umweltorientierte Produktpolitik. Verlag Moderne Industrie Landsberg/Lech (1995)

[Hube-2003] Huber, J.: Das Konzept der ökologischen Konsistenz als Beitrag zu einer nachhaltigen Technikgestaltung. In: Grunwald, A. (ed.) Technikgestaltung zwischen Wunsch und Wirklichkeit, pp. 217–233. Springer, Berlin Heidelberg (2003)

[Hubk-1976] Hubka, V.: Theorie der Konstruktionsprozesse: Analyse der Konstruktionstätigkeit. Springer, Berlin, Heidelberg (1976)

[JoRa-2015] Joshi, Y., Rahman, Z.: Factors affecting green purchase behaviour and future research directions. Int Strateg Manag Rev **3**, 128–143 (2015)

[Knau-2015] Knauer, R.: 25 Jahre FCKW-Verbot: Es bleibt ein Loch ohne Boden. www.spektrum.de/news/25-jahre-fckw-verbot-wie-steht-es-um-das-ozonloch/1352353. Abgerufen am 09 Mar 2020

[KnRe-1998] Knaus, A., Renn, O.: Den Gipfel vor Augen: Unterwegs in eine nachhaltige Zukunft. Metropolis-Verlag Marburg (1998)

[Köni-2013] König, Wolfgang: VDI-Richtlinie zur Technikbewertung. In: Grunwald, A. (ed.) Handbuch Technikethik, pp. 406–410. Verlag J.B. Metzler Stuttgart, Weimar (2013)

[Krei-1991] Kreibich, R.: Ökologisch produzieren: Zukunft der Wirtschaft durch umweltfreundliche Produkte und Produktionsverfahren. Dokumentation des Kongresses" Zukunft der Wirtschaft durch Umweltfreundliche Produkte und Produktionsverfahren" im Rahmen des Umwelttechnologieforums UTECH am 28. März 1990 im ICC Berlin. Beltz Weinheim (1991)

[LCHB-1971] Leopold, L., Bergere, C., Frank Eldridge, H., Bruce B., Balsley, J.: A procedure for evaluating environmental impact, Washington, D.C. (1971)

[Lehm-1993] Lehmann, S.: Umwelt-Controlling in der Möbelindustrie: Ein Leitfaden. Institut für Ökologische Wirtschaftsforschung, Berlin (1993)

[LiHi-1993] Linde, H., Hill, B.: Erfolgreich erfinden - Widerspruchsorientierte Innovationsstrategie für Entwickler und Konstrukteure. Hoppenstedt Darmstadt (1993)

[Loft-2006] Lofthouse, V.: Ecodesign tools for designers: defining the requirements. J Clean Prod **14**, 1386–1395 (2006)

[LSRH-2012] Leismann, K., Schmitt, M., Rohn, H., Baedecker, C.: Nutzen statt Besitzen: Auf dem Weg zu einer ressourcenschonenden Konsumkultur: eine Kurzstudie. Heinrich-Böll-Stiftung Berlin (2012)

[LuLa-2006] Luttropp, C., Lagerstedt, J.: EcoDesign and the ten golden rules: generic advice for merging environmental aspects into product development. J Clean Prod **14**, 1396–1408 (2006)

[MDBr-2009] McDonough, W., Braungart, M.: Cradle to cradle: remaking the way we make things. Vintage London (2009)

[Mein-1997] Meinders, H.: Point of No Return—Philips EcoDesign Guidelines. Philips Electronics, Eindhoven (1997)

[MOPL-2010] Micklitz, H., Oehler, A., Piorkowsky, M., Reisch, L., Strünck, Chr.: Der vertrauende, der verletzliche oder der verantwortungsvolle Verbraucher? Plädoyer für eine differenzierte Strategie in der Verbraucherpolitik. Stellungnahme des Wissenschaftlichen Beirats Verbraucher- und Ernährungspolitik beim Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz Berlin (2010)

[MPPG-2012] Metzger, E., Putt del Pino, S., ProWitt, S., Goodward, J., Perera, A.: Sustainability Swot User Guide (2012) http://pdf.wri.org/sustainability_swot_user_guide.pdf. Abgerufen am 23 Feb 2020

[OECD-2002] OECD, Indicators to measure decoupling of environmental pressure from economic growth (2002)

[Oerk-2015] Oerkermann, G.: Nachhaltige Produktgestaltung. In: Weber, T. (ed.) CSR und Produktmanagement, pp. 149–159. Springer, Berlin Heidelberg (2015)

[PiRA-2015] Pigosso, D., Rozenfeld, H., McAloone, T.: Characterization of the state-of-the-art and identification of main trends for ecodesign tools and methods: classifying three decades of research and implementation. J Indian Inst Sci S. 405–426 (2015)

[Prah-2002] Prahalad, C.: The fortune at the bottom of the pyramid. Strategy + business 26 (2002)

[Pram-2010] Prammer, K.H. (Hrsg.): Corporate sustainability. Der Beitrag von Unternehmen zu einer nachhaltigen Entwicklung in Wirtschaft und Gesellschaft. Gabler Research, Wiesbaden (2010)

[Pufé-2014] Pufé, I.: Nachhaltigkeit, 2nd edn. UVK-Verl.-Ges, UTB Konstanz, Stuttgart (2014)

[Rehb-2002] Rehbinder, E.: Das deutsche Umweltrecht auf dem Weg zur Nachhaltigkeit, in: Neue Zeitschrift für Verwaltungsrecht S. 657 ff (2002)

[RGKP-1997] Raskin, P., Gleick, P., Kirshen, P., Pontius, R., Strzepek, K.: Comprehensive assessment of the freshwater resources of the world: document prepared for the UN commission for sustainable development. In: 5th Session. Stockholm Environmental Institute, Stockholm (1997)

[Rock-2009] Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F., Stuart, I., Lambin, E., Lenton, T., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R., Fabry, V., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.: planetary boundaries: exploring the safe operating space for humanity. Ecol Soc 14 (2009)

[RuRM-2014] Russo, D., Rizzi, C., Montelisciani, G.: Inventive guidelines for a TRIZ-based ecodesign matrix. J Clean Prod **76**, 95–105 (2014)

[Rutt-2012] Rutter, K.: Sustainable Engineering. Vorlesungsreihe ENEL 301, University of Canterbury, Derpartment of Electrical and Computer Engineering, Christchurch (NZ) (2012)

[Schm-1992] Schmidheiny, S.: Changing Course. A global business perspective on development and the environment. World Business Council for Sustainable Development Genf (1992)

[ScSG-2012] Schlacke, S., Stadermann, M., Grunow, M.: Rechtliche Instrumente zur Förderung des nachhaltigen Konsums – am Beispiel von Produkten. Umweltbundesamt Dessau-Roßlau (2012)

[SGHS-2016] Schipperges, M., Gossen, M., Holzhauer, B., Scholl, G.: Umweltbewusstsein und Umweltverhalten in Deutschland 2014, Vertiefungsstudie zu Trends und Tendenzen. Umweltbundesamt Dessau-Roßlau (2016)

[ShYa-2017] Shvanefeldt, S., Yanagida, H.: Design for environment at Sony. In: Sarkis, J. (Hrsg.): Greener manufacturing and operations: From design to delivery and back. Routledge S. 290–302 (2017)

[SoAc-2014] Social Accountability 8000: International Standard, Hrsg. Social Accountability International, New York (2014). http://www.sa-intl.org/_data/global/files/SA8000 Standard2014(3).pdf. Abge-rufen am 26 Feb 2020

[SSSO-2010] Scholl, G., Schulz, L., Süßbauer, E., Otto, S.: Nutzen statt Besitzen - Perspektiven für ressourceneffizienten Konsum durch innovative Dienstleistungen. Wuppertal Institut für Klima, Umwelt Energie GmbH (2010)

[Stah-2000] Stahel, W.: Nutzen statt besitzen: Walter Stahel will die ökologische Dienstleistungsgesell-schaft. Aachener Stiftung Kathy Beys (Hrsg.), Perspektiven

Chancen Nachhaltigkeit: 1. Aachener Forum S. 38–43 (2000)

[Ston-2017] Stone, B.: Die Aufrührer: Wie Uber, AirBnB und die gefährlichsten Unternehmen des neuen Silicon Valley die Welt umkrempeln, 1. Plassen Verlag Kulmbach, Auflage (2017)

[TeHi-2015] Terlau, W., Hirsch, D.: Sustainable consumption and the attitude-behaviour-gap phenomenon—causes and measurements towards a sustainable development. In: Deiters, J., Rickert, U., Schiefer, G. (Hg.): Proceedings in System Dynamics and Innovation in Food Networks S. 199–214 (2015)

[Tisc-2000] Tischner, U. (Hrsg.) How to do EcoDesign?: A guide for environmentally and economi-cally sound design. Verlag form Frankfurt am Main (2000)

[UBA-2015] Umweltbundesamt, ecodesignkit, Dessau-Roßlau (2015). www.ecodesignkit.de. Abgerufen am 25 Feb 2020

[UnNa-1992] United Nations: Report of the United Nations conference on environment and development. United Nations New York (1992)

[UnNa-2015] United Nations: Paris Agreement Text English, Paris, 12. 12. 2015, http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf. Abgerufen am 26 Feb 2020

[USEP-2014] United States Environmental Protection Agency, Priority pollutant list. Washington (2014)

[VaKB-2011] Vajna, S., Kittel, K., Bercsey, T.: The autogenetic design theory—product development as an analogy to biological evolution. In: Birkhofer, H. (ed.) The future of design methodology. Springer, London (2011)

[VDI-3780] VDI-Richtlinie 3780:2000-9: Technikbewertung - Begriffe und Grundlage. Zugriff am 16 Mar 2020. https://www.beuth.de/de/technische-regel/vdi-3780/32141408

[ViFM-2011] Vicente, J., Frazao, R., Moreira da Silva, F. (Hrsg.): One basis to operationalize Sustainable Design. Vi CIPED Konferenz (2011)

[Vinc-2012] Vince, G.: Living in the Doughnut. Interview with Kate Raworth about a safe and just operating space for humanity. Nat Clim Change 2(2012) S. 225–226 (2012)

[Vogt-2009] Vogtlander, J.: The eco-costs/value ratio for quantitative, LCA based, assessment of sustainability. VSSD Delft (2009)

[Vogt-2010] Vogtlander, J.G.: LCA-based assessment of sustainability: the eco-costs/value ratio (EVR): Original publications on the theory, updated with eco-costs 2007 data, 1. Auflage, VSSD Delft (2010)

[WeHA-2000] Wenzel, H., Hauschild, M., Alting, L.: Environmental Assessment of Products: Volume 1: Methodology, Tools and Case Studies in Product Development. Springer Science & Business Media (2000)

[WeVo-2021] Wever, R., Vogtländer, J.: Design for the value of sustainability. In: van den Hoven, J., Vermaas, P., van de Poel, I. (eds.) Handbook of Ethics, Values, and Technological Design, pp. 1–31. Springer, Dordrecht Netherlands (2021)

[WhPB-2015] White, P., St. Pierre, L., Belletire, S.: Okala practitioner: Integrating ecological design. IDSA Phoenix, AZ (2015)

[Wien-1970] Wiendahl, H.: Funktionsbetrachtungen technischer Gebilde: Ein Hilfsmittel zur Auf-tragsentwicklung in der Maschinenbauindustrie. Dissertation RWTH Aachen (1970)

[Wint-2018] Winter, E.: REACH, Springer Fachmedien Wiesbaden GmbH, 19 Feb 2018. https://wirtschaftslexikon.gabler.de/definition/reach-51254/version-274447. Abgerufen am 28 Feb 2020

[WiZü-2001] Wimmer, W., Züst, R.: ECODESIGN Pilot: Produkt-Innovations-, Lern- und Optimierungs-Tool für umweltgerechte Produktgestaltung mit deutsch/englischer CD-ROM. Industrielle Organisation Zürich (2001)

[Wupp-2014] Wuppertal Institut, MIT Wertetabelle (2014) https://wupperinst.org/a/wi/a/s/ad/365/. Abge-rufen am 23 Feb 2020

[Yana-1995] Yanagida, H.: Design for environment to minimize the impact on the natural environment. Housou Gijutsu (JPI Journal) 33(1995)

[YCZS-2013] Yu, Y., Chen, D., Zhu, B., Hu, S.: Eco-efficiency trends in China, 1978–2010: Decoupling environmental pressure from economic growth. Ecol Ind 24 S. 177–184 (2013)

[Zeibi-2014] Zeibig, D.: Ozonschicht erholt sich wieder. https://www.spektrum.de/news/ozonschicht-erholt-sich-wieder/1308376. Abgerufen am 09 Mar 2020

[Beys-2012] Aachener Stiftung Kathy Beys: Lexikon der Nachhaltigkeit (dictionary of sustainability), http://www.nachhaltigkeit.info/artikel/definitionen_1382.htm, accessed on 2 December 2014

[Bend-2019] Bendel, O.: Nudging. https://wirtschaftslexikon.gabler.de/definition/nudging-99919/version-369156. Accessed on 26 February 2020.

Chapter 13
Fulfilment Attributes

Martin Dazer, Bernd Bertsche, and Sándor Vajna

In this chapter, the attributes safety, reliability and quality are presented in more detail, with which the fulfilment of the requirements can be assessed by the product attributes. The interaction of the three attributes is described in Sects. 3.2.2 and 3.4.

13.1 Safety

Safety describes the appropriate absence, avoidance or manageability of risks and hazards that could lead to the failure of a product component or of the whole product and thereby endanger the user or other persons. The central parameter in safety engineering is *risk*, which is composed of the probability of occurrence of a hazardous event, the resulting extent of damage and, if necessary, subjective (e.g. application-specific) weighting factors [Müll-2015]. This distinguishes safety from reliability, see also Sect. 13.2. Products with a low probability of failure, but with a high measure of damages, are therefore reliable, but do not necessarily have to be safe.

The limiting risk represents the maximum tolerable risk for an application (and is therefore subjective) [Bromb-2011]. Safety and risk are related by the equation

$$\text{Safety} = 1 - \text{Risk}$$

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The RAPEX methodology provides guidance for determining the overall risk for safety-critical functions, such as the braking of a motor vehicle [Euro-2009].

In IDE, safety is the minimum level of compliance with the requirements (in the broadest sense), which is required for a given limiting risk, so that the product cannot cause any damage to the user, the environment and the persons affected by the product during its period of use, when used as intended or not [MePe-1984]. Thus, safety within IDE can be formulated as

$$\text{Safety (IDE)} = 1 - \text{Limiting risk (IDE)}$$

The safety of the entire product results both from the individual safeties of all required characteristics and properties and/or installed components as well as from the interaction of the individual safety of each attribute and from quantity, degree and quality of interaction of the product components in the entire product. By appropriate combination of these components, a mutual offsetting of risks is achieved, and thus, the marginal risk is respected.

According to DIN ISO 31,000 [DIN-31000], safety can be divided into direct, indirect and indicative safety.

- Immediate safety requires that no danger can arise from the product and its application. Immediate safety is the goal of IDE.
- If this cannot be achieved at reasonable effort, safety must be achieved by means of aids such as protective devices (=indirect safety, for example, light barriers on machine tools).
- If this is also not possible, the only remaining safety option is to make reference to the hazards arising from the procurement, use and re-circulation of the product by means of appropriate warnings on the product or in its instructions for use.

The importance of the safety of a product has been growing, as customers increasingly demand that a product is used at its performance limit or can be used (partially or at for a short time) beyond its performance capacity. In addition, it should be noted that the improper use and possible misuse of the product cannot be excluded[1].

In order to intercept this phenomenon, at least within certain limits, the product must be designed to be robust, i.e. with a certain tolerance for misuse[2], so that its reliability (Sect. 13.2) is nevertheless ensured. Another major driver is the increasing automation of technical systems, especially in the area of autonomous driving. With more and more functions, the human being as direct user is no longer required and thus the fall-back level in the event of technical failure, which leads to a further increase in the number of safety-critical functions. As a result, the safety requirements in the vehicle are also increasing, which must be met with new efficient safety solutions.

[1] This is partly due to the fact that potential users of the product do not obtain sufficient information from the instruction manual, because it is often incomplete and insufficiently formulated.

[2] VDI Guideline 3542 Sheet 4: "Robustness [means] that a system is forgiving of operating errors and largely insensitive to deviations from the specified operating conditions." [VDI-3542]

If a failure or unsafe situation nevertheless occurs, the supplier is responsible for the resulting damage in accordance with Directive 85/374 EEC, Article 11[3]. This is another reason why complete product documentation is necessary. This documentation must be available internally at the time of production release, externally at the delivery in order to be able to take a clear position in case of questions of product liability. In order to design the product in a safety-conscious way and to minimize damages resulting from the use or failure of the product or one of its components, the following realization of a "safety hierarchy" can be used in product development [HaGo-2004]:

- Derivation of the limiting risks for the planned applications and environments based on valid standards[4]. Here, all those involved in the product life cycle (Chap. 4) must be taken into consideration.
- All components are designed in such a way that they do not pose a hazard or risk (immediate safety) and that sufficient tolerance of operating errors (robustness) is achieved [KGGO-2017, StSM-2017].
- Protective systems are added for critical components or those whose use can be interpreted differently (indirect safety)
- In principle, users are informed about possible risks and dangers during application preparation, use and re-circulation of the product (indicative safety).
- Users of a product are adequately trained.
- Personal protection measures of the user are encouraged.

Further measures for product design are given in Sect. 13.2.3.

Safety in this context does not only mean the safety of the user in handling the product, but also the safety that prevents the failure of one component of the product from propagating to further failure of other components and products, regardless of whether a human being is involved or not. In particular, care should be taken to ensure that during product development, a potential defect does not cause a propagation or amplification of the triggering defect, which could lead to a spiral of damage that results in the failure of the entire system.

13.2 Reliability

Reliability describes the functionality of a component or a product during or after specified periods of time under specified boundary conditions [DIN-40041]. Products with high reliability are therefore highly likely to remain usable during their specified

[3]Directive 85/374 EEC, Art. 11: "In order to be able to provide evidence of exoneration in possible product liability cases, it must be possible to trace back the state of design and the associated modifications for at least 10 years after the product has been placed on the market" [EEC-1985].

[4]For example, ISO 26262 for the safety of motor vehicles [ISO-26262] and ISO 13849 for the safety of Machinery [ISO-13849].

or expected lifetime. Usability describes the technical aspect, while availability (Chap. 10) together with readiness for use represents the temporal aspect[5].

IDE requires for the reliability of each attribute a minimum fulfilment to ensure the reliable use of the product. The reliability assurance of the product must be ensured. In addition to recourse payments and recalls, the consequences of unreliability in operation can lead to a loss of image and even civil and criminal consequences [Naun-2019].

Table 13.1 gives an overview of the basic reliability terms, their symbols and a brief description discussed in this chapter.

13.2.1 Definition and Description of Reliability

During their lifetime, products are subjected to loads caused by the user, resulting from the use of the product, which causes damages. In the case of mechanical products, for example, the use of the product causes a structural mechanical stress in the material, which can cause continuous growth of cracks and thus damage the product.

During the early phases of product development, the design, modelling and layout activities of the IDE procedure model (Sect. 16.1) determine the strength of a product by defining the design, material and manufacturing process. This strength is selected to be higher than the expected stress in order to ensure the specified lifetime of the product in its areas of application. Naturally inherent scattering of influencing factors such as material, design, external load and operating environment causes deviations from the nominal stress and strength of the product and therefore has an impact on its lifetime, which is why there will never be a constant lifetime. This situation can be illustrated exemplarily by complex components, which are often produced in a casting process. The mechanical material properties are determined both by those of the raw material and by the casting process. Process variations such as fluctuating casting temperatures and cooling times cause different mechanical properties in the cast product and thus different strengths. For this reason, this kind of products will always have different lifetimes.

If the stress exceeds the strength of the product at a certain point in time, a failure is to be expected. Figure 13.1 shows the interaction of the stress $f_B(\mu_B)$ and strength distribution $f_W(\mu_W)$ and their overlap, which describes the number of failures that occur. Since the interaction of stress and strength directly influences the expected product failures, both variables also have a direct effect on the performance of the product. The distribution functions are each exemplarily presented with a normal distribution and are therefore represented by their mean value $\mu_{B,W}$ and their standard deviation $\sigma_{B,W}$. In principle, other distribution functions can also be used to model stress and strength.

[5]Here, HUBKA goes further, describing reliability as part of the operating characteristics of a system that is on the same level as operational safety, lifetime, energy consumption, space consumption and maintainability [Hubk-1984].

Table 13.1 Overview of the basic terms of reliability

Term	Formula symbol	Explanation
Stress	–	The stress characterizes the damage caused by the use of the product
Strength	–	The strength represents the stress that the product can withstand after a defined period of time
Lifetime	–	If the stress exceeds the strength at a certain point in time, the product has reached the end of its lifetime
Reliability	$R(t)$	The probability with which the system is in a functioning state at a certain point in time
Probability of failure	$F(t)$	The probability that the system will fail at a certain point in time
Density function	$f(t)$	Number of failures in a specific time interval
Failure rate	$\lambda(t)$	Probability of observing a failure in the next time interval dt
Class width	n_k	Time interval on the abscissa of a histogram to scale the lifetime data
Weibull distribution		Used to establish a continuous relationship between failure probability and lifetime data
Characteristic lifetime	T	Represents the location of the lifetime data approximated by a Weibull distribution. It is always assigned to a probability of failure of 63.2%
Shape parameters	b	Represents the shape (scatter) of the life data approximated by a Weibull distribution. In the Weibull plot, the shape parameter is the slope of the Weibull straight
Failure-free time	t_0	Represents the time interval in which no failures occur, i.e. the probability of failure is 0%
Population	–	The quantity of all parts of a produced product
Random sample	–	Randomly withdrawn number of test specimens from the population
Confidence interval	–	The range in which the Weibull distribution of the population is located with a certain probability
Confidence	P_A	The probability with which the Weibull distribution of the population is located within the confidence interval

The scattering of the influencing factors material, design and load causes a scattering of stress and strength, respectively. If the scattering of the influencing factors increases, an increase in the scattering of the stress or strength is to be expected. In the example shown, the scatter of the stress σ'_B increases, which is evident to the broader distribution function $f'_B(\mu_B)$. The overlap of the two distribution functions thus becomes greater, whereupon the probability of observing failures increases and the sum of the expected failures for the defined point in time increases. Lifetime can thus be understood as a random variable that is always subject to scattering due to fluctuating influencing factors.

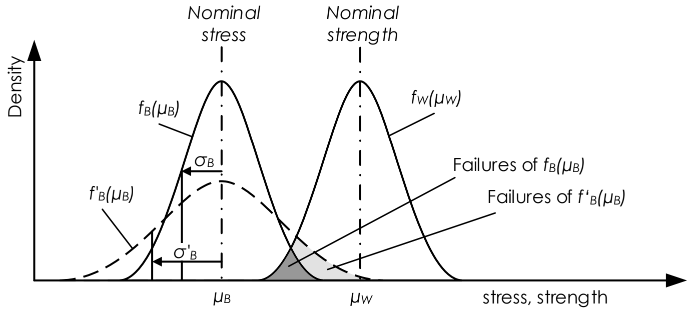

Fig. 13.1 Interaction of stress, strength and failures

Reliability engineering methods describe the scattering lifetime in order to make statements about the failure behaviour of products despite this uncertainty. The reliability of technical components or systems is defined as the probability with which the system is in a functional state at a certain point in time or during a time interval, under defined boundary conditions and whereby can be described mathematically by the reliability $R(t)$[6] [BeLe-2004]. The direct time reference of reliability can be recognized immediately. The reliability of products that have been correctly manufactured and assembled at the time before their first use t_1 is always 100%. With increasing lifetime (t_2, t_3), the probability of failure increases. Remember the Wöhler curve, where the scatter bands of stress and strength move towards each other in the fatigue strength range[7]. This increases the overlap and thus the probability of failure of the scatter bands with increasing time, Fig. 13.2. With increasing probability of failure $F(t)$, reliability decreases at the same time, from which it can be concluded that a reliability statement only makes sense with a direct reference to time, i.e. at a certain point in time.

In contrast to availability (Chap. 10), reliability only considers the period prior to the first failure. Therefore, reliability describes the probability that a product will be intact at a certain point in time. It thus gives the product developer information about the probability of failure of the product at a certain point in time, but makes no statements about the extent or consequences of a product failure. This relationship makes it possible to distinguish reliability from safety. Safety indicators are based not only on the probability of occurrence (corresponds, for example, to the probability of failure of the product and the probability that persons are in the danger zone) but also on the extent of damage and thus indicate an overall risk of a safety-critical failure [Müll-2015]. Evaluation and quantification of the safety risk are carried out by means of special guidelines such as the Rapex method [Euro-2009]. Safety-critical and serious product failures must be safeguarded not only by extremely low failure

[6] *R(t)* derived from “Reliability”

[7] The fatigue strength range in the Wöhler diagram is characterized by the inclined fatigue strength line, in which a load leads to failure of the product after a defined number of finite cycles. The following applies: The higher the load, the more likely it is that failure will occur [Haib-2006].

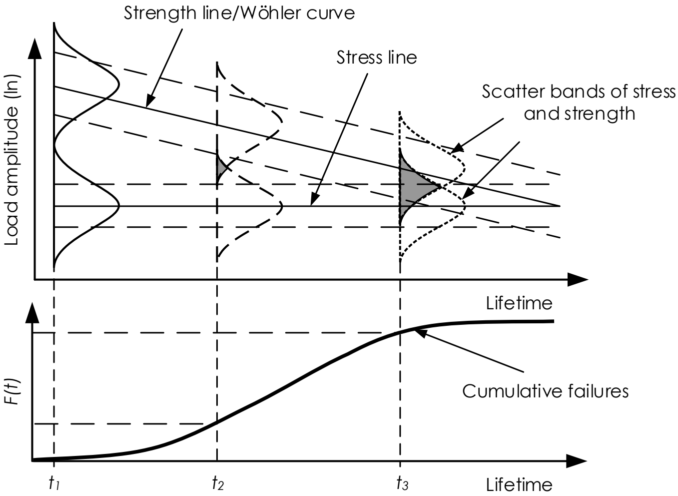

Fig. 13.2 Stress and strength along the Wöhler curve [BeLe-2004]

probabilities but also by special measures such as fail-safe principles. Such topics are usually referred as *functional safety*. Safety concepts, for example, are standardized in ISO-26262 or IEC 61508 [ISO-26262, IEC-61508].

The central point of a reliability analysis is not the performance-related parts or components, but their potential failure modes, which can be divided into three areas [BeLe-2004]:

- Early failures caused by errors in production, assembly or in the operation of machines.
- Random failures, in which the risk of failure is constant, but usually also relatively low, for example, in complex tribological systems such as the radial shaft seal. Here, penetrating dirt particles can lead to hardly predictable failures.
- Fatigue failures, ageing failures, wear failures and failures due to environmental influences, such as corrosion, caused by time-dependent, systematic changes in the materials involved, e.g. in highly stress/ed components of vehicle technology.

Early and random failures can only be described statistically with the help of empirical data, while concepts have established for fatigue strength and lifetime calculation in order to also provide mathematical prognoses for reliability [BeLe-2004, Haib-2006, Rada-2007, Timo-2002]. The necessary empirical life data from field or test rigs are used to obtain information on the failure behaviour of the product.

The simplest way to obtain information from empirical data is to use descriptive statistical methods such as histograms. The scattering lifetime data are divided into time intervals on the abscissa, which are called *classes*. The number of failures per class can be expressed as a relative frequency over time, Fig. 13.3. The number

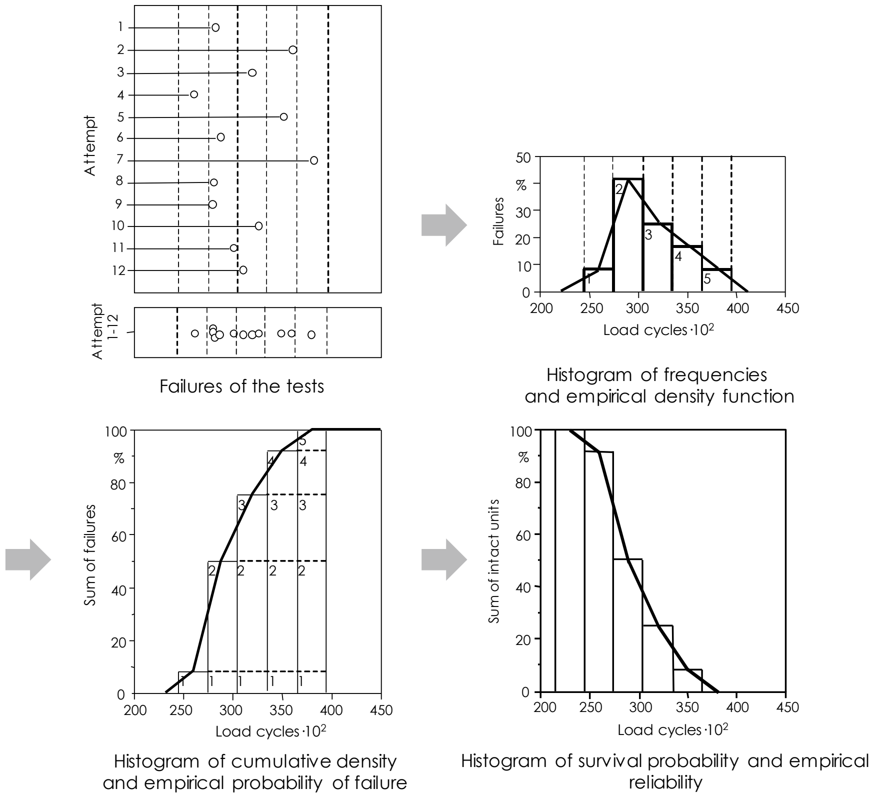

Fig. 13.3 Evaluation of empirical lifetime data with the empirical density and distribution function and their histograms [BeLe-2004]

of classes n_k can be calculated approximately from the sample size n by Eq. (1) [BeLe-2004]:

$$n_k = \sqrt{n} \tag{13.1}$$

By connecting the mean values of each class, the so-called *empirical density function is* created, which provides information about the number of failures for a certain point in time and can thus be used to determine the point in time with the highest number of failures. From the point of view of corporate strategy, however, the total number of failures up to a certain point in time is of far greater importance, since this information can be used to influence warranty and goodwill costs or to plan their expenses. By summing up all classes of the empirical density function, the empirical distribution function or the empirical probability of failure is created. The empirical survival probability or rather the empirical reliability results as a counterpart to the failure probability as a histogram mirrored on the *Y*-axis. Paradoxically, the probability of failure is usually the focus of any reliability analysis, not the reliability itself. The background to this is that customers often demand a maximum permissible number of failures at a certain point in time.

Now, a continuous and steady mathematical relationship between lifetime and probability of failure, reliability or density function is usually required for the prognosis, for which probability distributions are used. Intellectually, the transition to probability distributions occurs through the boundary course $n \to \infty$ where, according to the law of large numbers, the relative frequencies change into probabilities. The class widths become very small as a result of the boundary gait, resulting in a "smooth" curve that can be approximated by a probability distribution. However, in practical application, it is often necessary to fall back on a small amount of data or test specimens, which is why a Weibull analysis [Weib-1951] determines those parameters of a distribution function which most probably correspond to the population of the sample analysed [BeLe-2004].

- Weibull analysis is a central tool in statistical reliability analysis for assigning failure probabilities to empirical life data.
- With the help of parameter estimation methods (such as the "least squares method" or the maximum likelihood method), the Weibull distribution is estimated from the value pairs of lifetime and probability of failure [MeEs-1998, Nels-2005].
- The result of the analysis is a Weibull distribution or straight line, which establishes a continuous mathematical relationship between the lifetime and the failure probability of the product. With knowledge of the probability of failure at certain points in time, continuous reliability predictions can be made.
- The Weibull distribution is described by the shape parameter b and the characteristic lifetime T and can be used to map early, random and fatigue failures, giving it a high degree of flexibility. The shape parameter represents the form of the distribution function and thus the scatter of the lifetime data. The characteristic lifetime is a kind of mean value and thus indicates where approximately the middle of the distribution lies and thus represents the approximate position of the lifetime data [BeLe-2004]. Due to the fact that the Weibull distribution is described by two parameters, one also speaks of the *two-parameter Weibull distribution.*

Based on the term Weibull analysis, it can already be concluded that the Weibull distribution is frequently used in reliability engineering. However, in principle, other probability distributions can also be used for the description of life data, whereby some special features must be taken into account. The lognormal distribution offers similarly good properties as the Weibull distribution, while the normal distribution is not used for the evaluation of life data. The normal distribution is an asymptotic distribution, i.e. its area of definition also extends into negative areas, which can lead to negative lifetimes that cannot be explained physically. Exponential distribution is often used to describe the reliability of electronic components whose failure modes are not due to mechanical fatigue effects. It can only be used to model random failures, which is why it can only be used to a limited extent.

In addition to the probability of failure $F(t)$ as the central measure for evaluating the failure behaviour, the reliability parameters of a three-parameter Weibull distribution are calculated as follows:

$$\text{Dependability} \quad R(t) = e^{-\left(\frac{t-t_0}{T-t_0}\right)} \tag{13.2}$$

$$\begin{aligned}\text{Probability of default} \quad F(t) &= 1 - R(t) \\ &= 1 - e^{-\left(\frac{t-t_0}{T-t_0}\right)}\end{aligned} \tag{13.3}$$

$$\text{Desity function} \quad f(t) = \frac{\mathrm{d}F(t)}{\mathrm{d}t} = \frac{b}{T-t_0} \cdot \left(\frac{t-t_0}{T-t_0}\right)^{b-1} \cdot e^{-\left(\frac{t-t_0}{T-t_0}\right)^b} \tag{13.4}$$

$$\text{Failure rate} \quad \lambda(t) = \frac{f(t)}{R(t)} = \frac{b}{T-t_0} \cdot \left(\frac{t-t_0}{T-t_0}\right)^{b-1} \tag{13.5}$$

The distribution parameter t_0 (the third parameter, therefore *three-parametric distribution*) describes the so-called failure-free time in the three-parametric form of the Weibull distribution, i.e. a time span in which the probability of failure is exactly 0%. For the two-parameter form of the Weibull distribution, the following applies $t_0 = 0$. With the use of a failure-free time, more and more optimistic results are achieved, because by definition, no failures occur until the failure-free time is reached, whereas with the two-parameter form, there is a probability of observing failures right from the start—albeit a very small one. For this reason, some aspects should be considered when using the three-parametric form of the Weibull distribution. In addition to the statistically better approximation, there should be a physically valid justification for the existence of a time without failures in order to substantiate its real existence. An example of this is the course of wear on a brake pad. No matter how hard the driver brakes the vehicle, he will not be able to completely wear the brake pad immediately after the first braking manoeuvre, but it will take a few cycles before wear-out occurs. In such a case, the existence of a failure-free time can be assumed, because it is physically not possible that wear occurs directly at the beginning of use. It should also be noted that large sample sizes are always required for the verification of failure-free time.

The probability of failure is calculated as the counterpart of reliability from $1 - R(t)$. The total of intact and failed products of a produced population is always 100%. The density function is the derivation of the failure probability and thus representative of the failure frequency at a certain point in time. As a result, the probability of failure describes the cumulative frequency of all failures up to a certain point in time, which usually forms the design objective in development and thus underlines the central importance of this variable from the point of view of reliability engineering. The failure rate can be described as failure risk by referring the currently occurring failures to the still intact units in the field. It can therefore be interpreted as the probability of observing a failure in the next time interval d*t*. When the failure rate is applied over time, a so-called bathtub curve is formed, which is divided into three areas by the separation of the failure modes described above and thus represents the flexibility of the Weibull distribution, Fig. 13.4.

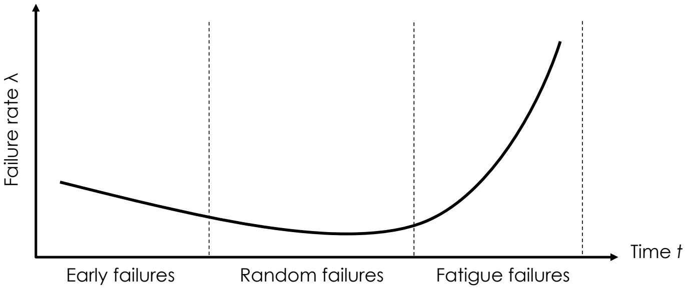

Fig. 13.4 Bathtub curve as classification of the various failure mechanisms

- A falling failure rate is characteristic for early failures, which can be observed especially during the development of new and adaptation designs. Extensive changes or completely new products increase the risk of adding new failure modes, which are eliminated again as the development time progresses by suitable detection and elimination measures—the risk of failure is reduced (e.g. FMEA, Sect. 13.3). Falling failure rates after the start of series production are often due to assembly or manufacturing errors or undiscovered design errors.
- Random failures are characterized by an almost constant failure rate and do not follow any systematic approach according to the designation and occur purely random—the failure risk in relation to the products still in the field remains almost constant. Penetrating dirt is a typical example of random failures. In most cases, the failure rate is not completely constant, since elimination measures eliminate failure modes, which results in a slightly decreasing failure rate with increasing runtime.
- The last area is fatigue failures, which are also the focus of product design, since these failure modes follow systematic physics of failure, such as wear, and thus determine the planned end of the lifetime of products. With longer lifetime, reliability decreases steadily and reaches 0% if the last component fails, increasing the failure rate continuously and eventually reaching infinity.

The focus of every Weibull analysis is the probability of failure, which is presented as the result of the Weibull analysis in a so-called *Weibull plot*. The probability of failure can be represented as a straight line by logarithms of the abscissa and double logarithms of the ordinate. Figure 13.5 a shows different Weibull distributions in the Weibull network with constant characteristic lifetime and different shape parameters. All common software packages for reliability analyses also use this form of representation.

It can be seen that the shape parameter b directly represents the scattering of the Weibull distribution, while the characteristic lifetime indicates the position. With a larger shape parameter, the Weibull straight line is very steep and thus only extends over small life spans, while a smaller shape parameter extends over larger areas and

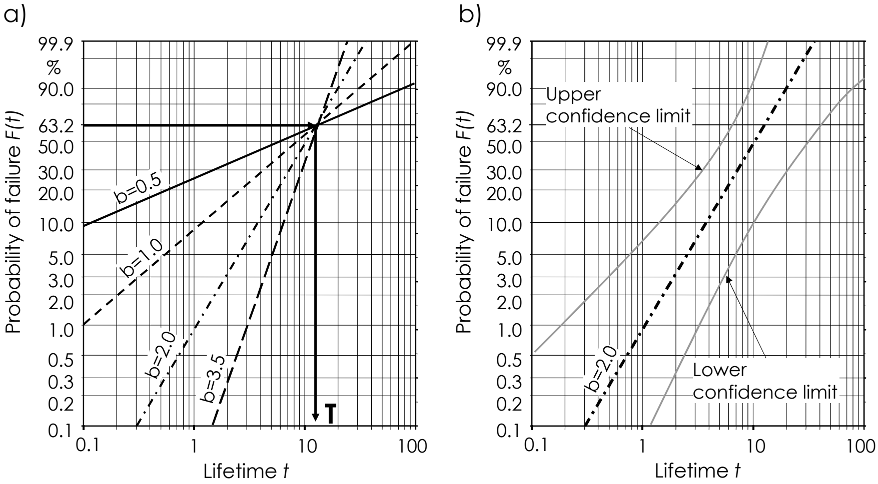

Fig. 13.5 **a** Weibull distributions with same characteristic lifetime but different shape parameters, represented in Weibull plot; **b** Weibull distribution with confidence interval

thus represents more scatter. By WEIBULL's[8] definition, the characteristic lifetime is always 63.2% failure probability and can thus be read directly from the Weibull plot [Weib-1951]. In order to take account of the fact that in practical application, only a very limited number of test specimens is usually used to carry out a Weibull analysis, a so-called confidence interval must be used for the result evaluation.

Statements of reliability should always apply to the population. However, it is not possible to capture this information precisely because it would require testing all parts of the population, which is practically impossible. Smaller samples from the population are therefore used. The samples have to be taken randomly from the population, which is why we speak of a random sample[9]. The results of the sample are therefore always subject to uncertainty, which can be described by the confidence interval. The Weibull straight of the sample thus becomes an area in which the "true" Weibull straight of the population is located with a certain probability. For example, if a confidence of 90% is required, the confidence interval can be defined as the area in which the "true" Weibull straight of the population is located with a probability of 90%. This certainty is called the confidence P_A. From the reverse conclusion of these considerations, it can be concluded that there is always a residual risk of a false statement of $1 - P_A$ remaining. However, this residual risk can be described quantitatively by the confidence interval and can thus be kept low in a

[8]Waloddi WEIBULL (1887–1979), professor at KTH Stockholm, developed the distribution function named after him in the 1930s. He published his research results in 1951 under the title "A statistical distribution function of wide applicability" in the Journal of Mechanics (9)1951, page 293–297.

[9]The following conditions shall be attached to a random sample: The test specimens are randomly taken from the population and the probability with which a test specimen enters the sample can be specified [SaHe-2006].

controlled manner. Figure 13.5b shows an example of a confidence interval for a Weibull distribution with a shape parameter of $b = 2$.

13.2.2 System Reliability Analysis

In systems that consist of a large number of subsystems and individual components, several failure modes can occur because there is a probability that each component will follow a different physics of failure. If several failure modes occur, each of these failure modes must be investigated separately and described accordingly, since the system reliability $R_s(t)$ is calculated from the product of the individual reliabilities. In principle, technical systems can be divided into two categories serial and parallel structures, whereby combinations of both structures are also possible. Figure 13.6 shows an example and the corresponding calculation of the system reliability of each structure according to Boolean system theory [BeLe-2004]. Requirements for the application of Boolean system theory are defined as follows [BeLe-2004]:

- The system components are not repairable.
- The components can only assume the two states “functional” or “failed”.
- The failure behaviour of all components is independent or they do not influence each other.

If these conditions are not met, further methods such as Monte Carlo simulation or the method of moments can be used, for which reference is made to the further technical literature [LDWB-2018, LDHB-2019].

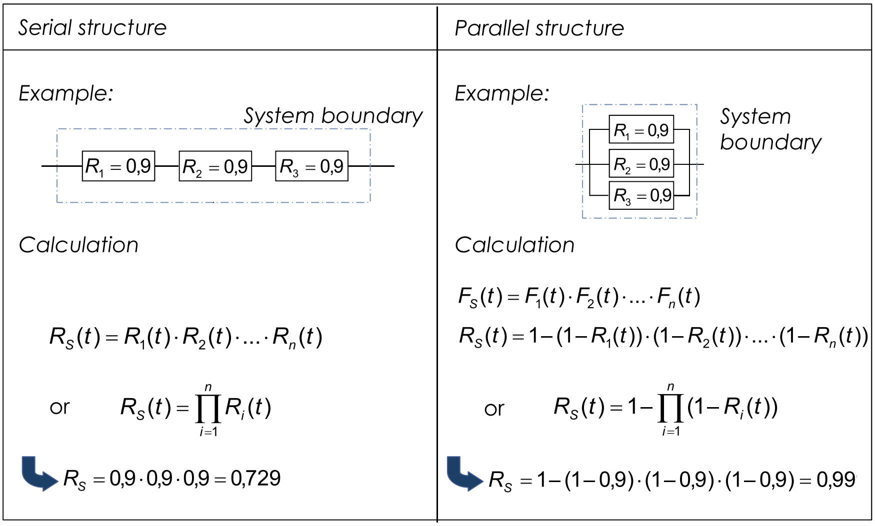

Fig. 13.6 Calculation of system reliability according to Boolean system theory

Today, for cost reasons, serial rather than parallel structures can be found far more frequently in technical systems, especially in mechanical components. In a serial structure, a component failure also ends the lifetime of the overall system, which is why the system reliability is calculated from the product of the individual reliabilities and is therefore always lower than the lowest reliability value of an individual component. Parallel structures are also referred to as redundancy, since if one component fails, the function can still be performed by one or more other components (completely or at least partially). In the parallel structure, the system reliability is calculated as the product of the failure probabilities and is therefore always higher than the highest component reliability. Especially, with extremely high reliability requirements, e.g. in safety-critical systems, the redundant parallel structure often offers the only possibility to achieve the reliability targets. For example, more and more electrical assistance systems are being used in highly automated vehicles to ensure that the vehicle comes to a safe stop at the edge of the road even in the event of a failure. In order to ensure the energy supply for the high number of consumers even in the event of failures, increasingly redundant onboard power supply systems with separate batteries are being established [HeHi-2018].

For reliability analyses at system level, a pure consideration of the individual components is not sufficient. Systems are developed to perform one or more specific functions, such as the freewheel shown in Fig. 13.7a. In addition to the “lock” function—i.e. transmitting torque—it should also be able to fulfil the “freewheel” function—i.e. not transmitting torque. The system consists of two roller freewheels and three shafts arranged on one axis. The principle sketch strongly resembles a pure serial structure, which is not sufficient from a reliability point of view to calculate the system reliability. For the cause of failure “interruption”, i.e. the non-fulfilment

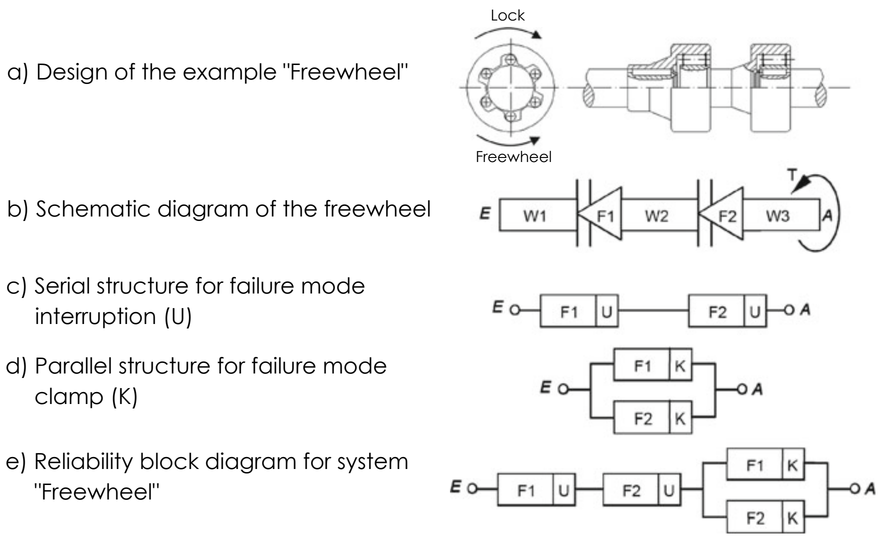

Fig. 13.7 Determination of a reliability block diagram using a freewheel as an example

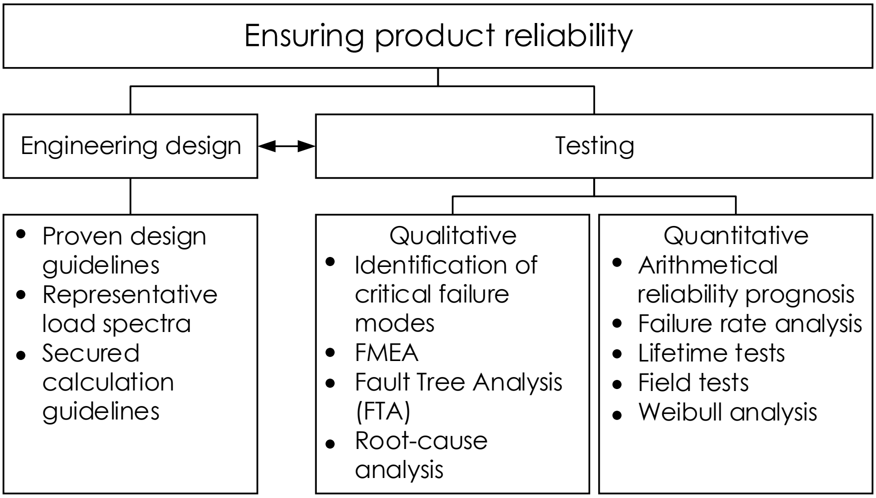

Fig. 13.8 Ensuring product reliability in accordance with [BeLe-2004]

of the function "lock", a serial structure does indeed apply, because the failure of an individual freewheel already leads to the failure of the entire system. For the failure cause "clamps"—i.e. the non-fulfilment of the freewheel function—a parallel structure applies, because the function can still be fulfilled even if a single freewheel fails. For the determination of the reliability block diagram, the combination of both described failure modes must be considered. With this circuit diagram, the system reliability can finally be calculated with the formulas from Fig. 13.6.

Individual components may also have different competing failure mechanisms whose probability of occurrence may depend on operating, material or environmental conditions. A typical example from the field of machine components is the gears in transmissions. Depending on the type and level of load, gears fail either due to tooth breakage, pitting[10] or seizure [Naun-2019]. Such competing failure mechanisms usually remain unconsidered at the component level, which is why the focus in reliability analyses should consciously be on the level of potential failures modes.

13.2.3 Reliability-Oriented Product Design Within IDE

The aim of product design in terms of reliability is to develop products with a defined lifetime and appropriate reliability. In addition, it is of essential importance to evaluate and prove the constructively determined reliability by suitable qualitative and quantitative methods, Fig. 13.8.

[10]Shell-shaped material breakout on the surface of the tooth flank of a gearwheel caused by alternating stresses. English term: Pitting

Both the design-dependent layout and the testing or assurance of products are directly interdependent. The design-dependent layout defines the actual reliability of the product by defining the strength through the design-dependent layout and the nominal stress through suitable load assumptions (Sect. 13.2.1). By means of the methods in testing and validation, the reliability designed into the component is recorded and evaluated. If the specified requirements cannot be met and the reliability targets thus not achieved, the reliability must be increased in additional development loops in an iterative process through design-dependent measures and must be again re-evaluated and proven, respectively.

During the design phase, all possible types of defects in the bathtub curve must be addressed at an early stage in order to avoid failures and thus achieve a high level of reliability. Proven design guidelines such as assembly (DfA) or production-ready design (DfM) allow early and random failures to be avoided by reducing the possibilities for incorrect assembly and manufacturing errors through design measures. The targeted recording of representative loads to be expected for the product in the field primarily addresses fatigue failures and thus the planned end of life of the product. Field loads can be recorded either by measurements on test vehicles or by simulations (Sect. 13.2.4) and are an elementary component of calculation guidelines, since incorrect load assumptions lead to incorrect calculation results and consequently result in incorrect reliability values. Calculation guidelines consist of the determination and subsequent calculation of the overlap of stress and strength. For complex products, the load is nowadays calculated almost exclusively with the aid of numerical simulations, while empirical approaches such as the FKM guideline or the concept of synthetic Wöhler curves have prevailed in the strength calculation [BeTh-1999, Renn-2012]. A separate calculation guideline exists for the reliability calculation of safety-related components, e.g. in nuclear power plants, which is published by the Nuclear Technical Committee [Kern-2016].

Once a product concept has been developed, it is evaluated using qualitative and quantitative methods from a reliability perspective. While the qualitative methods rather address the early and random failures, the quantitative methods primarily address the planned end of life and thus the systematic fatigue failures. Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA, see Sect. 13.3) are used to identify potentially occurring failure modes, evaluate their consequences and, if necessary, initiate suitable remedial action, especially if the identified failure mechanisms are random failures. In a root cause analysis, the cause of the failures identified in the FMEA or FTA is searched systematically and in a targeted manner.

The reliability at the planned end of the lifetime, which is specified by the systematic failure modes, can be determined by mathematical lifetime prognoses, testing or field tests with subsequent Weibull analysis of the empirically determined life data. Failure rate analyses on the basis of the literature values such as the Military Handbook [USDe-1995] or similar are to be viewed critically, as the values often cannot be assigned to any boundary conditions and these often differ considerably from one another for the same components. If products are heavily over-sized, reliability targets can be easily and cost-effectively proven, but over-sizing causes high material costs for large quantities. Low over-sizing or load-compliant dimensioning, on the other hand, requires higher efforts for successful reliability demonstration, but results in higher profits in the long term due to lower manufacturing costs. HERZIG investigates this relationship quantitatively and determines an optimum between the material and testing costs incurred as a function of the number of units and gives general recommendations for reliable product dimensioning in the trade-off between the resources used and the testing expenditure required [HeDB-2019].

13.2.4 Management of Reliability Throughout the Product Life Cycle

To control reliability, the testing and assurance activities must extend over the development process and the field life and thus over the entire product life cycle, Fig. 13.9 [Naun-2019]. Such a holistic process is called reliability management, which is standardized in the VDI guideline 4003 and DIN 6300 [VDI-4003, DIN-60300]. The German Association of the Automotive Industry (VDA) also lays down rules for the application of reliability methods in the automotive sector in the VDA Volume [VDA-2016].

The central starting point of any development is the definition of goals. This also applies to reliability engineering. The reliability target at system level must therefore

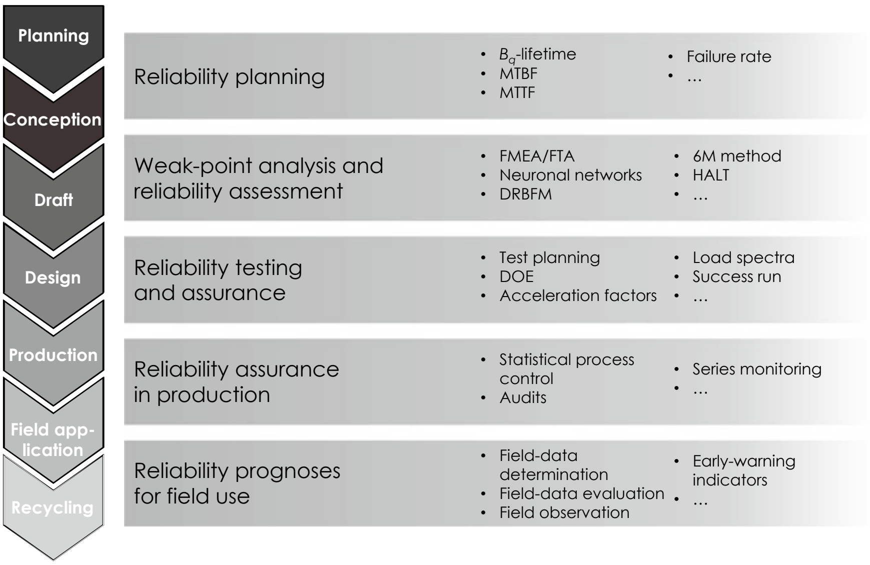

Fig. 13.9 Reliability management. Bq-lifetime: lifetime at which q % of all components have failed; MTBF: Mean Time Between Failures; MTTF: Mean Time To Failure; FMEA: Failure Mode and Effects Analysis; FTA: Fault Tree Analysis; DRBFM: Design Review Based on Failure Mode; HALT: Highly Accelerated Life Test; DOE: Design of Experiment [Naun-2019]

be defined, from which the targets for subsystems can be derived. This defines the framework for action in which reliability engineering methods are applied throughout the product life cycle [Naun-2019]. Reliability goals cannot be generalized, since they depend strongly on the respective product (safety-critical or not) as well as on further boundary conditions. Last but not least, reliability targets can also be part of the individual corporate strategy. Databases for the determination of goals can be:

- Legal requirements and specifications
- Placement on the market/competition
- Customer requirements
- Predecessor products
- Warranty and goodwill costs.

The highest priority is given to the legal requirements, whereby an enormous duty of care should prevail especially with safety-critical components. For example, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) publishes a safety concept for the operation of nuclear power plants [BMU-2009]. Companies often carry out extensive benchmarks of competitor products before the start of development, whereby the reliability of the competitor also provides valuable information for placing their own product on the market. In addition, customer requirements provide a basis for orientation. Nowadays, reliability expectations of customers extend partly into small substructures, such as comfort functions (e.g. seat heating in the vehicle), which is of additional importance for the planning of reliability targets. Market analyses, findings from predecessor products and internal requirements can also be incorporated into the targets [Naun-2019]. The warranty and goodwill costs of the current product generation can also be used to plan reliability targets in order to reduce costs through lower failure probabilities. The results are fully documented in the description of the expected performance of the product. In addition to the direct reliability targets, the functional, environmental and general boundary conditions must be specified and information on the testing and verification (procedures, conditions, duration, etc.) must be provided and documented in a testing manual.

In the conception and draft phase, the focus is primarily on qualitative methods such as FMEA, Fault Tree Analysis (FTA), checklists and design reviews (Sects. 13.2.3 and 13.3), since the degree of maturity of the product is still too low, and therefore, there is no representative basis for quantitative methods. While quantitative methods are based on mathematical and statistical principles with which, for example, failure probabilities can be calculated, qualitative methods combine all systematic methods in order to determine possible failures as well as their cause and effect [BeLe-2004]. To ensure functionality, potential failures and technical risks are analysed and the possible consequences assessed. By identifying the causes of the failure, appropriate remedial action can be taken to reduce the failure rate. If the causes of errors in completely new or highly complex systems cannot be identified by expert knowledge and system analyses, the so-called Highly Accelerated Life Tests (HALT) [MeEs-1998] can be used to remedy the situation Fig. 13.10.

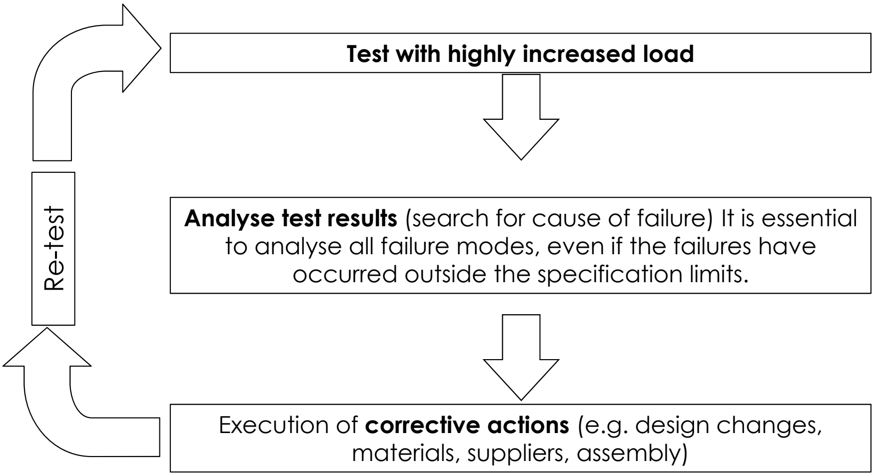

Fig. 13.10 HALT process

Due to the increased load, failures are deliberately provoked in a short period of time, so that the cause of failure can be identified through component inspection. The process can be repeated iteratively after measures have been taken, Fig. 13.10. The focus of this test procedure is on identifying relevant failure modes and their causes in the shortest possible time and at minimum cost. Since the failures are outside the specification limits, the HALT test cannot be used for the quantitative evaluation of failure behaviour. Rather, it is also integrated into the qualitative procedures.

With increasing maturity in the elaboration phase, the quantitative description and proof of reliability by life tests or field tests and subsequent Weibull analysis come to the fore [Naun-2019]. During testing, constant boundary conditions should be taken into account, as otherwise the reliability statements do not have a valid basis. Particularly, when comparing the reliability of different products or the development status of products, misjudgements often occur in practical applications due to a lack of consideration of constant boundary conditions. An essential part of a valid test is knowledge of the load on the product during the phases of its manufacture, logistics and use. Missing or distorted information about the expected exposure has a direct effect on reliability and lifetime and consequently leads to erroneous results in Weibull analysis. Before the actual load detection, the system limit must first be defined and the resulting relevant loads determined. Figure 13.11 shows the system limit using the example of a brake system for commercial vehicles. Once the relevant loads have been identified, a load-time or load-displacement record[11] is required for load spectra development, which can be determined from measurements or simulations.

[11] A load-time or a load-displacement record continuously records the behaviour of a variable (usually a load) over the distance travelled or over time for a specified duration.

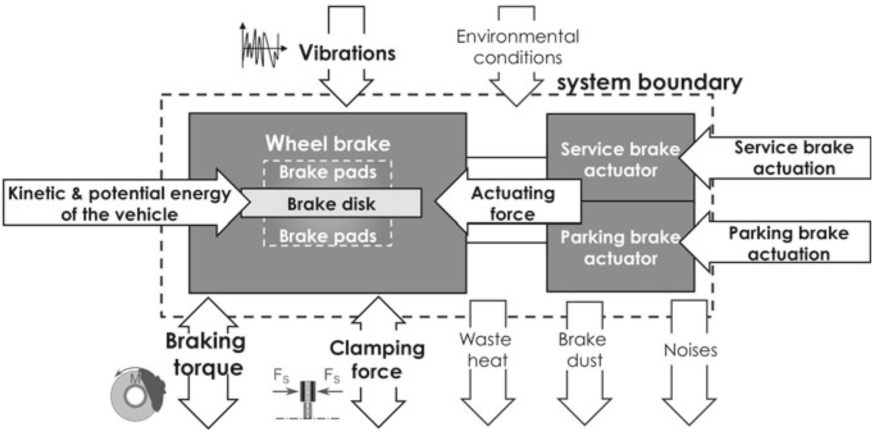

Fig. 13.11 System limits and loads using the example of a commercial vehicle brake system (based on [LuHB-2017])

Although measurements under real operating conditions promise high data quality, they are costly and often not directly possible at critical points on the product. These problems can be solved by measuring the load at an accessible point in the force path and then transferring it mathematically to critical points, while at the same time, minimizing the effort involved. For example, the clutch torque can be measured in a drive train and the torques at the wheels can be calculated taking into account the dynamic system. However, such systems cannot be regarded as rigid bodies, which is why, in addition to mass inertia, damping properties and component stiffness must also be taken into account. Nowadays, this can easily be realized with FEM [BeDH-2018]. For cost reasons, the focus in today's development is increasingly shifting from real experiments to simulations. Especially, in the automotive sector, driving distance load spectra are often determined by simulation. But even simulation cannot be performed completely without measurement data. Using the example of a vehicle, route, vehicle and driver data must be determined and used as input data for the simulation in order to determine the load-time record. Figure 13.12 shows a load-time record of a reference section with highway and city sections determined by simulation [BeDH-2018].

For further use, the mostly highly dynamic load-time records must be converted into a manageable format by means of counting methods. As the name suggests, the counting method counts the number of amplitudes (and in some cases the mean value) from the load-time records and classifies them into groups so that a load spectrum is created. Rainflow counting has become established for structural failure, since the counting system is strongly based on the expression of stress–strain hystereses [BeDH-2018, Naun-2019].

With the help of the representative load spectra, the failure behaviour can be determined by life tests and evaluated by a Weibull analysis. There are different life testing strategies, which pursue different targets. If appropriate boundary conditions

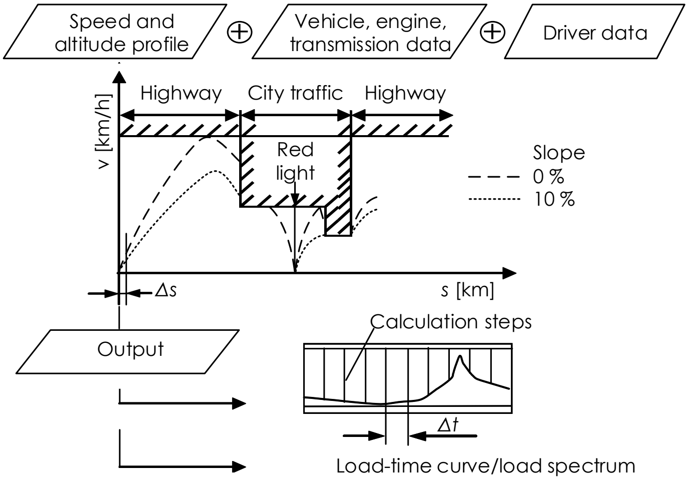

Fig. 13.12 Simulative determination of a load-time record (bottom right) using the example of a vehicle [BeDH-2018]

and objectives exist, the test strategy should be adapted accordingly. In the draft phase of a product, in which its product concept is not yet exactly defined, the reasons for a test are, e.g. [Yang-2007]:

- Comparison and evaluation of different components and materials
- Determination of optimal design alternatives
- Confirmation of the effect of a design change in terms of reliability.

In order to achieve the objectives above, information on product failure behaviour is needed, which is determined on the basis of (targeted) product failures. For this reason, only failure-based test strategies (end-of-life tests; EoL tests) can be used. Once the design is detailed and defined, prototypes can be tested under near-series production conditions for estimation or for demonstration and verification of product reliability [Yang-2007]. In addition to the EoL tests, failure-free test strategies with predefined runtimes, such as the Success Run Test, can also be used to prove a certain minimal reliability at a certain point in time. Figure 13.13 shows the most common representatives of these test strategies and their reasons in the overall context of the product development process.

The non-censored test is the simplest test strategy to perform an EoL lifetime test. All test specimens of the selected sample are specifically brought to failure, and from this, the failure behaviour is determined using Weibull analysis. Due to many failures generated, the statistical information content is highest, because the probability of identifying both long and short runners is high, allowing precise estimates of the Weibull distribution. The relatively high expenditure stands in contrast to this, since products with a large scatter may have to be tested for a very long time.

If the life test is aborted after a predefined time, this is referred as a time or type I censored test. From a sample with n test items, only f failures are generated instead

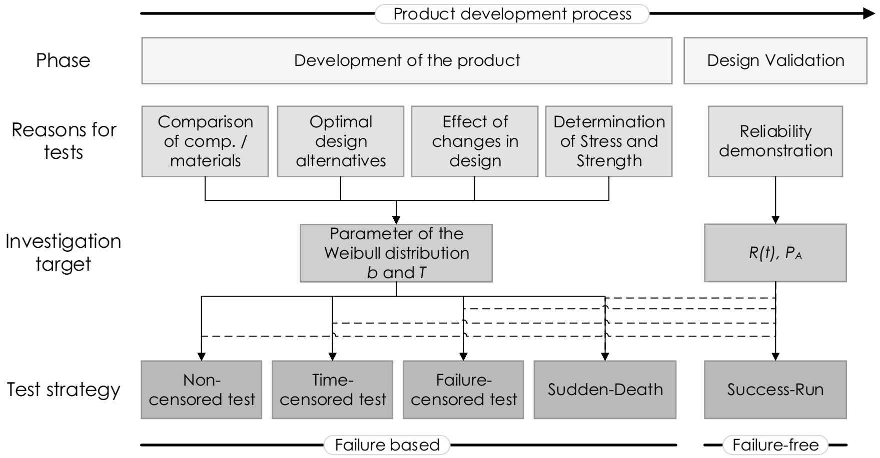

Fig. 13.13 Reliability test strategies and their reasons [Daze-2019]

of *n* failures. Samples that are still intact at the time of censoring are removed from the test bench.

The only difference to the Failure or Type II censored test is the censoring criterion. The test is finished as soon as a certain number of failures has been reached. The biggest disadvantage of this test strategy is the high number of necessary test benches, as the test specimens have to be tested simultaneously.

When evaluating censored tests in the Weibull analysis, it should be noted that the survival probabilities of the suspensions can only be considered with the maximum likelihood method [MeEs-1998, Nels-2005]. The runtimes of the suspensions then assume the runtimes of the censoring time for Type I censored tests and the runtimes of the last failure for Type II censored tests. For valid results in the Weibull analysis, the running times of the intact units must always be taken into account, because otherwise, the information is lost that a proportion of test specimens was still intact at the time of termination with the corresponding running performance or load.

Multiple censoring is a special form of the Type II censored test when more test specimens are used than there are test benches available [BeLe-2004]. Multiple censored data can be evaluated with the Sudden-Death System [BeLe-2004]. Figure 13.14 shows an overview of the differences between the described test strategies. For a detailed description of EoL test strategies, please refer to the literature of Bertsche, Meeker and Nelson [BeLe-2004, MeEs-1998, Nels-2005].

In addition to the EoL test strategies, there are also failure-free test strategies with predefined runtimes. The Success Run Test is the best-known representative of these test strategies. All test specimens are tested up to a pre-defined runtime in order to demonstrate a certain minimum reliability of the product. If all test items remain intact until the test time, the test is successful. In contrast to the EoL test strategies, the Success Run cannot be used to make statements about the failure behaviour of the product, since no Weibull straight can be determined without failures. The Success

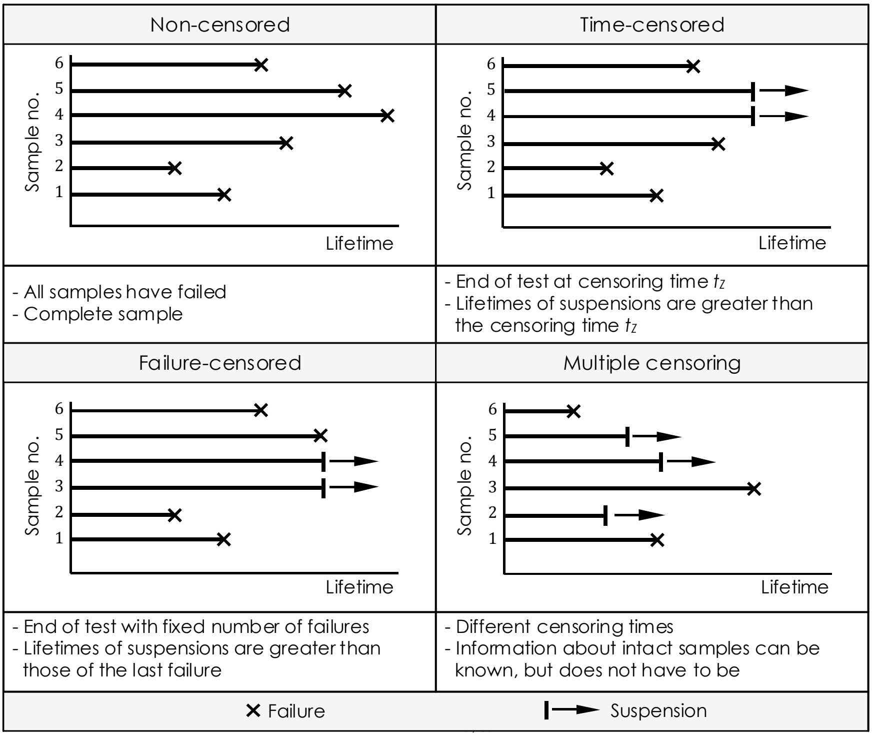

Fig. 13.14 Overview of different test strategies and censoring methods, based on [BeLe-2004]

Run is therefore often used for a reliability proof at the end of the development process, in which it must be proven that the product meets the reliability requirements. If the demonstrated minimum reliability of the Success Run Test is above the specified requirements, the proof of reliability is successful. Due to the fact that only a minimum reliability results from the Success Run, no statement can be made about the actual product reliability.

The general idea of the Success Run Test is based on the binomial equation, with which the necessary sample size n can be easily calculated for defined requirements on reliability $R(t)$ and confidence P_A at a certain point in time [BeLe-2004]:

$$n = \frac{\ln(1 - P_A)}{\ln(R(t))}. \tag{13.6}$$

Life tests can only be carried out on a sample basis as it is practically impossible to test the population. The reliability is needed to quantify the uncertainty of the statement, since the results are only obtained with the help of sampling information. If, for example, a customer's specifications require a minimum reliability of 90% for a gearbox of 100,000 km with a confidence of 90%, 22 samples are necessary to be tested up to 100,000 km tested without failure to verify the requirement. If, due to capacity bottlenecks or tight schedules, it is not possible to test to the target lifetime, the so-called lifetime ratio can be used, which is calculated as the ratio of the test time to the required lifetime:

$$L_V = \frac{t_P}{t_{\text{req}}}. \tag{13.7}$$

The required sample size n for a Success Run test with a higher or lower test time is calculated using the binomial equation:

$$n = \frac{\ln(1 - P_A)}{\ln(R(t))} \cdot \frac{1}{L_V^b}. \tag{13.8}$$

Therefore, from a statistical point of view, fewer specimens have to be tested using a higher lifetime ratio. The shape parameter b of the Weibull distribution must also be known. Since Success Run Tests do not calculate a Weibull distribution but only a minimum reliability, this is often difficult. For this reason, the information content of a Success Run Test is significantly lower compared to the failure-based test strategies, since no knowledge can be gained about the failure behaviour of the product [Daze-2019]. The EoL test strategies can also be used for reliability verification. As often mistakenly assumed, this does not necessarily require a Success Run Test. If the upper confidence limit is located to the right of the requirement (probability of failure *F(t)* at target life t_{req}) or exactly on top of it, the proof of reliability has also been successfully demonstrated with an EoL test, Fig. 13.15. If the requirement is located within the confidence interval, then the proof has failed.

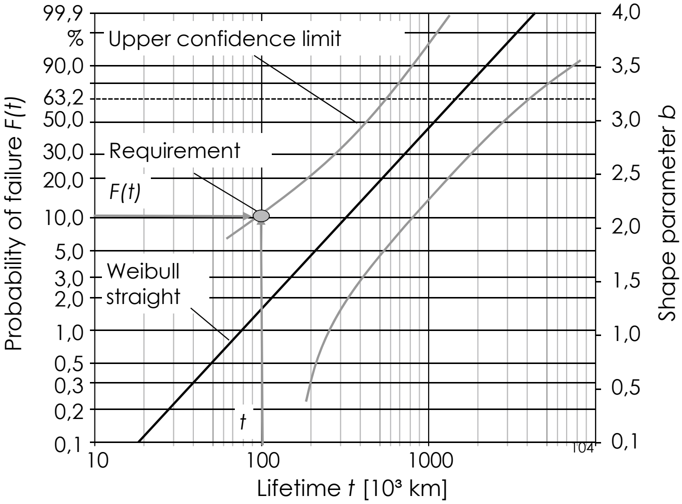

Fig. 13.15 Proof of reliability in the Weibull network [Daze-2019]

Due to its simple planning ability based on the binomial equation, the Success Run is very often used in industrial practice. In contrast, the planning of EoL tests is more difficult, since costs and time depend directly on the scattering lifetimes and thus make it more difficult to estimate the costs. For this reason, HERZIG and DAZER examined all test strategies in a reliability DOE for different boundary conditions such as test infrastructure, product over-sizing or different reliability requirements and classified them in the trade-off between probability of success, costs and time [Daze-2019, DBLB-2018, Herz-2019]. In this context, the probability of success represents the accuracy aspect and indicates the probability with which a test configuration is able to demonstrate reliability successfully. This enables efficient and requirement-compliant planning of life tests with individual boundary conditions. Product over-sizing can also be taken into account for the planning of life tests. This can be understood as a relative deviation from the requirement and the actual product failure behaviour (e.g. taken out of prior knowledge) and is of central importance for efficient life test planning, Fig. 13.16. The closer the requirement comes to the real reliability, the higher the testing effort, because the requirement can only be proven by narrow confidence intervals.

Figure 13.17 shows a cost comparison of different test strategies for different design concepts or over-sizing. The test cost consists of the cost for the procurement of all test items and the runtime cost for the operation of the test bench. For a valid comparison, the total test cost is standardized as a multiple of the cost of one specimen. The processes represent the cost-optimized configuration of each test strategy, which just reaches the required probability of success of 90% for the proof of reliability.

Figure 13.17 immediately shows the areas for which the Success Run is predestined—high over-sizing. If the over-sizing falls below 70%, the Success Run will no longer meet the requirements without approved failures. The easy plannability of the Success Run Test is somewhat complicated by the high product over-sizing required to achieve a reasonable probability of success [DBLB-2018]. The Success Run is always successful when all test specimens are still intact at a defined test time. The Success Run can only continue to be applied through approved failures,

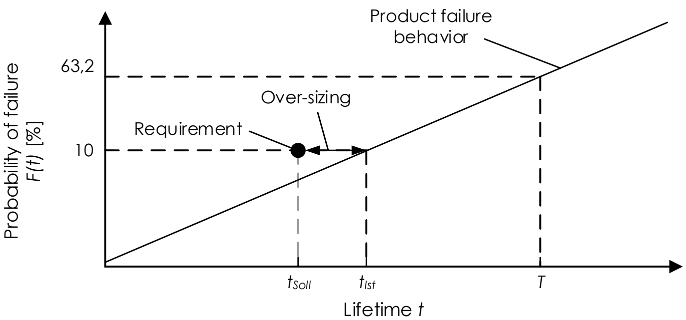

Fig. 13.16 Product oversizing related to service life [Daze-2019]

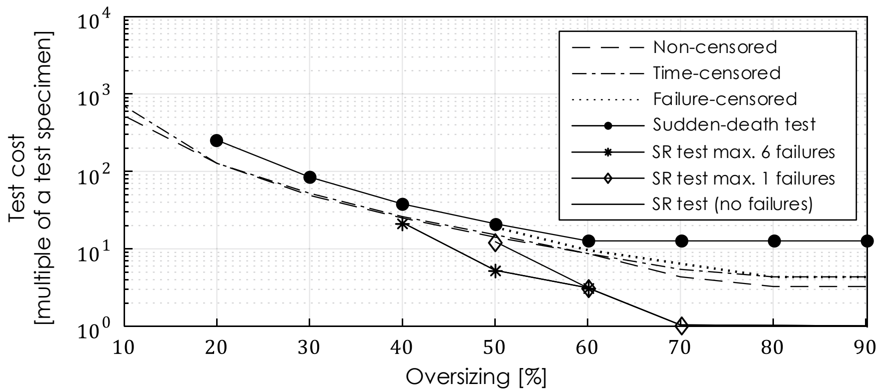

Fig. 13.17 Comparison of test strategies regarding test costs [Daze-2019]

which increases the test cost more than tenfold and almost reaches the cost of the EoL tests, which also provide significantly more information due to their ability to completely map the failure behaviour. The Success Run Test is only applicable to a limited extent for products with an over-sizing between 10 and 40%. Consequently, only EoL tests can be used in these areas of over-sizing.

Reliability can change significantly when changing from the last prototype stage to series production, despite successful verification testing, because series processes often differ from prototype processes. For this reason, the proof of reliability should be performed on a close-to-production product [Naun-2019]. Reliability monitoring of the current reliability parameters during testing allows reliability growth models to be used to make predictions for the further course of testing in order to be able to intervene at an early stage in the event of deficiencies [Kece-1991].

The maintenance of product-specific reliability requires stable manufacturing, assembly and testing processes after the start of series production. Reliability management does not end when the product enters the field, as manufacturers and producers are obliged to monitor the product in accordance with § 833 Para. 1 BGB (German Civil Code). Manufacturers are therefore obliged to monitor their products even after they have entered the market, for example, to check whether the products are being used or misappropriated in the areas for which they are intended. It is advisable to observe the field situation even when the products are used correctly by the end customer, because the field load can never be set exactly the same on the test bench. Thus, differences can occur between the product reliability determined on the test bench and the real field reliability. Statistical analysis of returns is used to make field predictions for warranty cost and risk assessment. With these indicators, decisions on potential recalls can be made as early as possible and the damage minimized [Naun-2019].

13.3 Quality

The term “quality” can include both objective representations and subjective evaluations, as well as those that can be used either neutrally or in an evaluative way [Wahr-1978, Webs-1983].

- Objective representation includes nature, quality and variety of a product. These describe the facts available absolutely and neutrally and do not contain any evaluation of the product.
- The evaluative presentation includes usability, quality and value level, which are dependent on the respective field of application and environment of the product, for which there are usually pre-formulated requirements and (value) standards. These have a relative, subjective and evaluative character. This view corresponds to the definition of DIN ISO 9000:2005, in which quality is defined as the totality of characteristics[12] of a unit with which the requirements specified and assumed with regard to its suitability are fulfilled [DIN-9000].
- The representations, which can be both neutral and evaluative, include (characteristic) properties and capabilities of the product, within IDE both in terms of the expected performance and the performance of the product through its attributes.

Within IDE, quality in the sense of the third mirror point is therefore defined as the current condition (objective) as well as usefulness (subjective) of the combination of the Fulfilment of the product requirements. The requirements serve as a reference framework. In the case of an individual attribute, quality corresponds to the interaction of the nature, extent and quality of the fulfilment of requirements by that attribute. For the entire product with its components, the quality of the product (see also Sect. 3.3) is

- the sum of the individual qualities of each component,
- the additive interaction of the components and
- the synergy of interaction throughout the product.

Quality is not an absolute value, but the relationship between demands and fulfilment, always depending on the respective frame of reference (absolute aspect). Quality is also not a physical quantity, but the sum of relevant features and characteristics in a specific environment (diversity aspect). Their importance varies along the product life cycle, Fig. 13.18.

In the exploratory phase of the potential buyer, in addition to the customer demands on the product, above all, the procurement costs and the delivery date play an important role. This distribution changes only slightly during the product provision phase (product development and production). If the product has been delivered, installed and paid for and the utilization phase has begun, the quality of the fulfilment of all attributes plays the main role, provided that the usability from safety and

[12]Characteristics and properties as defined by Weber [Webe-2005], according to which characteristics can be directly influenced by the product developer (e.g. dimensions and material), while properties result from the interaction of characteristics (e.g. functions and usability)

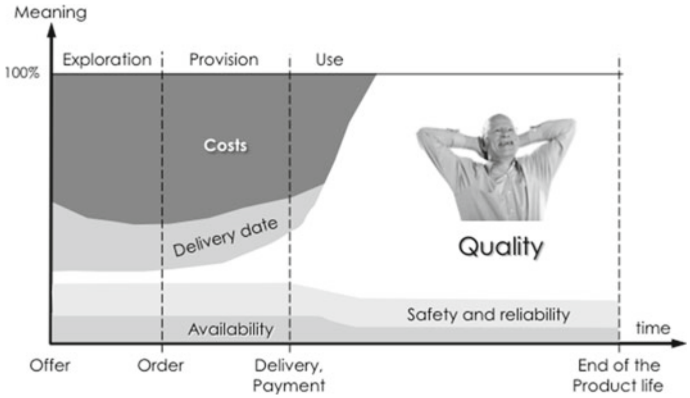

Fig. 13.18 Different meanings of quality (based on [EhMe-2017])

reliability as well as the readiness for use as availability of the product according to the user's expectations is maintained.

There are numerous standards, procedures and strategies for not only achieving the required fulfilment of the attributes in all phases in which the product is developed, manufactured and delivered within the company, but also preserving them in such a way that nothing can be lost during the run through the phases and the product is delivered with exactly the fulfilment that the customer or the market expects.

The efforts to ensure the required quality throughout all phases are summarized under the term *quality assurance*; the organizational measures and tools required for this are summarized under *quality management*[13].

The Total Quality Management (TQM) describes a comprehensive quality philosophy, in which quality is the highest corporate objective. It is based on a comparable, holistic and preventive approach comparable to that IDE uses for product development. In TQM, quality is not only checked at certain points later on by random sampling ("Cinderella principle"), but also already taken into account during the design phase and continuously verified, so that a cost reduction is achieved by reducing rework.

TQM requires a holistic approach to quality in all activities from all parties involved, because not only the quality of the product, but also all services of the company are to be improved, so that a high level of quality can be achieved and maintained. TQM sees itself as a management system within the company and as a preventive quality assurance, in which responsibility is transferred to the person carrying out the work.

Conceptual and strategic decisions made in the early stages of product development lead to far-reaching specifications for the rest of the product life cycle. Similarly,

[13]This field will not be discussed in detail here. Relevant literature is for example [Masi-2007, GeKo-2008], the corresponding standard is DIN EN ISO 9000 Quality Management [DIN-9000].

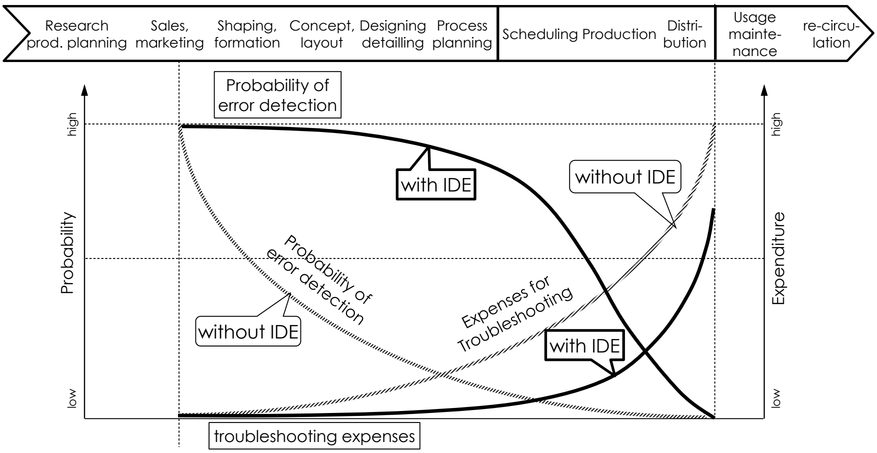

Fig. 13.19 Probability of error detection and effort for error correction

mistakes made in the early stages can lead to extensive damage. The benefit of preventive quality assurance is now to detect these defects as early as possible in order to be able to eliminate them at an early stage and with little effort, Fig. 13.19. Especially for the detection and avoidance of early and random failures during product operation, suitable quality measures are required.

Although the probability of discovering errors decreases as product development progresses (curves "Probability of discovering errors" in Fig. 13.19), the integrative approach of IDE means that this occurs to a much lesser extent than in product development without an IDE. With IDE, the curve of the effort required for troubleshooting also rises much flatter than in product development without IDE. Thus, most errors can be detected and corrected with little effort.

Preventive quality assurance applies suitable methods and tools for its support. Due to their proximity to and good usability within IDE, these include the cause-and-effect diagram (Ishikawa diagram), the Failure Mode and Effect Analysis (FMEA) and the Quality Function Deployment (QFD).

Preventive quality assurance also ensures that the necessary product documents can be handed over in a largely error-free condition at the time of release for production.

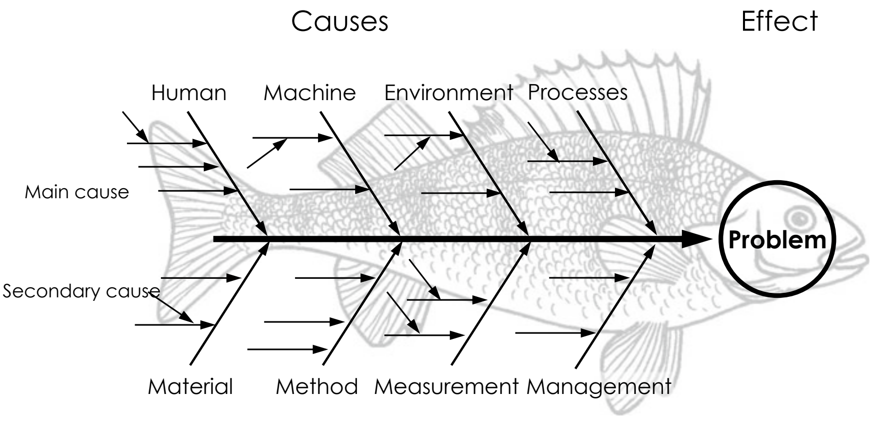

Fig. 13.20 Ishikawa diagram

13.3.1 Ishikawa Diagram

The cause–effect diagram developed[14] by ISHIKAWA can be used both for systematic (and largely complete) failure analysis and for finding solutions [HeTB-1996], Fig. 13.20.

As within IDE for all problems, the diagram is edited in a team. After the problem to be solved has been formulated as a target (at the right end of the "main bones"), inclined cause arrows are now attached from the top and bottom left. The main arrows symbolize the eight influencing factors that are man, material, machine (the "classical" production factors) and proceses as well as of method, environment, management, measurement and processes. If necessary, the inclined arrows can be further detailed by horizontal arrows, these again by inclined arrows, etc., until the problem is completely described based on the eight influencing factors. When searching for a solution, components of the solution (successively detailed) are positioned to the arrows.

[14]In 1943, Kaoru Ishikawa (1915–1989) developed what is often referred to as a "herringbone slide-gram" because of its shape, in order to visualize possible causes that can influence a problem in a structured arrangement.

13.3.2 Failure Mode and Effect Analysis

The Failure Mode and Effect Analysis (FMEA) is based on MURPHY's law[15], the core statement of which is ironically summarized as: Everything that can go wrong will go wrong. For a product this means that it cannot provide the expected performance and performance behaviour if, for example, unforeseen types of use, misuse or accidental influences occur. FMEA is probably the best-known qualitative quality or reliability method [BeLe-2004]. Originally developed by NASA for the Apollo project in 1963, Ford was the first automotive company to introduce FMEA into its quality process in 1978. Today, FMEA is widely used in a wide range of industrial fields.

FMEA is a preventive qualitative method for systematically identifying, recording and reducing potential risks, problems and errors. The aim is to identify risks as early as possible in the development process in order to be able to implement suitable improvement measures [BeLe-2004]. In order to record the actual state of the product, a system and weak point analysis must first be carried out, and the results of which (components and their relationships) are entered FMEA sheet. This is followed by the prioritization and selection of those components that have the highest risk of failure, so that potential errors can be analysed and assessed for influence and severity. On this basis, countermeasures can be selected and evaluated in order to then implement the measures. FMEA therefore deals not only with the possible risks but also with the consequences and their causes.

13.3.3 Quality Function Deployment

Quality Function Deployment (QFD) supplies the assignment of characteristics of a product that the customer wants to have to characteristics of this product that the vendor with aim of developing and manufacturing products according to customer requirements, Fig. 13.21. For this purpose, individual matrices are combined in QFD to form the "House of Quality", which in Fig. 13.21 are marked with the numbers 1-6 and which have the following contents[16].

- In matrix 1, the requirements are formulated and weighted. IDE contains the attribute profile (target profile) expected from the customer's point of view as shown in Fig. 3.13. Usually, there is no specification how the target profile should be implemented.
- In the second matrix, the resulting attributes are derived from the provider's point of view (actual profile), also without reference to a concrete implementation.

[15]Captain Edward A. MURPHY (1908–1990) worked as an engineer in the American Air Force. During tests to measure the maximum acceleration of gravity a human being can withstand, he formulated the law later named after him in about 1949 on the basis of erroneous measurements in which errors had occurred due to human negligence and incapacity.

[16]Very detailed descriptions of the QFD and its further possibilities (which are not discussed here) can be found at HEHENBERGER [Hehe-2011] and SAATWEBER [Saat-2016].

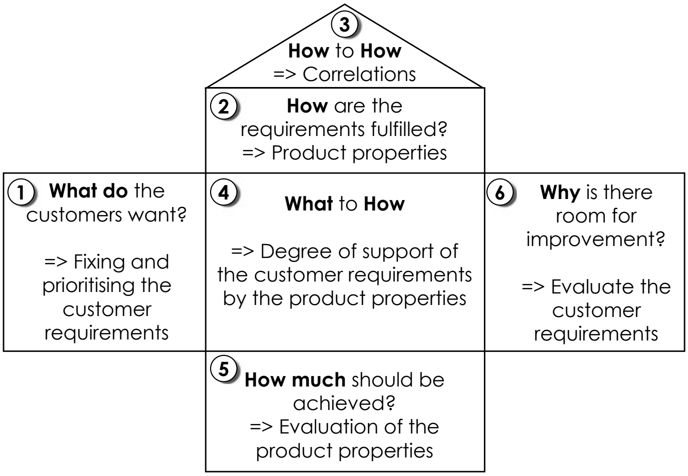

Fig. 13.21 Scheme of the “House of Quality”

Instead of the *availability* attribute used in Matrix 1, the *producibility* attribute must be included here.

- Matrix 3 contains the implementation of producibility with the possibilities of the supplier. It is here that it is decided whether the product can be produced with the facilities and possibilities available at the supplier, whether new technologies have to be procured or (partially) outsourced to third parties and whether the product can achieve an attractive level of profitability.
- Matrix 4 contains the possible fulfilments of the individual attributes by the provider.
- Matrix 5 puts the achievable fulfilments from matrix 4 (as-is profile) in relation to the target profile of the attributes from matrix 1, i.e. the overlapping representation from Fig. 3.13. In the case of a capital good, there should be no differences between the actual and target profile. In the case of a consumer product, provided that the minimum profile for the target market is met, differences may occur which should lead to better defence against competitors. This step forms the transition to
- Matrix 6, in which a re-evaluation of the target profile of the customer’s attributes can be carried out if necessary, compare Fig. 3.15.

13.4 Interaction of the Fulfilment Attributes During Usage

Figure 13.22 shows a form of interaction between the fulfilment attributes safety, reliability and quality.

The actual profile of the attributes, that is, performance and performance of the product delivered to the customer, is composed of the minimum compliance for product safety, the minimum compliance for its reliability and the quality as a

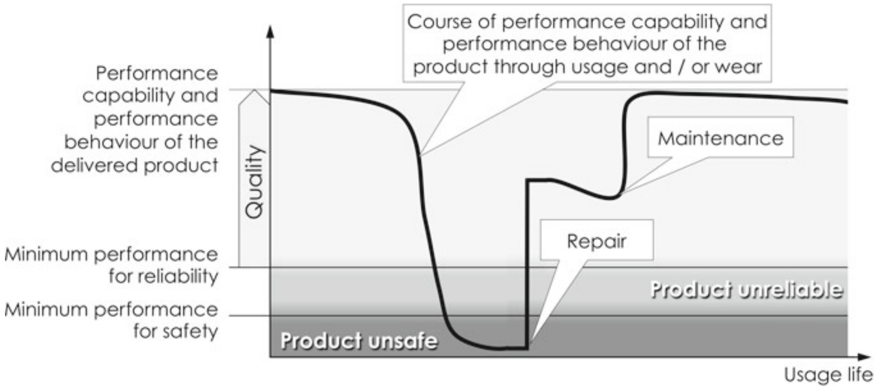

Fig. 13.22 Interaction of the attributes safety, reliability and quality

description of the current performance and performance of the combination of the compliance of the product requirements by the attributes.

As shown in Fig. 13.22 an example, the product has the expected performance and performance behaviour at the beginning of its useful life and it is safe and reliable. Use and the resulting wear and tear of the product can change the course of performance and performance behaviour, in the first case shown in Fig. 13.22 such an extent that repair of the product is necessary to restore to achieve reasonably useful performance and behaviour. In the second case in Fig. 13.22, maintenance of the product is sufficient to return to the initial level of performance and performance.

References

[BeDH-2018] Bertsche, B., Dazer, M., Henß, M.: Handbuch Konstruktion, Betriebsfestigkeit und Systemzuverlässigkeit, 2nd edn. Hanser-Verlag, München (2018)

[BeLe-2004] Bertsche, B., Lechner, G.: Zuverlässigkeit im Fahrzeug- und Maschinenbau, 3rd edn. Springer-Verlag, Heidelberg (2004)

[BeTh-1999] Bergmann, J., Thumser, R.: Synthetische Wöhlerlinien für Eisenwerkstoffe. Verlag und Vertriebsgesellschaft mbH, Düsseldorf (1999)

[BMU-2009] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Hrsg.): Sicherheitskriterien für Kernkraftwerke. Revision D (2009)

[Bromb-2011] Bromba, M.: Was ist Sicherheit? - Versuch einer Definition. http://www.bromba.com/knowhow/sicherh.htm, Zugriff am 15 Oct 2019

[Daze-2019] Dazer, M.: Zuverlässigkeitstestplanung mit Berücksichtigung von Vorwissen aus stochastischen Lebensdauerberechnungen. Dissertation, Stuttgart: Berichte aus dem Institut für Maschinenelemente (2019)

[DBLB-2018] Dazer, M., Bräutigam, D., Leopold, T., Bertsche, B.: Optimal planning of reliability life tests considering prior knowledge. Proc. RAMS 2018, 22 Jan to 25 Jan 2018, Reno, USA, https://doi.org/10.1109/ram.2018.8463098

[DIN-31000] DIN ISO 31000, Allgemeine Leitsätze für das sicherheitsgerechte Gestalten von Produkten. Stand: Mai 2011. Beuth-Verlag Berlin (2011)

[DIN-40041] DIN 40041, Zuverlässigkeit elektrischer Bauelemente, as of December 1990. Beuth Berlin (1990)

[DIN-60300] Deutsches Institut für Normung (DIN): DIN 60300 – Zuverlässigkeitsmanagement – Teil 1: Zuverlässigkeitsmanagementsysteme (IEC 60300-1), Berlin: Beuth-Verlag, 2004

[DIN-9000] DIN EN ISO 9000, Qualitätsmanagement – Grundlagen und Begriffe, as of December 2005. Beuth Berlin (2005)

[EEC-1985] Council Directive 85/374/EEC of 25 July 1985: Liability for Defective Products

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, 6th revised and enhanced edition. Hanser München (2017)

[Euro-2009] Europäische Kommission (Hsg.): Richtlinie 2001/95/EC, Artikel 12, ABI L22 (2009)

[GeKo-2008] Geiger, W., Kotte, W.: Handbuch Qualität - Grundlagen und Elemente des Qualitätsmanagements: Systeme – Perspektiven. 5. Auflage. Springer – Vieweg (2008)

[HaGo-2004] Hales, C., Gooch, S.: Managing Engineering Design, 2nd edn. Springer, London (2004)

[Haib-2006] Haibach, E.: Betriebsfestigkeit. Springer, Verfahren und Daten zur Bauteilberechnung, Berlin (2006)

[HeDB-2019] Herzig, T., Dazer, M., Bertsche, B.: Zuverlässigkeitsabsicherung ressourcenschonender Produkte durch effiziente Erprobungsplanung. Stuttgarter Symposium für Produktentwicklung 16 May—17 May 2019, Stuttgart (in print)

[Hehe-2011] Hehenberger, P.: Computerunterstützte Fertigung – Eine kompakte Einführung. Springer, Heidelberg (2011)

[HeHi-2018] Heidinger, F., Hildebrandt, T. et al.: Simulation based powernet analysis regarding efficiency and reliability—truck battery analysis as an example. 8. Internationaler VDI-Kongress: MarketPlace 2018, 16 Oct to 17 Oct 2018, Baden-Baden, Deutschland

[Herz-2019] Herzig, T. et al.: Cost- and Time-effective Planning of Accelerated Reliability Demonstration Tests—A new Approach of comparing the Expenditure of Success Run and End-of-Life Tests. RAMS 2019, 28 Jan to 31 Jan 2019, Orlando, USA

[HeTB-1996] Hering, E., Triemel, J., Blank, H.P. (Herausgeber): Qualitätssicherung für Ingenieure. VDI-Verlag Düsseldorf (1996)

[Hubk-1984] Hubka, V.: Theorie Technischer Systeme – Grundlagen einer wissenschaftlichen Konstrukti-onslehre. Springer, Berlin Heidelberg (1984)

[IEC-61508] International Electrotechnical Commission (IEC): IEC61508: Funktionale Sicherheit sicherheitsbezogener elektrischer/elektronischer/programmierbarer elektronischer Systeme

[ISO-13849] Internationale Organisation für Normung (ISO): ISO13849: Safety of machinery

[ISO-26262] Internationale Organisation für Normung (ISO): ISO26262: Road vehicles—Functional safety

[Kece-1991] Kececioglu, D.B.: Reliability Engineering Handbook, vol. 2, 4th edn. Prentice-Hall, New Jersey (1991)

[Kern-2016] Kerntechnischer Ausschuss (KTA): Sicherheitstechnische Regel des KTA 3201.1: Komponenten des Primärkreises von Leichtwasserreaktoren. Teil 1: Werkstoffe und Erzeugnisformen, Salzgitter, KTA-Handbuch (2016)

[KGGO-2017] Krause, D., Gebhardt, N., Greve, E., Oltmann, J., Schwenke, J., Spallek, J.: New trends in the design methodology of modularization. In: Vajna, S. (ed.) Proccedings of the 11th International Workshop on Integrated Design Engineering, Magdeburg 2017, Seiten, pp. 49–60

[LDHB-2019] Lucan, K., Dazer, M., Hintz, K., Bertsche, B.: Effect of Competing Failure Modes on the System Reliability Estimation. RAMS 2019, 28 Jan to 31 Jan 2019, Orlando, USA

[LDWB-2018] Lucan, K., Dazer, M., Waller, J., Bertsche, B.: Analysis of the Weibull Estimation for Competing Failure Modes. Proc. RAMS 2018, 22 Jan to 25 Jan 2018, Reno, USA, https://doi.org/10.1109/ram.2018.8463053

[LuHB-2017] Lucan, K., Henß, M., Bertsche, B.: Working group cv-brakes—procedure for a commercial vehicle brakes' standard. Proceeding of the 2017 Eurobrake Conference (2017)

[Masi-2007] Masing, W.: Handbuch Qualitätsmanagement, 5. Auflage. Herausgegeben von T. Pfeiffer und R. Schmitt. Hanser München (2007)

[MeEs-1998] Meeker, W.Q., Escobar, L.A.: Statistical methods for reliability data. Wiley, New York, NY (1998)

[MePe-1984] Meyna, A., Peters, O.: Handbuch der Sicherheitstechnik, Band 1. Hanser München (1984)

[Müll-2015] Müller, J.R.: Die formalisierte Terminologie der Verlässlichkeit technischer Systeme. Springer Vieweg, Berlin (2015)

[Naun-2019] Naunheimer, H. et. al.: Fahrzeuggetriebe, Grundlagen, Auswahl, Auslegung und Konstruktion. 3. Auflage (2019, in print)

[Nels-2005] Nelson, W.B.: Applied life data analysis. Wiley-Interscience, Hoboken, NJ (2005)

[Rada-2007] Radaj, D.: Ermüdungsfestigkeit. Birkhäuser - Verlag für Architektur, Grundlagen für Ingenieure, Basel (2007)

[Renn-2012] Rennert, R., et al.: Rechnerischer Festigkeitsnachweis für Maschinenbauteile. VDMA Verlag GmbH, Frankfurt am Main (2012)

[Saat-2016] Saatweber, J.: Produkte entwickeln mit Quality Function Deployment. In: Lindemann, U. (Hsg.) Handbuch Produktentwicklung. Hanser 2016, Seiten 629–671

[SaHe-2006] Sachs, L., Hedderich, J.: Angewandte Statistik. 12, vollst. neu bearb. Aufl., Springer, Berlin, Heidelberg (2006)

[StSM-2017] Storga, M., Skec, S., Marjanovic, D.: Failure identification and analysis methods for engineering design. In: Vajna, S. (ed.) Proccedings of the 11th International Workshop on Integrated Design Engineering, Magdeburg 2017, Seiten, pp. 135–143

[Timo-2002] Timoshenko, S.P.: Strength of materials, 3rd ed., repr. CBS Publishers & Distributors, New Delhi (2002)

[USDe-1995] U.S. Department of Defense (Hrsg.) MIL-HDBK-217F Notice 2—Reliability Prediction Of Electronic Equipment (1995)

[VDA-2016] Verband der Automobilindustrie e.V.: Qualitätsmanagement in der Automobilindustrie. Zuverlässigkeitsabsicherung bei Automobilherstellern und Lieferanten. 4. Auflage. Frankfurt am Main: VDA-QMC (2016)

[VDI-3542] VDI-Richtlinie 3542 Blatt 4 (zurückgezogen): Sicherheitstechnische Begriffe für Automatisierungssysteme - Zuverlässigkeit und Sicherheit komplexer Systeme (Begriffe). VDI-Düsseldorf (2015)

[VDI-4003] Verein Deutscher Ingenieure (VDI): VDI-Richtlinie 4003 – Zuverlässigkeitsmanagement, Düsseldorf: VDI-Verlage (2007)

[Wahr-1978] Wahrig, G.: Deutsches Wörterbuch. Bertelsmann Lexikon-Verlag Gütersloh (1978)

[Webs-1983] Webster's New Universal Unabridged Dictionary: Simon and Schuster, 2nd edn. New York (1983)

[Webe-2005] Weber, C.: CPM/PDD—An extended theoretical approach to modelling products and product development processes, 2nd German-Israeli symposium on advances in methods and systems for development of products and processes, Berlin 2005. In: Bley, H., Jansen, H., Krause, F.-L., Shpitalni, M. (Hrsg.) Proceedings of the 2nd German-Israeli Symposium, Fraunhofer-IRB-Verlag, Stuttgart, S. 159–179 (2005)

[Weib-1951] Weibull, W.: A Statistical Distribution Function of Wide Applicability. Journal of Applied Mechanics, S. 293–297 (1951)

[Yang-2007] Yang, G.: Life cycle reliability engineering. Wiley, Hoboken (2007) https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31985L0374:en:HTML (Zugriff am 16 Dec 2018)

Chapter 14
Department Integration

Sándor Vajna

The integration of departments within IDE ensures that knowledge and information in the form of results, decisions, effects, and influences can flow from product development to all other areas of the product life cycle and back. This is achieved primarily by employees from the areas in question, then by organizational, methodical, and technical measures.

The departments of IDE that are supported by the information flow use different methods of modelling, simulation, and evaluation to develop such products that not only meet customer requirements (manifested in the target profile of the attributes) but are also designed in such a way that they can be sensibly and economically generated, distributed, used, and traced back in the departments after production release. The interplay between modelling, simulation, and evaluation of future events and the associated decisions is also known as *predictive engineering* [Wart-2000]. This results in a forward shift or front loading of decisions on issues and activities from production, product use, and product exploitation to product development (Figs. 1.1 and 2.10).

In order to make well-founded forecasts and decisions, product development (as reinsurance requires) advance information on existing technologies and processes as well as feedback from decisions made in advance. This process is also known as *reverse engineering*[1]. This is the only way to model, simulate, and evaluate decisions and their effects as realistically and completely as possible.

When applying front loading, as many activities as possible should be shifted to product development so that necessary decisions can be made at the latest possible point in time, i.e., in the case of a real product shortly before release for production,

[1]Reverse engineering is also a popular approach in highly competitive markets. Whenever a company launches a new product, it is bought by the competition and broken down into its component parts to determine where the technical progress can be found in it.

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when programming a software shortly before its implementation and testing, so that, on the one hand, previously made change requests can be taken into account by modelling and simulation and, on the other hand, the resulting change effort is kept within limits. This is possible because product development within IDE, supported by the information flow, can consider possible change requests of product concepts and product models much easier and cheaper than it is the case in the departments dominated by material flow after production release [Otto-1996].

The aim of IDE is to release only those products for production in which there are no more inconsistencies and errors, so that production and further phases of the product life cycle can run as required and as much as possible without disruptions, as long as there are no further external influences, for example, in the form of changed conditions from the environment of the product. The additional expenditure caused by front loading, forecasting, and reinsurance is more than saved in the subsequent departments because (as many practical examples show) the modelling, calculation, and simulation of the resulting product in advance results in significantly fewer errors than with the conventional approach.

As already stated in [Wien-1970] (Fig. 1.1), 75% of the later total costs of the product are already determined in the product development stage by the interaction of advance, forecast, and reinsurance, as well as about 2/3 of the production costs, which are determined in process planning by the selection of manufacturing and assembly methods.

A comparable cycle is evident in the financial flows within the company, since both monetary (e.g., CAx systems) and intangible investments (e.g., level of qualification and the knowledge and creativity of employees) are primarily made in product development. These investments lead to performance and quality improvements in the departments following the release for production. To this extent, product development always involves advance financial investment. The different benefits arising in production, product use, and recycling serve as "remittances," which lead to compensation for the investments made in product development.

The integration of the individual departments of the product lifecycle takes place

- primarily by the members of project teams within IDE and, if necessary, by additional employees, who contribute their respective knowledge from the various departments of the product life cycle (see also Chap. 17),
- by the use of integrating methods for topic-oriented development under the collective terms Design for X (with "X" as a placeholder for different departments at the supplier and/or topics, e.g., X = manufacturing, then DfX is "Design for Production"[2]) [Meer-1994, BoDe-2003] and X for Design (where the "X" is the same placeholder) [GaGa-2015], combined with the transfer of the necessary knowledge, and

[2]In this context, "Design for X" should be understood as "suitable to rules and conditions of an area X." In this context Design for Manufacturing (DfM) stands for a design work suitable for manufacturing. Within IDE, however, influences on production, product use, and recycling are defined in all areas of product development, so that the term *development* is used here. DfM is therefore translated within IDE as *development suitable for manufacturing.*

- by technical measures through networking and computer support applications and systems

In the following, methodological integration is presented first, followed by organizational and technical integration forms and tools.

14.1 Methodical Department Integration

The methodical department integration is carried out via control systems with which requirements for properties, specifications, restrictions, and procedures as well as the associated knowledge from other departments can be transferred into IDE and taken into account in the development of the product. A requirement, a specification, a restriction, or a procedure should not be changed neither by their content nor by their structure and consistency. By taking these into account, it is to be ensured that the product is designed in such a way that it can provide the planned and required performance in the intended environment for the respective department. In addition, by front loading into IDE, a simplification of specifications and activities in the respective department should be achieved. In this context, it is inevitable that requirements and rules may also contradict each other (see Sect. 14.1.1.5). In such a case, a synthesis of the conflicting topics must be found. Ultimately, the application of these rules and requirements results in a multi-criteria optimization (for their possible solution with the Autogenetic Design Theory see Sect. 1.7. The two options "Design for X" and "X for Design" differ as follows, Fig. 14.1:

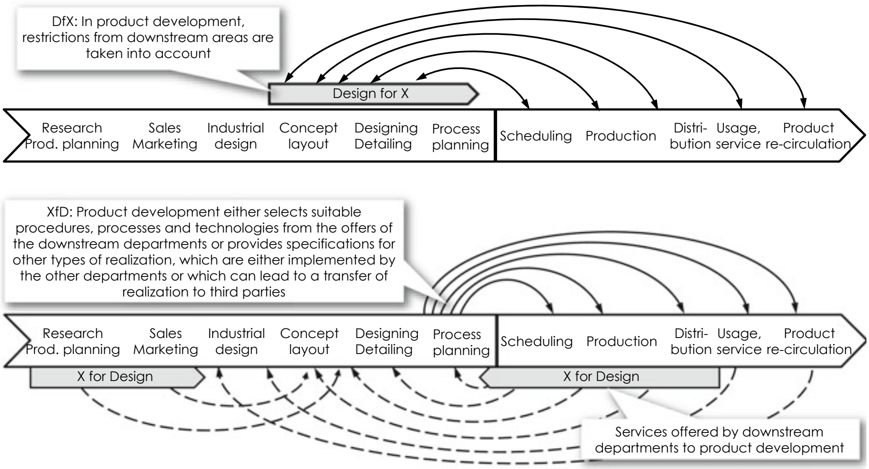

Fig. 14.1 Methodical department integration with DfX (upper half of the figure) and XfD (lower half of the figure)

- In Design for X, the solution, which becomes increasingly concrete during product development, is adapted step by step to the possibilities of the downstream departments in the product life cycle by continuously taking into account specifications (e.g., available production technologies, workspaces) from the downstream departments, which can lead to limitations in the quality of the solution. This adaptation is verified for feasibility, completeness, and consistency at the latest in process planning before release for production can take place.
- With X for Design, all other departments make their product realization capabilities available as a service offering during the entire product development process. The product development department can either take these into account when concretizing the solution or instead formulate requirements that can lead to a change in the realization possibilities, for example, by procuring other production facilities or by (partially) outsourcing the realization to third parties.

14.1.1 Design for X

Suitabilities can be linked to the attributes within IDE in a variety of ways. Figure 14.2 shows such a selection (see also Fig. 1.21).

The individual suitabilities occur in the following departments:

- Research and product planning: Research for Development (RfD).
- Sales and marketing: Marketing for Development (MfD), Marketing for Research (MfR), see also Chap. 21.
- Design: Design for Marketing (DfMk).
- Product attributes: Design for Aesthetics (DfAe, Chap. 6), Design for Functionality (DfF, Chapt. 7), Design for Ergonomics (DfE, Chapt. 8), Design for Usability (DfU, Chap. 8 and Sect. 15.4, Design for Manufacturing (DfM), Design for Assembly (DfA), Design for Logistics (DfL; see for DfM, DfA and DfL also Chapt. 9), Design for Maintenance (DfMt, Chapt.11), Design for Sustainability (DfSu, Chaps. 5 und 12) and, as subset of Design for Sustainability, Design for Disassembly and Recycling (DDR).

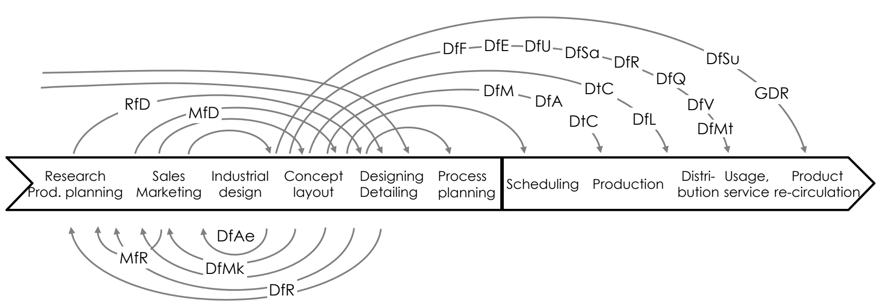

Fig. 14.2 Suitabilities within IDE

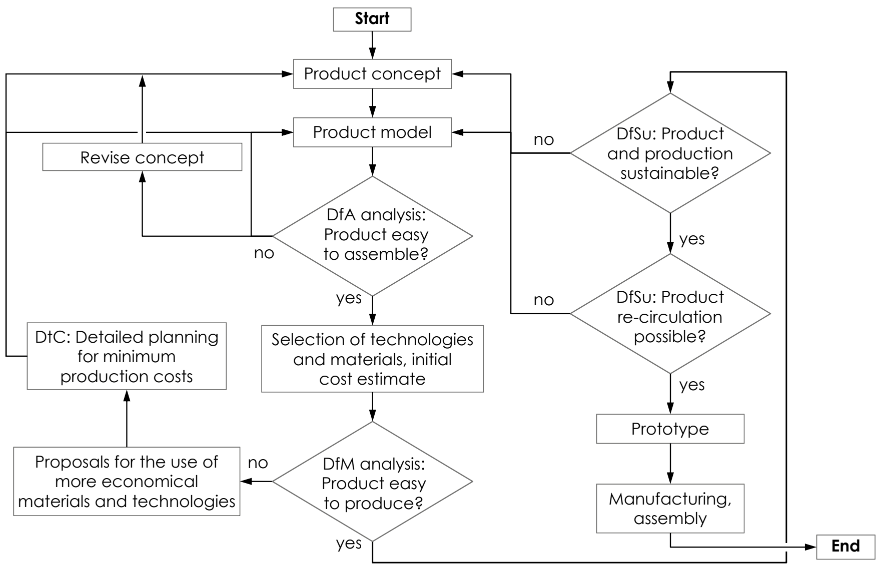

Fig. 14.3 Interplay of the suitabilities DfA, DfM, DtC, and DfSu

- Fulfillment attributes: Design for Safety (DfSa), Design for Reliability (DfR), Design for Quality (DfQ), see also Chap. 13.
- Economic efficiency: Design for Added Value (DfV), Design to Cost (DtC), see also Chap. 25.

All suitabilities are linked together and influence each other. Figure 14.3 shows examples of the interaction of DfM, DfA, DfSu, and DtC and the resulting effects when designing a product. This mutual influence can lead to inconsistencies of the respective partial models in the individual CAx systems, especially if the product is modelled with CAx systems and the effect of tolerances is checked with simulation systems[3].

The first concrete decisions for the later realisation of the product are made at DfX by starting with the phase of Layout and (detail) Engineering design. The subsequent on-going adaptation of the developing solution to the conditions in the departments after release for production generally leads to restrictions in the possible variety and quality of solutions, because during the increasing concretization, only those (partial) solutions may be used that can also be realized in the downstream departments, Fig. 14.4.

In the following sections, examples of suitability to assembly, suitability to manufacturing, and cost-effective development will be discussed. A detailed description of DfX can be found in [Meer-1994, EhMe-2017].

[3]Such optimization problems can also be solved with the Autogenetic Design Theory (Sect .1.7 and [VaKB-2011]).

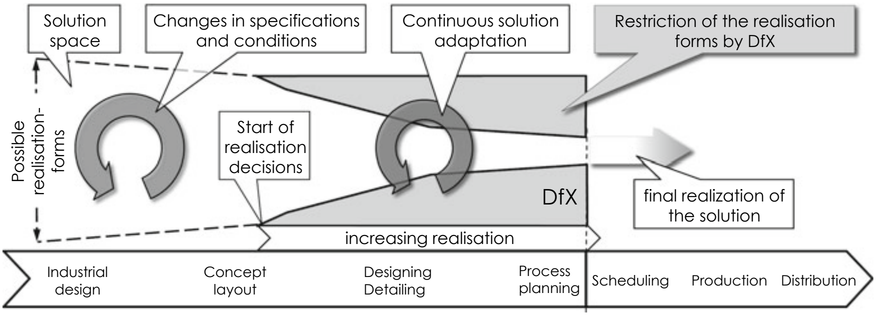

Fig. 14.4 Schematic procedure of a product development with DfX

14.1.1.1 Integration of the Departments Before Product Development

Prior to product development, product planning, including research, creation of the product portfolio and marketing and sales, is carried out with varying degrees of intensity. Product planning and product development influence each other as follows.

- With its work, research provides the basis for innovations in products and processes for IDE (RfD, Research for Development), both within the current product portfolio and for strategic concepts. Conversely, IDE hands over such tasks, which cannot be solved within the framework of "normal" development, but only in principle or in the medium to long term, in a form suitable for research, so that suitable solutions can be found in research (DfR, Design for Research, research-suitable development).
- Product planning creates the current product portfolio. This describes (especially in the consumer goods industry) by structure and content the space for existing and possible solutions and their possible chances in the market. If either an order with high profitability is placed or market research discovers a promising need in the market, the portfolio can be changed accordingly, creating new framework conditions. Conversely, the structure of the portfolio is influenced not only by the corporate strategy and the opportunities in the market but also by the current product range with its different service offerings and the possibilities of production.
- In marketing, market research continuously records the needs of the market and feeds this information into both the product portfolio (MfP, Market Research for Product Portfolio, portfolio-oriented market research) and IDE (MfD, Market Research for Development, development-oriented market research). Conversely, robust ideas and concepts from product planning and IDE (DfMk, Design for Marketing, marketing-oriented development) provide the impetus for investigations as to whether and to what extent these ideas and concepts are fundamentally suitable for placement in the market and at what expense they may need to be adapted. Marketing is dealt with in detail in Chap. 21.

- Sales can only successfully acquire customers if a suitable product range, or one that can be adapted at economically justifiable expense, as well as viable ideas and concepts are available that can be implemented with appropriate use of resources. In addition, the sales department draws on the results of market research and the statements of resource planning. It is the link between product planning and product development.

The integration of the departments prior to product development ensures that not only customer demands and requirements from the later application environment of the product (recorded in the target profile of the attributes) but also all other influences from external and internal environments can be fully taken into account, even if these may be subject to dynamics.

14.1.1.2 Design for Manufacturing (DfM)

In the case of a product suitable for manufacturing, the aim is to use manufacturing processes that are as simple and as well controlled as possible. Simple manufacturing processes for a tangible product usually

- result as a consequence of a structured product design with largely standardized modules and product families, in which the variability to the customer can be realized mainly through the flexible combination of configurable modules and product families.
- exist if the surface of the product can be described mathematically during ablative machining (this applies to drilling, turning, and milling processes).
- depend on the number of pieces of a product and its quality requirements, also additive processes where, for example, there are hardly any restrictions on its geometry from this manufacturing process (see also Sect. 9.2).

The choice of a simple manufacturing procedure shall be deemed to be acceptable if

- the tolerances used in the product are not too strict or large tolerance ranges are used.
- the choice of materials is not only based on questions of load-bearing capacity but also on the manufacturing, assembly, and testing possibilities in the company.
- during development, attention is already paid to the fact that components can be completely removed without retooling, so that non-value-adding processes (which also include all setup procedures) are minimized. This is not the case with additive manufacturing, as products are created in one "set-up."

The selection of the most suitable production process for a tangible product is made during process planning, taking into account the technological possibilities available in the company, without, at this moment, taking into account their availability in terms of time. If sufficient information from production is available, the individual components of production costs (material costs, preparation costs, non-productive costs, tool costs, setup and transport costs, production costs) can be determined relatively precisely and comprehensibly.

Wherever possible, manufacturing processes should not only be simplified but also avoided and replaced by assembly of existing components. This can be achieved, for example, by

- the use of standard components and materials, which also have the advantage that they can be purchased from suppliers in large quantities as well as in defined and reproducible quality.
- the abandonment of complex casting molds and their replacement by curved components or by joining components that are easy to produce (e.g., by welding and gluing), depending on the number of pieces required. As a rule of thumb, the production of a component with joining processes is more economical than the production by original forming or shaping for small quantities.
- a skilful selection of the blank (if the corresponding quantities exist). This not only allows more complex production processes to be replaced by simpler ones and the quality of the end product to be improved (for example, by forging the blank very close to the finished contour in order to save machining costs and to increase the strength of the component) but also minimizes the number of non-value-adding processes (which are known to include setup, transport, and buffering processes).

The contribution of DfM to ensuring manufacturability is shown using the example of the flow-optimized and air-cooled rotor blade in the high-pressure compressor of the GP 7000 engine in the Airbus A 380, Fig. 14.5.

- The working environment of the blades is characterized by high pressures and high temperatures up to 2200 °C, in which the blades rotate at high speed.
- The blade is die cast complete with all cooling holes and fastenings.

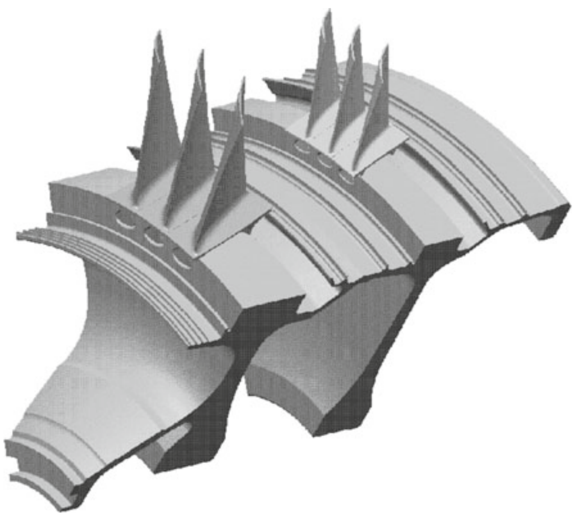

Fig. 14.5 Rotor blades on the shaft in the high-pressure compressor of the GP 7000 aircraft engine [GeHa-2000]

- The high-temperature material used in such an environment (e.g., nickel-based super alloy [Hein-2014]) is tough and resistant and exhibits high creep and fatigue strength at high temperatures, but after shaping it can only be polished, not machined, so that production had to produce the blades with an approximate finished contour.

With DfM, the restrictions from production were built up as rules in such a way that they could be applied in product development with 3D modelling and simulation of the blade in CAx systems in time and completely. The simulation of the production was carried out on the CAx model of the blade in advance in order to determine a suitable variant and the most suitable manufacturing phase sequence. Thus, only those blades were developed that could actually be produced [GeHa-2000][4].

14.1.1.3 Design for Assembly (DfA)

DfA means ensuring the assembly suitability of all components in a company. The aim is to minimize the number and variety of parts to be assembled and to reduce the complexity and number of assembly steps, especially in the case of tangible products.

Number and variety of parts can be reduced by

- the preference for standard parts instead of individually developed and manufactured parts, even if the standard parts partly exceed requirements. In the case of large quantities, it must therefore be checked whether in this case, the individual part is not cheaper, for example, because it can be better (and possibly also cheaper) adapted to the requirements.
- the use of as few different fasteners as possible, such as screws of the same size, length, and head shape. However, by using two different screws, a clear installation position can be created, thus simplifying an assembly process. Fasteners can be omitted if self-locking parts are installed in products that do not need to be dismantled at all or only very rarely [Baue-2003].
- the realization of several functions in one component. For example, the keyboard of a smartphone serves as a protective and functional surface. The headphone cable of this smartphone can be used both as a radio antenna and for the purpose of providing additional transmitting and receiving capacities.
- the combination of different materials in one component, also for realizing several functions. For example, the lower shell of an electric shaver is made of three materials: One material ensures carrying, insulating, and protective functions, while the other two materials provide the design, a positive impression, and good ergonomics. Nevertheless, only one part needs to be fitted (but see also Sect. 14.1.1.5).
- the grouping of components prior to actual assembly, where a component does not move relative to other components during normal product operation or is made of

[4] These blades have been in trouble-free operation since the A380's maiden flight on 27 April 2005.

the same material as those components, and where the component does not need to be insulated from the other parts

- the leaving out of a component if it has properties that are worthless for the user.

Manual or automatic assembly should always be carried out in such a way that

- parts can only be installed in one way. This is achieved by guiding elements to prevent incorrect installation, by symmetrical parts so that installation directions do not play a role, by form-fitting parts and by avoiding moving parts. In the event of incorrect assembly, it must not be possible to carry out the next assembly step in order to avoid consequential errors.
- only simple and linear movements are used and parts do not have to be turned during assembly. The parts should already be clearly in the intended position before releasing.
- self-adjusting or self-locking parts are used. Non-self-locking parts must fill the respective installation space when inserted (positive locking) so that they cannot change their position after installation.
- subsequent adjustment of the individual components can be avoided, as such adjustments can have a negative effect on reliability and safety.
- instead of mechanical adjustments, electrical adjustments should be preferred,
- critical connecting surfaces should be mounted in one unit if possible, and
- there are adequate clearance fits between functional surfaces.

In manual assembly, the number of components to be assembled is first determined. From this, the assembly sequence, assembly time, and assembly costs can be determined. Assembly processes should be carried out with special consideration of the skills of the assembly personnel so that possible bottlenecks and difficulties in manual assembly can be identified in advance.

The planning of an automatic assembly is basically no different from the planning of manual assembly. In addition, however, consideration must be given to the possibilities and capabilities of the assembly systems, which must be selected according to the product, to the quantity to be produced, and to economic efficiency. Accordingly, the respective possible procedures (mechanical, pneumatic, hydraulic and electrical automation) must be simulated. It must also be taken into account that assembly systems are only fault-tolerant to a very limited extent, so that the simplest possible assembly steps should be aimed for.

With regard to maintainability, access possibilities and a (largely) unrestricted view on installed parts should be ensured. For this purpose, an adequate space for hands and tools should be provided (the so-called service space) and the components should remain visible to the maintenance technician or be made visible with little effort (e.g., unscrewing a cover).

14.1.1.4 Design to Cost (DfC)

The aim of cost-effective development is to find the most cost-effective solution for each component in product development in relation to all costs incurred by that component during the product life cycle. However, it must be ensured that the performance of the component is guaranteed in every case. A common tool for this is value analysis (Sect. 1.2.3.1, [Mile-1972]), from which numerous measures for cost reduction and simplification can be derived. Examples of suitable measures are:

- Downgrading or coarsening of a component by means of a design that is easier to produce, assemble and maintain, and that is more sustainable, by means of less complex surfaces, simpler part structures, material substitution, etc.
- Replacement of individual components with standard and norm parts or with components that are used in large quantities in numerous products of a company. In the automotive industry, for example, components that are visible to the customer are usually individual parts, while "invisible" parts are used in parallel in numerous vehicle types of the manufacturer (keywords platform strategy, modular transverse construction kit [Melt-2012]). For each application, it must be considered whether under certain conditions (number of units, manufacturability depending on the place of manufacture, transport costs of standardized parts to the place of use, legal and social environment, etc.), the use of an individual component is more cost-effective.
- In the case of components that do not have to be dismantled during the product life or only under very specific circumstances, the use of simpler joining processes (e.g., gluing or plug connections) instead of screw connections can be considered (but see also Sect. 14.1.1.5).
- Combining components with similar performance requirements into a uniform component that can be produced in large quantities and at low cost. It may happen that in certain applications, this component exceeds the respective requirements. In this case, a balance must be found between the additional costs resulting from over-fulfilment of requirements and the savings resulting from high production volumes.

Design to cost is usually supplemented by the specification of cost limits with target costing. This can be done either globally for the finished component or broken down to each individual phase of the product life cycle (see also Chap. 25).

14.1.1.5 Possible Contradictions Between DfX Views

The different rules of DfX, when applied in their entirety, are not free of contradictions, because the requirements from the different phases of the product life cycle for product development are not consistent, but are oriented according to the respective interests [Baue-2003]. Especially, the requirements of sustainability-oriented development (Chaps. 5 and 12) are not consistent with most other forms of DfX with regard to

- individuality and durability of the product,
- using only materials with complete re-circulation abilities,
- production with minimum energy input without environmental impact, and
- concept of usage of a product rather than its ownership.

The same applies to the combination of

- production- and assembly-oriented development with maintenance-oriented development, for example, when using such connection forms which, although they are quickly produced and assembled, cannot be detached again during maintenance or at the end of their product life, or only with difficulty or only with their destruction.
- reliability-based development with cost-based development if the reliability of task fulfillment cannot be fulfilled over the entire life cycle due to cost limits being exceeded. This is the case, for example, with holding devices that, for cost reasons, have been dimensioned so weakly that they lose their function even at low overload without the holding component being damaged, but still have to be replaced with the defective holding device.

Possible contradictions between the individual DfX views can be illustrated using the example of the electric razor's lower bowl already mentioned in Sect. 14.1.1.3. Such an apparatus consists of a lower shell and an upper shell. The lower shell simultaneously houses the motor, power supply unit and battery, control elements and the actual devices for cutting the beard. The upper shell serves as a lid and as an additional fixation of the "inner life" of the shaver. Marketing and product design demand that the surfaces of the lower and upper shell should convey a valuable impression. Production, on the other hand, wants easy assembly, customer service wants good maintainability, and the product return point wants the ability to easily disassemble the two shells for recycling[5].

The solution installed by the manufacturer consists of shells made of several different materials that are glued together. In the lower shell, the core shell consists of thermoset plastic coated on one side with aluminum. It provides carrying, insulating, and protective functions and ensures a high-quality design. For good ergonomics, an elastomer molded part is inserted through the shell and bonded inseparably. The upper shell has a similar structure.

This solution meets the requirements for both a high-quality appearance and an easy assembly. The demand for easy maintainability is only partially met because dismantling the lower shell requires special tools (but this also ensures that only qualified personnel can open the shaver). The requirement for complete recycling, on the other hand, is not met because (even if the shells are shredded) the materials bonded together cannot be separated from each other without causing contamination (violation of the material combination rule) and thus actually only landfill or incineration ("thermal recycling") with all the associated problems remains.

[5]This approach is also known in English-speaking countries as "GDR", Design for Disassembly and Recycling.

14.1.2 X for Design

With the X for Design approach, the producing and distributing divisions in the provider's company make their various options available in different ways and formats as a *service offering* for product realization throughout the entire product development process. Product development can either take these into account when concretizing the solution or instead formulate requirements that can lead to a change in the realization options, for example by procuring other production equipment or by (partially) outsourcing the realization to third parties. Within IDE, the decisions on the concrete realization of a product (definition of type, degree and quality of fulfillment, Sect. 3.4.2) only take place in the process planning phase, Fig. 14.6.

Figure 14.6 shows a schematic diagram of a product development with XfD. The project team works together on the given target profile of the attributes using the methods, possibilities, procedures, and knowledge provided by the following departments. The solution finding process checks the possible implementation disciplines at the provider and selects the appropriate ones (symbolized by the network in the background of Fig. 14.6). This provision is achieved by integrating the respective experts from the relevant departments into the IDE team and using the methods of knowledge management in the form of data, information, and rules (Chap. 17). In the development of tangible products, these can be, for example, the following service offerings:

- Research and product planning: Current research results concerning the products and their genesis, patent research, research trends (RfD, Research for Design).
- Marketing and sales: Market research, market situations and trends (emerging markets), product acceptance, competitors, assessment of product success (MafD: Marketing for Design, SfD: Sales for Design).
- Production: From a technological point of view, these are available manufacturing and assembly methods, workable materials, available working areas, operating resources, and processes (MfD: Manufacturing for Design, AfD: Assembly for

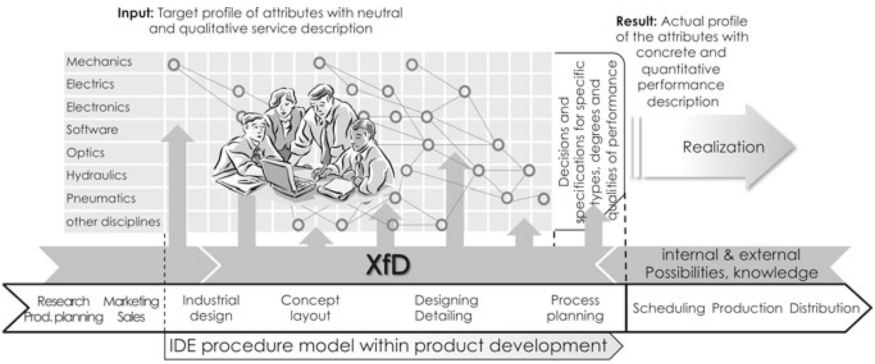

Fig. 14.6 Diagram of XfD (based on Fig. 3.17)

Design). From an organizational point of view, these include structures, capacities, and availabilities and the possibilities of production logistics. From a quality assurance point of view, the existing procedures for quality assurance and control. From a business management point of view, costing procedures and respective cost situations. For example, if the supplier is a member of a production network, corresponding possibilities of partner companies and suppliers with the respective delivery conditions and (logistical) delivery possibilities are added.
- Logistics and shipping: Maximum volumes and weights of products to be delivered, types, shapes, and materials of packaging
- Maintenance: Design, production, and maintenance guidelines.
- Possible uses of information technology tools with all existing modelling, calculation and simulation tools, product models, procedures for interfaces, availability of tools and networks, etc.

The possibilities offered by XfD in the downstream departments thus form an extensive data and knowledge base with which the most diverse scenarios can be tested both during product development and in the phase of realization decisions by (almost) any technical, organizational, and business management simulations. However, these can also lead to the need for other or additional (and economically presentable) implementation options.

Finally, the question arises as to which of the DfX options can be switched to XfD. Of the measures and procedures required for this, this is basically possible for all DfX variants, but with the following restrictions and special features:

- Only those DfX can be converted to XfD that affect those phases of the product life cycle that are directly or indirectly attributable to the provider, both organizationally and technically, i.e., primarily production and distribution, but also during usage phase (which usually takes place at the customers site) the DfMt, Design for Maintenance, and at the end of the product life, the procedures for product re-circulation, of which the latter remain tasks of the provider.
- The implementation of the requirements for safety (DfSa) is based on specifications, compliance with which is intended to ensure that the product cannot cause harm to customers, users, and affected persons under any circumstances (Sect. 14.1). Safety is a fixed criterion that must be observed in all cases and to which the design and implementation of the product must be subordinate. A reversed approach SafD can only show by means of examples how DfSa could be achieved.
- The requirements for ensuring and maintaining sustainability during the creation, use, and recycling of the product (DfSu, see also Fig. 3.5) result from the planetary and social boundaries (Chap. 5 and Sect. 12.2), which, in conjunction with reasonable economic efficiency, must be observed in all phases of the product life cycle. Planetary and social boundaries limit the possibilities of each discipline and domain of knowledge and do not offer the possibility of their shifting or modification. Again, the inverted approach SufD can only provide examples.

14.1.3 Comparison Between DfX and XfD

The main differences between DfX and XfD are, on the one hand, the relationship between product development and downstream departments. In DfX, specifications from these departments must be taken into account in order to be able to achieve producibility. The *downstream departments* are thus the *customers* for product development. On the other hand, in XfD, all other (so as well the downstream) departments offer their services to product development, whereby the development department decides whether or not it will use this range of services. In the XfD, *product development* is therefore the *customer* for the other departments. This can may lead to the complete production of a product being outsourced to a third party if the range of services offered by the own department cannot meet the requirements of product development.

On the other hand, there is a difference in the respective point in time of the start of the decisions on the concrete implementation, which must be made within IDE at the latest possible point in time so that changes in customer demands and in other requirements can be considered as long as possible. While with DfX the first decisions have to be made already during the layout phase, but at the latest during the phase of detailed design of a product, it is entirely sufficient in XfD to make these decisions not until in the process planning phase during the preparation of the release for production. Thus, XfD provides an additional time window, within which further changes in customer requirements and current knowledge can be taken into account, Fig. 14.7.

14.2 Organizational Department Integration

The organizational integration of departments within IDE is primarily ensured by employees from all departments and disciplines of the product life cycle. In accordance with a project-oriented organization, they work together in teams whose task is the integrated and complete development of a product or product family upto the release for production, taking into account all influences from all other phases of the product life cycle (vertical integration[6]).

From the organizational structure side, an IDE team covers the departments of industrial design, concept, draft, layout, engineering design, and detailing as well as process planning. If required, customers, partners, suppliers, and employees from the production and distribution phases can be integrated into the teamwork.

The number of members of a team is determined by the range of leadership or management (Sect. 15.6), which describes the appropriate number of people who should be under a leadership function so that all members of the team (including the

[6]This is complemented by horizontal integration. Here, the organization is structured according to functions, each of which is responsible for one function across all product areas (for example, computer-aided design for all products).

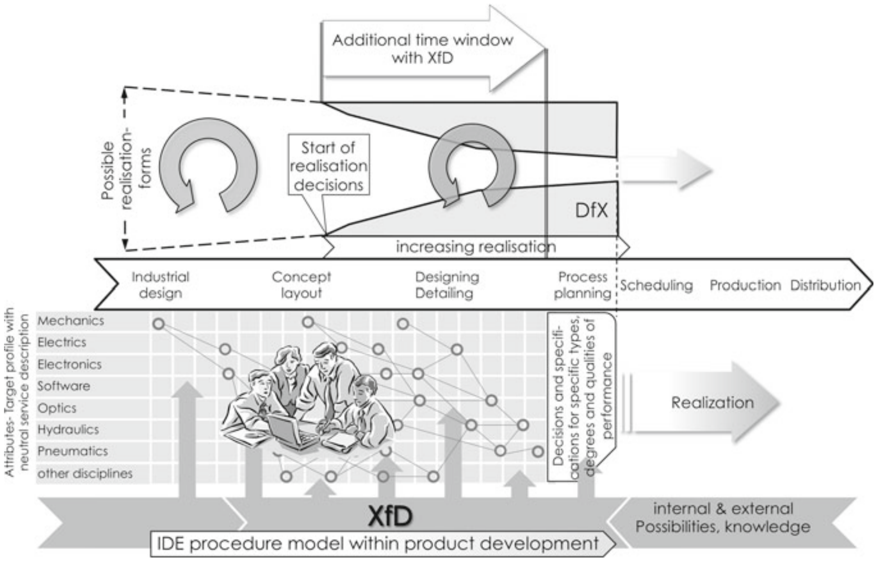

Fig. 14.7 Comparison of DfX and XfD procedures with the additional time window in XfD for further changes and decisions

project leader) are able to understand and evaluate the tasks and activities of the other team members (even if they come from different departments), so that a common level of communication can be found with all [Kafu-2013]. Within the IDE team, the project manager has the only leading function, although this is not a permanent task, because due to the high degree of self-organization of the team, the role of the project manager is predominantly that of a moderator, who works on the project in the same way as the other team members. The leadership span within IDE (and thus the number of team members) should empirically not exceed 10.

On the part of the process organization, the processing is modelled in processes and carried out in project form. This is discussed in Chap. 15.

The organizational divisional integration leads to

- an improved identification of people with their tasks through more responsible and higher quality work (*job enrichment*) and by taking on more extensive tasks beyond one's own work to date (*job enlargement*), thus leading to greater job satisfaction.
- a shift of responsibility directly into the team as the executive body and thus also to a front loading of activities and decisions,
- a reduction of hierarchical levels as well as to the establishment of flat organisational structures with short information and decision-making paths. On the one hand, this will reduce the internal administrative expenses of the company; on the other hand, it will reduce overheads. This results in a reduction in the number of

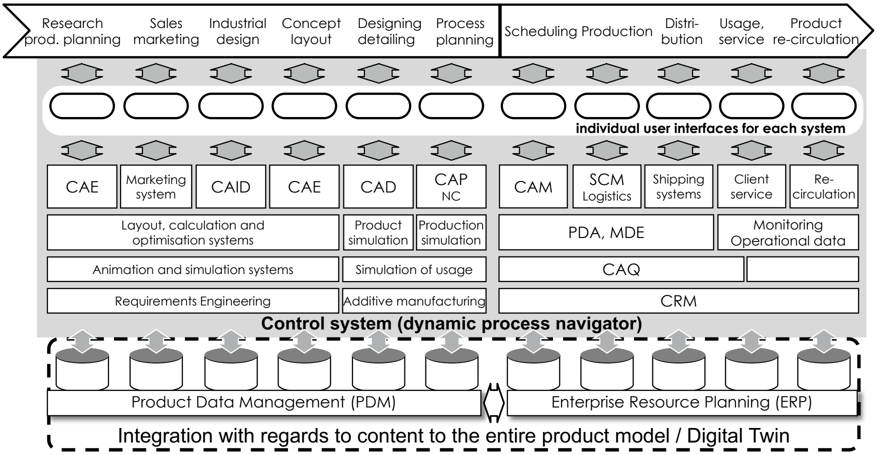

Fig. 14.8 Technical department integration (CAE/CAID/CAD/CAP/CAM/CAQ: Computer-aided Engineering/Industrial Design/Design/Planning/Manufacturing/Quality Assurance. NC: Numeric Control, SCM: Supply Chain Management, PDA: Plant data acquisition, MDA: Machine data acquisition, CRM: Customer Relationship Management) [VWZH-2018]

interfaces between the individual departments and thus a decrease in the frequency of errors.
- a renunciation of multidimensional structures by eliminating matrix and parallel organizations and thus also to reduce multiple responsibility for one task.

Within IDE, this results in clearly structured organizational units with a high degree of individual responsibility, whereby the units manage themselves.

14.3 Technical Department Integration

The technical integration of the departments within and for IDE is carried out by computer-aided generation systems, customer loyalty systems and administration systems, which are closely linked to each other via suitable networks. The components shown in Fig. 14.8 are currently used for the product life cycle.

The systems relevant for department integration within IDE are all systems and applications that are used before release for production[7]. The individual systems in Fig. 14.8 essentially have the following tasks [VWZH-2018, Thom-2006]:

[7] A detailed description of the systems relevant for IDE can be found in Chap. 18.

- Systems for customer acquisition, retention, and support ensure that customer concerns are identified in advance, during development and production as well as during use and return, and that they are taken into account appropriately (CRM).
- Generation systems generate data and process existing data. They enable the modelling, simulation, and evaluation of products in the broadest sense, both before release for production (CAE, CAID, CAD, CAP, NC and all systems listed in Fig. 14.8) and after release (CAM).
- Systems for managing production and for ensuring the required quality allow a largely loss-free and smooth implementation of the specifications from IDE into production (SCM, logistics, CAQ, BDE, MDE).
- Management systems (PDM for IDE, ERP for subsequent departments, Sect. 18.3) enable a first level of integration by jointly managing the data generated by the other systems, even if the actual data is stored in separate databases.

Integration via the PDM and ERP management systems is currently the only form of technical department integration within IDE. In the context of the further development of the systems in Fig. 14.8, following work is therefore of great interest for IDE:

- Provision of a uniform and consistent user interface for all IT systems as a further important integration component from the user's perspective.
- Simple and versatile configurable and combinable systems depending on the specific application.
- Permanent quality assurance running in the background for immediate detection of deviations of the currently developed solution from target specifications or requirements during the processing steps (Design Spell Checker [Vajn-2003]).
- Transition from system-specific and separate data sets to a single product model ("digital twin," which tracks the state of the product in every phase of the product life cycle, so that the product has a virtual image at any time, Chap. 18) for the consistent storage of all product and process data of the product life cycle, not only for consistent, always up-to-date storage, but also to avoid interfaces between the individual systems.
- Integration of a knowledge base parallel to the uniform product model for the consistent acquisition, provision, use, and archiving of knowledge from the individual phases of the product life cycle and all associated activities (Chap. 17).

Integrated systems use a wide range of possibilities of special and general networks (for example, the Internet) to be used either within a company at any location or to realize a development network between companies, customers and suppliers.

References

[Baue-2003] Bauer, S.: Design for X—Approaches to definition and structuring. In: Meerkamm, H. (publisher): Design for X, Contributions to the 14th Symposium Neukirchen (2003)

[BoDe-2003] Boothroyd, G., Dewhurst, P.: Design for Assembly: A Designer's Handbook. Dewherst Inc., Wakefield (USA) (2003)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrated Product Development, 6th revised and extended edition. Hanser Munich (2017)

[GaGa-2015] Gardan, N., Gardan, A.: Improving the Competitiveness of the SMEs using Trade Knowledge and Simulation Based Design. Br. J. Econ. Manag. Trade **6**, 3 (2015)

[GeHa-2000] Geidel, H.-A., Hackenberg, H.-P.: Change—knowledge—competition. Product development in aircraft propulsion systems. In: Developing Products in a Real Environment, VDI Conference Munich (2000)

[Hein-2014] Hein, B.: Nickel-based superalloys for aircraft engines from a metallurgical point of view. WOMag (2014)1, WOTEch Waldshut-Tiengen, www.wotech-technical-media.de

[Kafu-2013] Kafurke, T.: http://www.unternehmerinfo.de/Lexikon/L/Leitungsspanne.htm. Accessed on 11 Aug 2013

[Meer-1994] Meerkamm, H.: Design for X—a core area of design methodology. J. Eng. Des. 5(1994)2, Seiten 165–181 (1994)

[Melt-2012] Meltzow, A.: Unprecedented success story. ATZextra 17(2012)6, S. 6–7 (2012)

[Mile-1972] Miles, L.D.: Techniques of value analysis and engineering. McGraw-Hill New York (1972)

[Otto-1996] Ottosson, S.: Dynamic product sevelopment—findings from participating action research in a fast new product development process. J. Eng. Des. 7(1996)2, Seiten 151–169 (1996)

[Thom-2006] Thome, R.: Fundamentals of Business Informatics: Integration of Information Processing in the Organization of Enterprises. Pearson Munich (2006)

[Vajn-2003] Vajna, S.: Approaches of knowledge-based design. In: Proceedings of 2003 ASME, Design Engineering Technical Conferences, DETC2003/DAC-48741

[VaKB-2011] Vajna, S., Kittel, K., Bercsey, T.: The autogenetic design theory—product development as an analogy to biological evolution. In: Birkhofer, H. (ed.) The Future of Design Methodology. Springer, London (2011)

[VWZH-2009] Vajna, S., Weber, Ch., Zeman, K. Hehenberger, P., Wartzack, S., Gerhard, D.: CAx for Engineers, a Practical Introduction (third completely revised edition). Springer, Berlin Heidelberg (2018)

[Wart-2000] Wartzack, S.: Predicitive Engineering—Assistance System for the Multi-criteria Analysis of Alternative Product Concepts. Dissertation University Erlangen-Nuremberg (2000)

[Wien-1970] Wiendahl, H.-P.: Functional Analysis of Technical Structures—A Tool for Order Processing in the Mechanical Engineering Industry. Dissertation RWTH Aachen 1970

Chapter 15
Integration of Processes and Organizations

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IDE covers product planning, marketing, industrial design, development and engineering design, process planning, prototype and sample manufacturing as well as testing up to production release (Fig. 2.10). Process integration and organization integration include all measures necessary to describe, consolidate and improve business and development processes and organization forms. These concern both the structure of an organization and the way in which and under which conditions

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Effects from \ to	Product	Organisation	Process
type of coupling Product	Results of human ability, competence, and actions	Product - organisation influences organisation	Product - process leads to the process basic structure
type of coupling Organisation	Organisation - product Provision of the structural organisation and functions	dedicated cohesion of structures	Organisation - process Provision of the operational organisation and resources
type of coupling Process	Process - product results in a product	Process - organisation influences organisation	Specification to handle a task

Fig. 15.1 Interaction and coupling of product, organization and process (grey-shaded areas on the main diagonal: definition of the respective object)

the activities for processing tasks are carried out. In IDE, task processing and organization must both be flexible in order to be able to react appropriately to changes of requirements and environments. This is achieved in IDE by making structures and processes, respectively, increasingly dynamic.

Figure 15.1 shows the interaction of product, organization and process as well as the resulting mutual conditions and dependencies

- The product as the result of human skill and action requires a basic process structure for its creation. At the same time, an appropriately adapted organization must be available for its creation.
- The organization as the purposeful cohesion of a structure of people and units provides the structural organization for the creation of the product and the process organization for carrying out the processes required for this.
- The process as a guideline for working on a task can only function in appropriately adapted organizations in order to enable the creation of a product.

Product, organization and process form a stable and indissoluble network in which the relationships of the participants are clearly defined, which must be observed in terms of organizational and process integration. While the variety of products was presented in Sect. 2.3, this chapter deals with the processes and projects required for the development of a product and possible forms of organization for IDE. A distinction is made between the structural organization and the process organization.

Activities in IDE are neither predictable nor fully reproducible due to their creative part and the high probability of changes. Due to unclear processes and information flows as well as changes in requirements and environment, it is often difficult to track current project progress. Moreover, in this dynamic environment, it is hardly possible to fully control and document the goals, times, resources and costs of a project. This means that activities in IDE differ fundamentally from those in production, sales, administration and controlling, Fig. 15.2.

	Production, controlling, administration (Business processes)	Integrated Design Engineering (Engineering Processes)
Objects and their descriptions	Products, material, technologies, tools, documents, data are completely available and precisely described	Objects of thought, concepts, ideas, drafts, approaches, trials (and errors) are always virtual and can't be described precisely
Results	must be predictable	can't be always predicted
Possibility for disturbances	low because objects and their respective environments are described completely and sufficiently	high because of incomplete objects and continuous changes of requirements and conditions
Processes and projects	are fixed, rigid,100 % reproducible, and always to be verified	are dynamic, creative, not structured; many loops and jumps
Dynamic reaction capability	usually not necessary	is always necessary
Process and project management	**Control:** Defined specifications for mastered and predictable processes, without feed-back loop, sporadic checking of results	**Navigation:** Assessment of actual situati-ons, creation of evaluated alternative activities, selection by the developer

Fig. 15.2 Differences between activities in manufacturing, controlling, administration and IDE

After release for production, the downstream areas can only work with fully described objects as well as with fully described processes. Otherwise, for example, production cannot produce products of the same quality regardless of their quantities, cannot create comparable financial balances in company accounting (to which controlling department also belongs), and, in administration, cannot assure comparable procedures for payroll accounting. Because objects and activities are complete and reproducible, a process control is usually sufficient.

Activities in IDE are usually complex and dynamic, not only because both the creative development and realization of surprising innovations do not follow a strictly prescribed path, but also because many projects are carried out by different employees with growing ranges of tasks and different qualifications, predominantly simultaneously and often at different locations (e.g. in development partnerships in the automotive industry). IDE often contains complex configurations of activities in which some are serial and others are parallel. In industrial practice, it is also difficult to monitor current project progress due to unclear processes and information flows.

When placing an order, customers often do not know all requirements for the desired product (as a lot of them only arise during development) or change their requirements during on-going development on the basis of new knowledge that has arisen[1] whereby it is expected as a matter of course that, despite these changes, once agreed requirements, time and cost frames are kept without being adjusted accordingly.

This chapter describes possible measures for improving development processes, different forms of structural organizations and process organizations, and dynamic navigation. The IDE procedure model based on these is described in Chap. 16.

[1] Both effects are also referred to as "running targets".

15.1 Process Improvement

In terms of activities, IDE distinguishes between processes[2], workflows and projects.

- An (organizational) process is a concept, a specification or a rule for processing a task in the form of a structure of interrelated activities (process steps) or subprocesses in logical sequences. Activities or subprocesses are not limited in length and duration. Links between activities and subprocesses are not rigid; they can be active or inactive. Accordingly, the management of processes does not serve their control but their design with the aim of simplifying and improving them.
- A workflow is a fixed, rigid sequence of activities and subprocesses that cannot be changed for reasons of comparability and reproducibility or due to legal regulations (e.g. release process or change process in IDE, but also every organizational process in production, administration and controlling).
- A project is characterized by a concrete order with unique individual conditions. It has a defined start (project start) and a defined end (delivery date). A project comprises all processes and/or workflows for creating and documenting an individual product described by actual (and individual) requirements, boundary, initial and environmental conditions for a specific purpose and in a specific configuration (scope of services). The project is subject to limitations in the number of agents, the tools and resources available, and budgeting. For the successful execution of a project, project management includes various management tasks, organization, techniques and means [DIN-69901].

The transition from a process to a project takes place through a specific internal or external order with a defined scope of services and fixed conditions regarding budget, resources and delivery date.

The aim of process improvement is to increase efficiency through faster processing, the most economical use of resources and the avoidance of processing errors. The aim is to enable better cooperation through integration, appropriate use of resources and parallel procedures, thus leaving behind a rather work-sharing organization with predominantly fragmented processes.

There are numerous methods for process improvement. The so-called direct methods redesign the process structure in advance, such as business process reengineering [StVa-1996], indirect methods record and evaluate the results of processing in order to derive changes, such as Six Sigma (a method of quality management and process optimization [DaHa-2009]) and the continuous improvement process [EhMe-2013].

The improvement of processes can take place in several stages. In doing so, the basic structure of the process organization (Sect. 15.3) is not called into question.

[2]The process term is used here from a purely organizational point of view. It should not be confused with the same term from production, where "process" means the sequence of technological steps and tools used for production and assembly (e.g. manufacturing process, assembly process).

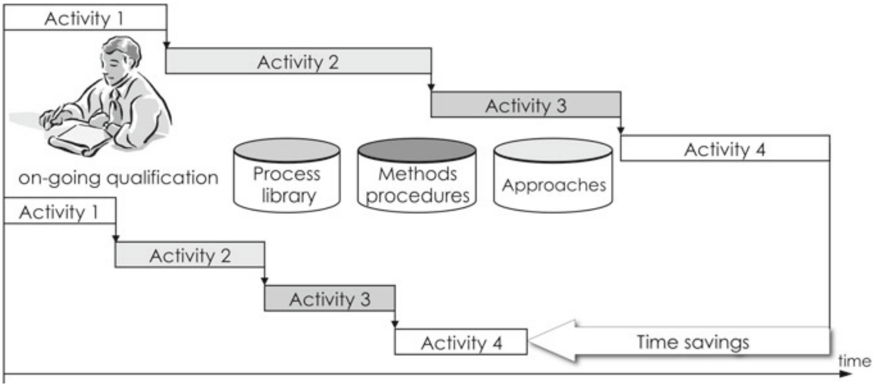

Fig. 15.3 Results of skills improvement, use of best practices and higher value methods, means and tools

- The required qualification for each activity is determined and compared with the actual qualification profiles of the employees. Usually, employees with appropriate qualifications are deployed for processing. However, if employees with higher qualifications are deployed, processing is more efficient and processing times are shortened.
- Instead of individual procedures, procedure patterns are used that have proven themselves in the company or with external parties (the so-called best practices).
- Sophisticated methods, aids or tools are used more than before. On the one hand, this improves the quality of work. On the other hand, either the processing time can be reduced or more results can be achieved in the same time.

The results of these measures are shown in Fig. 15.3.

- Activities with which comparable tasks are processed are complemented and linked to subprocesses. This serves not only a "mild" standardization of procedures, but also the elimination of interfaces between individual activities and the tools used for support. This contributes to the realization of error-free and interdisciplinary working methods.
- Activities can, if the processing logic allows it, be moved into different sequences and arranged differently.
- Activities are parallelized according to the procedures of Simultaneous Engineering (SE) and of Concurrent Engineering (CE), Fig. 15.4. In SE, different (and originally consecutive) activities are overlapped and executed in parallel (in product development, e.g. development, design and process planning). In CE, a single task is divided among several persons (step TS), who process it in parallel. Therefore, the definition of physically and logically delimited areas (the so-called *design spaces*) with clear interfaces is necessary. The results of the activities are merged and compared at the end of processing and thus consolidated (step MC). For SE and CE, the most important criterion for parallelization is the question

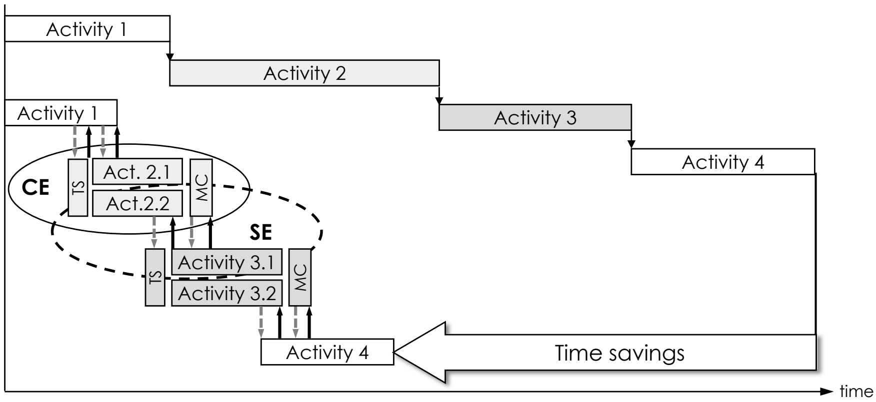

Fig. 15.4 Possibilities of parallel processing (SE = Simultaneous Engineering, CE = Concurrent Engineering, TS = Task sharing, Z & A = Merging and alignment)

when the results of the previously started work step are so stable that the statistical probability of a change and the associated change costs are lower than the costs caused by working and delivering too late [VWZH-2018].

- As further measures, where technically and organizationally reasonable, activities can be broken down into smaller units (such as CE) and their arrangement and their processing sequence can be changed. This sequence can be further improved by changing the process topology accordingly.

The measures described here are mainly of organizational nature. No great effort is required to implement them. Conversely, this means that if the result does not meet the expectations, it is also possible to restore the original state with little effort so that the economic risk of these process improvements is low.

15.2 Structural Organization

A basic distinction is made between the structural organization and the process organization [Burc-2001]:

- The structural organization regulates the distribution of the tasks of a socio-technical system (enterprise, authority, association or other systems) between different organizational units as well as the relationships and cooperations of these units. The organization can be structured in different ways, for example in permanent positions and departments or in temporary teams that are only formed to process a task and then break up again. Management, staff and communication relations serve to regulate cooperation [Groc-1983]. The organizational plan provides the structures for the implementation of targets and company goals as

well as for the provision of services with content over time, time, composition and scope.
- The process organization describes the spatial and temporal sequence of the interaction of employees, resources and work objects or information and the associated activities in the fulfilment of work tasks, taking into account factual-logical, personal and spatial-time aspects. The process organization is dealt with in detail in Sect. 15.3.

The structural organization is divided into the *line* in which the company's value is created, and the *staff* that supports the line and can thus only indirectly contribute to value creation.

- The line organization includes those areas of the product life cycle that are located within the company or are influenced by the company.
- The staff organization includes the central areas for the entire company or within a line (e.g. personnel area, purchasing, payroll accounting).

The structural organization can be function-oriented, a matrix organization, a project organization or a mixture of these.

A task can be processed either by a workgroup or by a team. A workgroup is

- a group of employees who work together in an organizational unit on a permanent basis, either on a factual or process-related basis. The number of group members is unlimited.
- usually hierarchical and function-oriented and remains together[3] for a very long time. It mainly works on routine tasks, whereby work and structuring can be oriented to functions, assemblies, product properties or phases.

The exchange of information or the coordination of procedures with other workgroups usually takes place via the superior unit. Within the workgroup, information exchange and coordination primarily serve to make decisions that support an individual member in providing performance within his or her own area of responsibility. In the workgroup, individual performance is rated higher than the overall result, especially as the performance evaluation of the employees is carried out individually.

Teamwork is discussed in detail in Sect. 15.6.

15.2.1 Function-Oriented Structural Organization

In a function-oriented structural organization, there is a clearly arranged hierarchical structure which is divided into functional areas of competence and responsibility (division of tasks) and in which the relationships between the individual organization units are built up in the form 1:n. Units are often isolated from each other due to the division of tasks. They have a specific profile of skills and abilities to solve limited

[3] At least until the next reorganization of the company.

tasks, but do not cover the overall solution. Skills and abilities are usually execution-oriented; i.e., they provide the same functions for different tasks or product groups. For example, a unit can be the management, a department, a group of employees or a single employee. Other units can be subordinate to one unit. Superior units are authorized to give instructions to the subordinate units.

In such an organization, work tasks must be clearly described and structured. Thus, fixed procedures are used in which a high degree of detail already exists for task processing and only limited product or process adjustments have to be made. Therefore, the function-oriented process organization has a low ability to react to changing requirements. Due to its lack of dynamism, it is usually unable to react flexibly to changes; instead, the tasks have to be adapted to the rigid hierarchical structure.

Figure 15.5 shows an example of a structure divided into the specialist areas of industrial design, engineering design and process planning. For each subordinate unit, the task is divided into smaller and smaller parts. Each unit exclusively fulfils its own task. The results are combined and passed on via the respective upstream units.

Since units often operate independently of each other, the know-how of one unit is difficult to access by the other units. This is why there is a risk of redundant developments without timely comparison of information and knowledge. Cross-functional goals are difficult to realize, as integration into hierarchical structures is generally difficult to achieve.

Information and communication flows run according to the structural organization from the superior to the subordinate unit (top-down) or vice versa (bottom-up), but usually not between units at the same hierarchy level (peer-to-peer). As a result, many interfaces (and idle times) are created between the units during the job run,

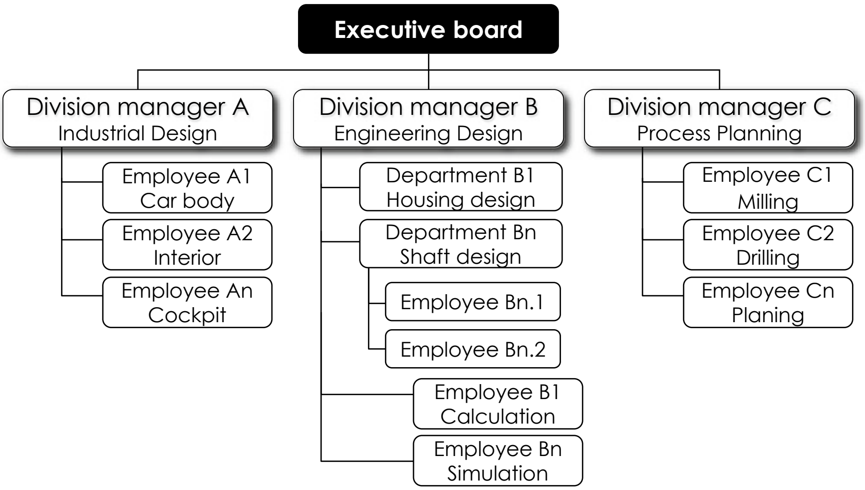

Fig. 15.5 Function-oriented organization

by what the individual activities become more difficult to control and cumbersome decision-making processes can occur [Lang-1998].

This form of organization is very well suited for routine tasks in which the results of a task are passed on between the units by "pushing" them (push: Obligation to hand over the completed results to the successive unit; Sect. 15.2, see also Fig. 1.14). Processing is serial and static, since these are recurring activities.

15.2.2 Matrix Organization

The matrix organization results from the combination of two (planar matrix) or three function-oriented organizations (spatial matrix), Fig. 15.6. Thus, a unit at an intersection point of the matrix can be subject to several equally ranked positions with authority to give directives. For example, in the flat matrix, unit B1 reports to both the head of the design department and the head of product group 1. In the case of the spatial matrix, a further specialist area with authority to issue directives is added (In Fig. 15.6, these are the managers of the countries in which the product is distributed. It often happens that different versions of the product exist for each country (e.g. left-hand and right-hand drive vehicles, depending on the type of traffic).

Within the matrix organization, the units at the intersections can be not only the groups mentioned in Sect. 15.2.1, but also may again forms of organization, for example project organizations.

At the intersections, however, an intensive flow of information and communication can also occur, combined with a high level of know-how transfer. Certainly, there is also competition in the areas of responsibility and the decisions associated with them, so that in the worst case scenario there will be a mutual blockade. For this reason, as in a function-oriented organizations, a single unit in such a matrix is usually subordinated directly only to a single management function (disciplinary or personnel directive authority), while the other management functions have technical

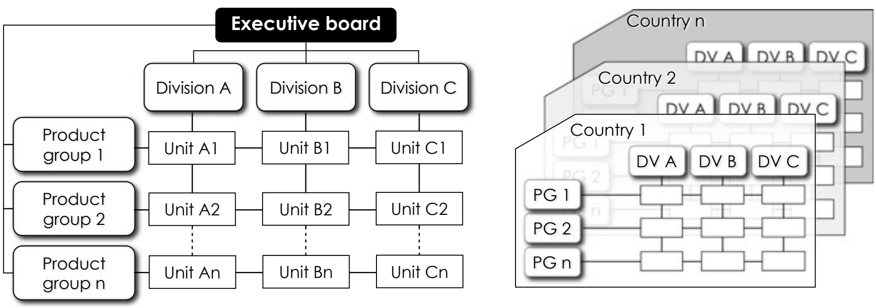

Fig. 15.6 Matrix organization (left: planar matrix with two responsibilities, right: spatial matrix with three responsibilities per unit)

directive authority ("dotted line"), with which they can influence the development of a product, for example.

15.2.3 Project Organization

In project organization there are no permanent subordinations and no fixed structures. Instead, the units required for processing a project are separated from the individual departments and brought together to form an independent organizational unit for the duration of the processing of the project, the project team. Project tasks are handled in parallel and dynamically, with the project members working with both "pushing" the results and "pulling" the results (pull: Obligation to collect the completed results from the preceding unit) as required. In this way, interdisciplinary cooperation is achieved, which contributes to a high degree of identification of the project participants with the project. The project is the responsibility of a project manager, who ideally reports directly to the executive board, Fig. 15.7. After completion of the project, the project members return to their original structures.

The project manager flexibly coordinates and controls the work tasks of his team. He ensures that each project member has their own workspace, which should provide sufficient overlap with the other workspaces to ensure communication within the project team.

For very small or very short-lived projects, employees from different departments can form a project team, but remain under the disciplinary supervision of their respective superiors. In this type of project, the project team coordinates itself, Fig. 15.8.

There is currently no company that is completely organized in projects. Rather, hierarchically structured functional areas exist on an equal footing with project teams

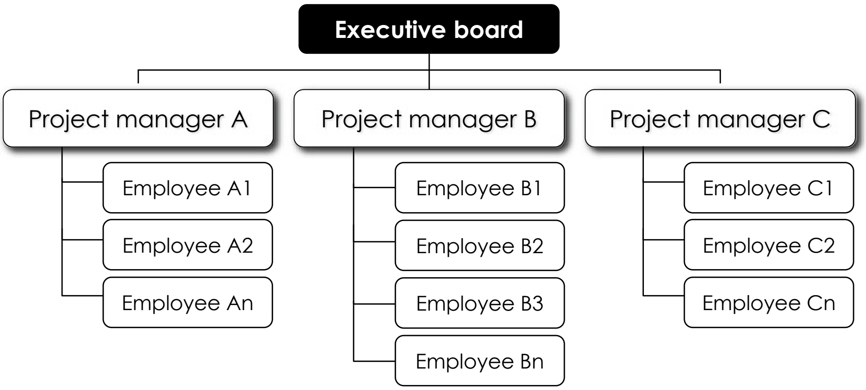

Fig. 15.7 General project organization

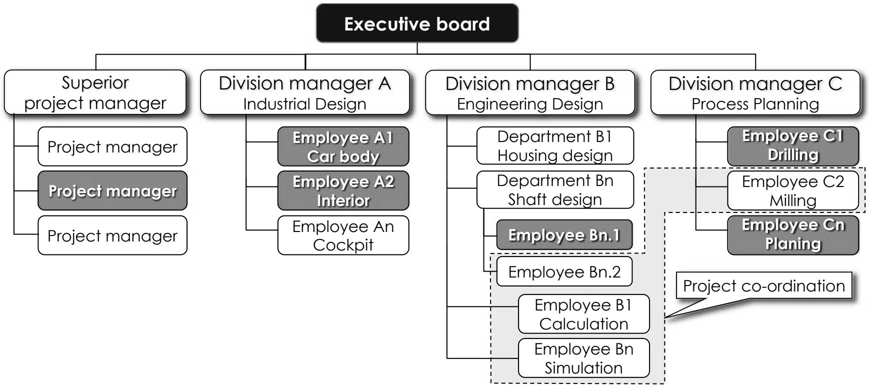

Fig. 15.8 Different project organizations (dark grey elements: members of a project with full-time project manager, light grey background: members of a self-coordinating project)

led by project managers. If the rules of cooperation are not clear, this can lead to non-ambiguous information flows and competence problems.

Project organization is best suited for IDE with its temporary teams that only work together for the duration of a project, because it enables a holistic view on and the integration of all processes with the least organizational effort. This results in both departmental integration in IDE (Chap. 14) and the integration of operational processes, technologies and information technologies as well as the implementation of cross-departmental, interdisciplinary cooperation with flat hierarchical structures, short decision paths and an increased flow of information and communication. In order to facilitate the associated transfer of know-how between the individual projects, it is helpful if the project managers themselves can work together in a team of project managers under the direction of the executive board.

In an IDE team, the project manager is more of a moderator and a coach than a "classic" project manager, because the proportion of self-organization in the team in IDE is high right from the beginning and it increases as the project progresses. This results in transparent project responsibility in which all team members are involved. This enables know-how to be acquired together, combined and made available to all project members. If required, additional organizational units can be formed with individual project members within the project team. Such units are used to work on subject-related goals and content.

15.2.4 Networked Organization

The organizational forms presented so far in product development must be dynamized, because IDE requires sufficient flexibility in the composition of the team as well as in reacting to changed external and internal requirements and changed environments.

Dynamic forms of organization are characterized by flexibility, reactivity and a process-flow-oriented liveliness or agility of processes. In contrast to function-oriented organization forms with structural and process organizations with the inherent rigidly structured, hierarchically organized structures, dynamic project-oriented structural organizations use open, flexible and customer-oriented organization forms. The hierarchy levels are less, decision-making responsibilities in the operative areas are extended and work tasks are executed interdisciplinarily across areas and functions [Burc-2001].

Dynamic forms of organization can be mapped in the form of network structures. In general, a network consists of nodes that are connected to each other via edges. With regard to an organizational form, the nodes correspond to the units discussed in the previous sections and the edges represent the connections between the units, whereby these connections can represent organizational dependencies or information and communication flows, for example[4].

The structure of a networked organization results from both type and scope of the units involved in the network, as well as from the type of relationships between them [Vier-1996]. In addition to the function-oriented structure, a distinction is made between internal, dynamic and stable networks, Fig. 15.9.

- Function-oriented structures were discussed in Sect. 15.2.1.
- Internal networks exist within a company in a fixed and equal network cohesion without redundancies. There are little or no external contacts. A separate unit coordinates them. Each network participant has its own exclusive task. The stability of this type of network is low, because in the event of a network member's failure, the respective task is no longer processed and it is often difficult to replace a network member. The organizational flexibility is correspondingly low.
- Stable networks are the result of permanent and predominantly long-term connections between a leading company and external companies (partner or supplier). The resources of the external companies complement the resource pool of the

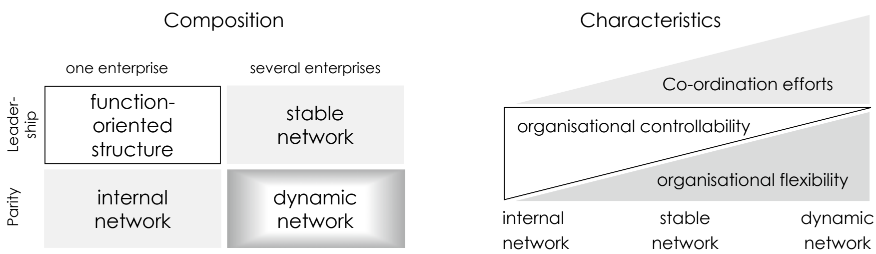

Fig. 15.9 Composition and properties of different network types

[4]Organizational networks can be configured in the same way as technical networks for coupling computer-supported systems in information technology. Their respective functions and behaviour are also comparable.

leading company (even if there may be deliberate redundancies). Core competencies and entrepreneurial risk are mainly located at the leading company. The coordination effort is higher because, in addition to the internal coordination, the integration of external parties must be taken into account. The flexibility of a stable network is very high.

- Dynamic networks are made up of loose but equal connections between companies that are independent of each other and thus do without redundancies. A common form is the development partnership[5]. When defining common goals and tasks, different company interests must be reconciled in the sense of equal cooperation. Since each individual company has its own structures, some of which have different decision paths, it is less controllable than an internal network and often requires more effort to coordinate the collaboration. In return, organizational flexibility increases.

The development of a larger pool of know-how in the network is advantageous, which can release higher innovation potentials, for example. With stable and dynamic networks, this also entails the risk of an undesired transfer of information to other companies and a resulting outflow of know-how.

As it has already been stated, project organization is the most suitable form of task management for IDE. This is now applied to a network structure to enable and support dynamic and flexible approaches that are product- or process-oriented and not function-oriented. This includes the close and interdisciplinary cooperation of all project participants, the development of teamwork structures, and a high degree of transparency of processes and decision paths as well as unimpeded information and communication flows.

The flexible form of a network structure is an ideal organizational form for IDE project work. A network structure supports any desired working constellation of units, such as serial, parallel, feedback or mixed forms. Dynamic activities, such as changes in forms of cooperation and/or partners during a project, are also supported. The basis of this network structure is the mesh network, in which basically any unit can be connected to any other. A mesh network allows to represent flexibly possible as well as actually realized and currently used connections and relationships.

In such a network the structures are flat and permeable with short and direct communication and information paths. Each unit can work largely autonomously so that a clear division of tasks and clear responsibilities become possible. This accelerates the coordination of work processes as well as decision-making and solution finding. The flexible design of the forms of cooperation and communication enables the involvement of all participants in the development process, promotes interdisciplinary work, increases the ability to react to external influences and supports decision-making [Burc-2001].

Based on Fig. 15.7 the resulting IDE network structure shown in Fig. 15.10, in which essentially three types of units are represented.

[5]For example, the first two generations of a minivan for up to seven passengers, marketed under the names Sharan, Galaxy and Alhambra, were jointly developed and built by Volkswagen and Ford.

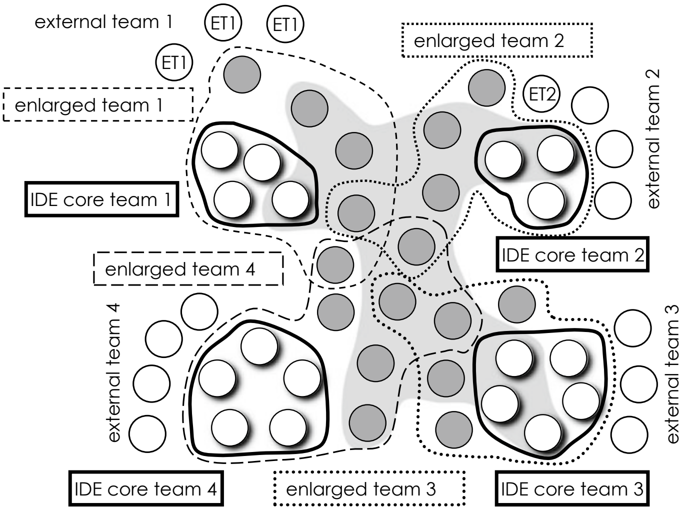

Fig. 15.10 IDE network structure (units in IDE core team: shaded circles, units in the extended team: dark grey circles, units in the external team: empty circles. grey area: department) [Burc-2001]

- The IDE core team works on the core tasks of the project. It acts as the central coordination office together with other teams. It consists of representatives of the departments required for this work and it remains in duty throughout the entire project duration.
- The extended team is made up of specialists from the company who are needed at certain times or at work sections, but who do not carry out the actual project work. It can happen that one person has to be integrated into several extended teams.
- If experts are needed from customers, partners, suppliers and other external parties, they are integrated into external teams.

Interdisciplinary and interdepartmental coordination institutions control and manage this network structure. Such an institution can be, for example, a superior project manager (Fig. 15.8) or a department head.

15.3 Process Organization Approaches

The process organization can be divided into the processing of routine tasks and of projects. Principle of operations may be either the “push” (obligation to deliver the completed results to the successive unit(s)) or the “pull” principle (obligation to collect the completed results from the preceding unit(s)). From a structural point of view it can be structured into serial or parallel processing and from a reaction type point of view into static and dynamic processing, Fig. 15.11.

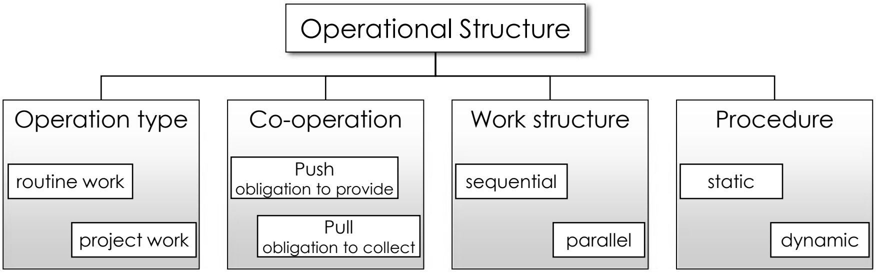

Fig. 15.11 Elements of the process organization

The two types of activity are routine tasks or projects:

- Routine tasks are recurring activities that hardly (or no longer) require creative work, but can always be carried out with comparable results using experience that was gained once.
- The characteristics of a project with individual objectives as well as fixed deadlines and resources lead to a one-time (and often also first-time) application of certain processes, procedures, tools and aids. This requires an individual approach to a task each time, even if existing experience and solution patterns can be used for subareas of the project.

When working with other units, a distinction is made between the push principle and the pull principle:

- With a push principle a unit processes a task and must pass on its partial and final results to the next unit, which then processes the task further.
- With the pull principle the downstream unit must obtain partial and final results from the upstream unit. It can then begin processing.

The workflow can be structured into sequentially, parallel or mixed forms:

- In sequential processing, the individual steps are processed one after the other. A new step can only be started as soon as the previous one has been completed.
- Simultaneous Engineering (SE) or Concurrent Engineering (CE) can be used for different types of parallel processing (see Sect. 15.1).

The processing procedure can be static or dynamic:

- The static procedure triggers a process flow that cannot be changed during processing (workflow[6]). External changes (regardless from whom or from where they originate) are not taken into account.
- The dynamic approach allows you to react appropriately to changes in requirements or the environment at any time in order to meet deadlines and budgets.

[6]Workflows are used when processes must be reproducible, for example in change and release processes, processes for quality assurance or in accounting.

This results in the following preferences for IDE:

- Since there are almost no routine tasks in IDE, only the processing in the form of projects is possible. Integration of the individual areas involved in the product life cycle can only be achieved in the project organization.
- Team members work with the push or the pull principle, as required.
- In the projects, people work in parallel as a team, whenever possible. Which of the parallelization forms is applied depends on the extent of the respective task (then preferably CE) and whether it is time-critical (then preferably SE). If a task is extensive and time-critical, the mixed form shown in Fig. 15.4 is used (but see also Fig. 15.7).
- Static procedures are more likely to be found in the areas downstream of IDE (see also Fig. 15.2). In IDE itself, all procedures are dynamic.

There are numerous concepts for designing and managing the process organization, of which typical representatives are presented. These are the Stage-Gate process, the milestone-based project processing, two approaches of Agile Development (Scrum and Extreme Programming), Lean Product Development, and, as a transition to dynamic navigation (Sect. 15.7), Dynamic Product Development, which has already been presented in Sect. 1.4 but is described here from an organizational process perspective, as well as an approach to recognize and use recurring patterns in the problem-solving space of product development.

15.3.1 Stage-Gate Process

The stage-gate process by Cooper [Coop-2002] distinguishes between a work phase (stage) and decisions to make at a certain time (gate). Stages and gates are defined with regard to their content and consequences, Fig. 15.12.

- Stages are preliminary studies in the basic plan, detailed investigations and preparation of the business plan, development work up to the prototype, test and evaluation of the results to date, start of production or market launch as well as the final evaluation (review). It is possible to add further stages at the beginning of the project.

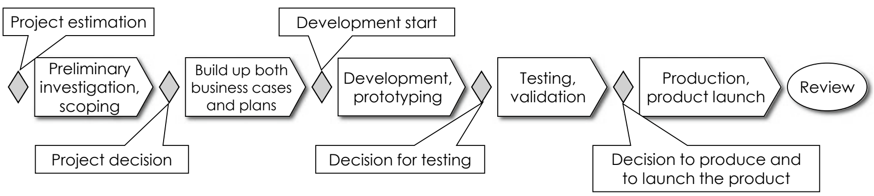

Fig. 15.12 Stage gate process (white arrows with text: stages, grey rhombuses: gates) [Coop-2002]

- Gates are at the beginning of the project (project estimation: decision whether the project should be started at all) and then after each stage. These decisions are defined in terms of content and time. Before passing to the next gate, the results of the respective preceding stage are evaluated by all groups involved in the project according to previously defined criteria. This can lead to rectification within the current stage. A gate can either be passed (then the next stage will begin) or not passed (then the project will be aborted). A gate cannot be passed through twice.

The stage-gate process is a sequential and rigid approach, which (like traditional Engineering design methods) assumes that the requirements formulated at the beginning will remain fixed during the course of the project and that the environment will not change either [Otto-2013]. This model is therefore not suitable for structuring project work in IDE.

15.3.2 Milestones

Milestones serve for structuring and thus for a better overview of the project process. On the one hand, they describe intermediate results relevant for the project process [DIN-69901], which can be achieved by using pre-defined (predetermined) resources (e.g. the availability of suitably qualified employees, machine capacities). During their scheduling, dependency and priority relationships are also established between them and milestones that have already been completed and to subsequent milestones. If a milestone cannot be reached at the time specified for it, the employees involved in a project must run through the relevant work packages again (also across working phases) to fulfil the milestone. Existing results are revised until the results are compatible with the milestone conditions or the assigned requirements of the milestone have been changed accordingly.

Milestones, on the other hand, are timely determined targets at which previously defined results must be presented. They provide a snapshot of all current activities of a project and evaluate their results. After negative evaluation, milestones can be repeated or offset.

The milestones include, for example

- Project start (the so-called kick-off) and project end,
- the respective logical end (completion of a project phase and transfer of the results to the next project phase) or financially conditioned end of a project phase (release of funds for the next phases takes place depending on the results achieved so far) and
- the “point of no return”, i.e. the point in time from which it is no longer possible to terminate the project without significant damage (technical, economic, political, etc.).

Most of the milestones used in IDE refer to the complete fulfilment of particular work packages. They are therefore defined in terms of content and not in terms of time and they are of a dynamic nature. This gives the employees involved the time they need and helps them to manage the project in a result-oriented manner. These milestones are intended to coordinate the development work.

Decisions that could jeopardize the continuation of the project are taken, where applicable, in timed milestones[7]. In industrial practice, such milestones are preferred because they enable the client (or the higher management of the development company) to call up the current project status at any time and to keep an open decision on the continuation of the project. Due to this permanent possibility of project termination (often for cost reasons), work results have to be generated continuously so that they can be verified. Extensive process parallelization with work results that are open over a longer period of time is therefore only possible to a limited extent.

In summary, the term "milestone" can be defined and understood in very different ways (e.g. in terms of time, content, repeatability, rigidity). The most common application is fixed in terms of content and time and is therefore rigid and inflexible.

It therefore makes sense for IDE to delimit certain development phases no longer by milestones but by various events defined in terms of content (project status queries and decision points in time) in order to maintain the flexibility and dynamics of the development processes, especially with regard to the processing time of the individual phases.

An IDE process is structured in such a way that project management can react as easily as possible to problems and changes in requirements within the entire project. The properties of the different elements of the process should therefore be exploited as much as possible in order to save as much processing time as possible. The main instruments are the phase endings [Neut-2010]:

- Project status query (PSA): Since PSA is defined in terms of content rather than of time, one has the option of bringing forward or postponing a roughly planned phase end. In this way, bottlenecks can be compensated or time buffers can be created.
- Decision point in time (DPT): The phase end by a DPT is basically not always to be regarded as fixed. Rather, it is to be seen as partially dynamic, i.e. it is quite possible to bring forward the DPT in the event of early provision of results. Only the time after the specified decision date cannot be used, as otherwise the timely completion of the project cannot be guaranteed.

[7]In the automotive industry, for example, fixed variants of the components of a vehicle must be available at certain points in time in order not to endanger the start of production of a product.

15.3.3 *Agile Development*

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Generally seen, Agile[8] Development refers to a group of development methods based on iterative development, where requirements and solutions evolve through collaboration within self-organizing teams. The Agile development methods have their origins and roots in software development, from practice rather than from academia (e.g. [SuNa-2018]). The Agile view is spreading rapidly also to non-technical areas. Agile development (AD) is an umbrella term for a set of frameworks and practices based on the values and principles expressed in the Agile Manifesto [Agil-2019].

Agile methods all stress the use of autonomous self-organizing teams (see also Sect. 15.6). The term *self-organizing team* means "individuals [that] manage their own workload, shift work among themselves based on need and best fit and participate in team decision making." The most widely adopted agile methods are *Scrum* and *Extreme Programming* (XP) (e.g. [HoSG-2018, PHSA-2008]). Scrum is becoming increasingly used for a lot of development tasks (e.g. [SAGS-2019, LiFu-2018]). While Scrum mainly covers project management, XP focuses on developmental practices. Both methods will be discussed further down.

15.3.3.1 Agile Foundational Values and Supporting Principles

Principles and philosophy of agile development are described in the Agile Manifesto from 2001, which comprises four foundational values and twelve supporting principles [Agil-2019]. The four Agile foundational values tell that

1. *Individuals and Interactions Over Processes and Tools*

Valuing people more highly than processes or tools is easy to understand because it is the people who respond to business needs and drive the development process. If the process or the tools drive development, the team is less responsive to change and less likely to meet customer needs. Communication is an example of the difference between valuing individuals versus process. In the case of individuals, communication is fluid and happens when a need arises. In the case of process, communication is scheduled and requires specific content.

2. *Working Product Over Comprehensive Documentation*

Historically, enormous amounts of time were spent on documenting the product for development and ultimate delivery. Technical specifications, technical requirements, technical prospectus, interface design documents, test plans, documentation plans, and approvals required for each are examples of this. The list was extensive and was

[8] In large, "to be agile" means to be able to move quickly and easily, often following an impulse to improvise activities in a flexible way without planning far ahead.

a cause for the long delays in development. Agile development does not eliminate documentation, but it streamlines it in a form that gives the developer what is needed to do the work without getting bogged down in minutiae. Agile documents require user stories, which are sufficient e.g. for a software developer to begin the task of building a new function. The Agile Manifesto values documentation, but it values working on a working product more.

3. *Customer Collaboration Over Contract Negotiation*

Negotiation is the period when the customer and the product manager work out the details of a delivery, with points along the way where the details may be renegotiated. With development models such as the Waterfall model (e.g. [Wien-2014]), customers negotiate the requirements for the product, often in great detail, prior to the start of any work. This means that the customer is involved in the process of development before development begins and after it is completed, but not during the process. Collaboration is a different creature entirely. The Agile Manifesto describes a customer who is engaged and collaborates throughout the development process. This makes it easier for development to meet the needs of the customer. Agile methods may include the customer at intervals for periodic demos, but a project could just as easily have an end-user as a daily part of the team and attending all meetings, ensuring the product meets the business needs of the customer.

4. *Responding to Change Over Following a Plan*

Traditional development regards change as an expense. The intention is to develop detailed, elaborate plans with a defined set of features and with everything, generally, having as high a priority as everything else, and with a large number of many dependencies on delivering in a certain order so that the team can work on the next piece of the puzzle. Agile responds to changes instead of following a plan.

The Agile philosophy is described in twelve central principles telling that

1. The highest priority is to satisfy the customer through early and continuous delivery of valuable products.
2. Changing requirements are welcome, even late in development. Agile processes harness change for the customer's competitive advantage.
3. Deliver working products frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
4. Business people and developers must work together daily throughout the project.
5. Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.
6. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.
7. Working products are the primary measure of progress.
8. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.

9. Continuous attention to technical excellence and good design enhances agility.
10. Simplicity—the art of maximizing the amount of work not done is essential.
11. The best architectures, requirements, and designs emerge from self-organizing teams.
12. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behaviour accordingly.

The terms in the manifesto are not well defined, which allows for individual interpretations that give a freedom but that also can cause misunderstandings and problems. Some of the principles of the manifesto may be out-dated in the meantime [ClCY-2018]. Principle 6 is such a one, as the development of IT-possibilities make it feasible to sit at different places still cooperating in a perfect way. Another weakness is that the manifesto has no product or system lifecycle perspective [ClCY-2018].

15.3.3.2 Scrum

Scrum[9] is an iterative, incremental and agile development framework. Small development teams work as units to reach common goals. Agile can mean extremely short sprints (stages/phases) that deliver continuously, sometimes multiple times per day. Another interpretation understands agility as a waterfall-style development, but with burn-down charts[10], daily stand-up meetings or scrum meetings[11] to summarize results and progress, often supported by someone called the Scrum Master, who himself doesn't belong to the team. Note that in agile organizations teams manage themselves why project leaders are not used (Agile manifesto principle 5).

In a Scrum organization people have specific roles, e.g. as Product Owner, Scrum tagger[12], Scrum master, Scrum team member, etc. However, they don't set the team's goals and directions by themselves. In fact, these two conditions normally are derived from business needs [High-2004].

In this kind of development a Sprint is "an iterative cycle of development work" [Schw-1995] and as such, it essentially is the same concept as an iteration [Royc-1970] or cycle [Boeh-1988]. One could therefore claim that a sprint can be described using a combination of existing terms, perhaps as a short iteration.

Generally a Sprint is a time-box of one month or less during which a "Done", i.e. a useable, and potentially releasable product increment is created. Sprints have consistent durations throughout a development effort. A new Sprint starts immediately after the ending of the previous Sprint. During the Sprint

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[9] As to be agile means to move quickly and lightly as well as to be mentally quick, there may be a connection to the rugby terms "scrum" (short form of scrummage) and "sprint" for a short and fast run with the ball.

[10] A burn-down diagram is a graphical representation that shows over time the unprocessed tasks of the project and thus the work still to be done for the project.

[11] Meetings to summarize the results and progress of the project.

[12] A person, who applies tags to the artefacts being generated in order to register the technical skills necessary to develop the characteristics associated with artefact in question (see also Fig. 17.19).

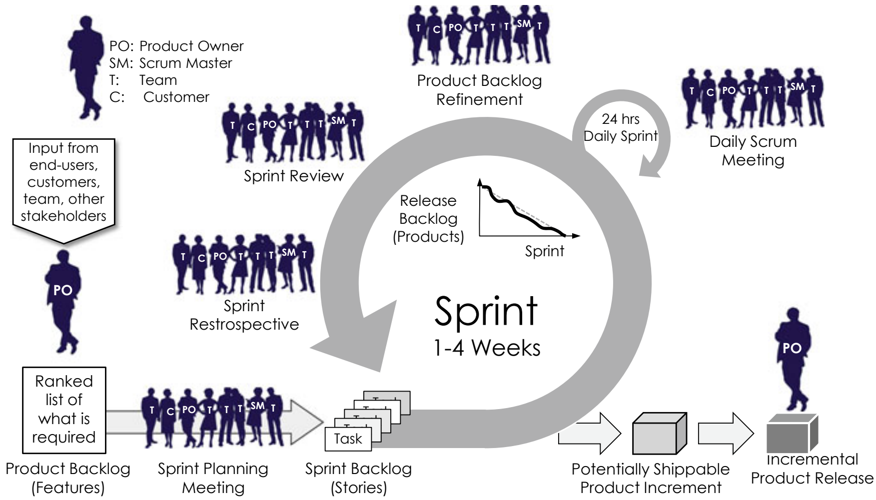

Fig. 15.13 General scheme of scrum (based on [Kshi-2015, Scru-2019])

- no changes are made that would endanger the Sprint goal;
- quality goals do not decrease; and
- scope may be clarified and renegotiated between the Product Owner and Development Team as more knowledge has been created and more has been learned.

Each Sprint may be usually considered as a subproject with no more than a one-month horizon. Like projects, Sprints are used to accomplish something. Lie a common project, each Sprint has a goal of what is to be built, a design, and a flexible plan that will guide building it, the work, and the resultant product increment, Fig. 15.13.

15.3.3.3 Scrum of Scrums

Scrum of Scrums or *Meta Scrum* [ScSc-2019] means to divide larger projects in smaller Scrum teams and organize them in a classic line organization pattern with an *Integration Scrum Team* on top. This Integration Scrum Team is responsible for the coordination and the assembly and integration of the different solutions to one single product or system. An Integration Scrum Team can be set up with team members that work only on the integration mission. Team members from each of the Scrum teams can be designated to be the links between the teams and the Integration Scrum Team.

The Project Owner is the same person also for the development teams unless the project is not too big for one person to have that responsibility. For bigger projects, subproject owners have to be appointed to handle the ownership. Also the Scrum

Master of the Integration Team can be Scrum Master for the underlying Scrum Teams. For real big projects the line organization pattern will get more hierarchy levels for which the term “Scrum of Scrums and Scrums” is used.

Each daily scrum within a subteam ends by designating one member as *ambassador* to participate in a daily meeting with ambassadors from other teams. Depending on the context, the ambassadors may be technical contributors. If an Integration Scrum team is not used for the Scrum Masters, the Scrum Masters of the teams can also be used as ambassadors, which also can be managers of each team.

The Scrum of Scrums meting proceeds otherwise as a normal daily meeting, with the ambassadors reporting completions, next steps and impediments on behalf of the teams they represent. Resolution of impediments is expected to focus on the challenges of coordination between the teams; solutions may entail agreeing to interfaces between teams, negotiating responsibility boundaries, etc. The Scrum of Scrum will track these items via a backlog of its own, where each item contributes to improving between-team coordination.

For teams working on disparate projects or products that have no integration, the Scrum of Scrums can be used as a coordinating mechanism for the organization. In that case they meet less frequently.

Outside the Scrum of Scrums meetings, relevant individuals from the meeting volunteer to deal with eliminating operational impediments that are identified related to the release and deployment process. This is partly equivalent to Scrum team members working together in a Sprint. For example, a Scrum of Scrums would have coordination mechanisms to deal with cross-team dependencies related to completion of epics required for release.

The role of management in a Scrum of Scrums is critical. They hold the Scrum of Scrums Master accountable for delivery. As a result the Scrum of Scrums Master is usually a more senior person, often at the Director of Engineering or higher level. The Scrum of Scrums is not the management team that deals with company impediments. The Scrum of Scrums may refer company issues to management team mentioned before, although the Scrum of Scrums deals directly with operational issues.

15.3.3.4 Extreme Programming

Extreme Programming (XP) is an agile work principle method with a strong focus on software development. “XP isn’t really a set of rules but rather a way to work in harmony with your personal and corporate values.” ([XP-2019]) Thus, it gives a philosophical view more than it gives work principles.

Similar to other Agile Methods of development, XP aims to provide iterative and frequent small releases throughout the project, allowing both team members and customers to examine and review the project’s progress throughout the entire development process. Thus, XP is a software development methodology designed to improve the quality of software and its ability to properly adapt to the changing needs of the customer or client.

XP has five Extreme Values that provide the foundation on which the entirety of the Extreme Programming paradigm is built, allowing the people involved in the project to feel confident in the direction the project is taking and to understand that their personal feedback and insight is as necessary and welcome as anyone else ([XP-2019]).

- "Simplicity: We will do what is needed and asked for, but no more. This will maximize the value created for the investment made to date. We will take small simple steps to our goal and mitigate failures as they happen. We will create something we are proud of and maintain it long term for reasonable costs.
- Communication: Everyone is part of the team and we communicate face-to-face daily. We will work together on everything from requirements to code. We will create the best solution to our problem that we can together.
- Feedback: We will take every iteration commitment seriously by delivering working software. We demonstrate our software early and often, then listen carefully and make any changes needed. We will talk about the project and adapt our process to it, not the other way around.
- Respect: Everyone gives and feels the respect they deserve as a valued team member. Everyone contributes value even if it's simply enthusiasm. Developers respect the expertise of the customers and vice versa. Management respects our right to accept responsibility and receive authority over our own work.
- Courage: We will tell the truth about progress and estimates. We don't document excuses for failure because we plan to succeed. We don't fear anything because no one ever works alone. We will adapt to changes whenever they happen."

Figure 15.14 presents a general project approach of Extreme Programming.

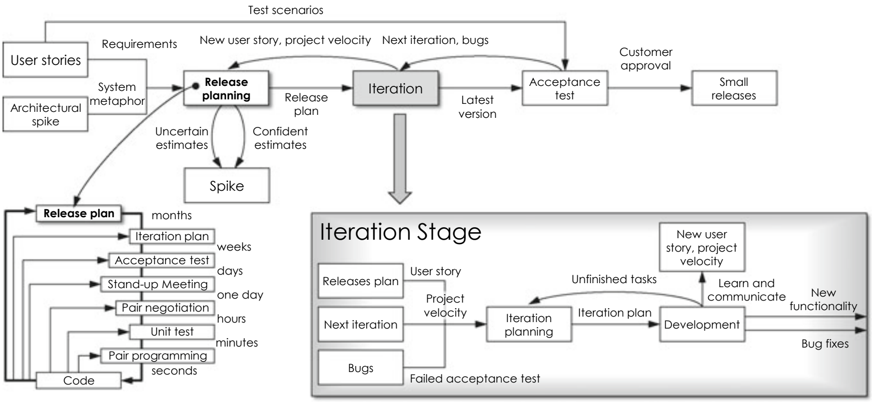

Fig. 15.14 Extreme programming project approach (based on [SlXP-2019, Lara-2019, Hash-2019]). User story: a user requirement formulated in everyday speech. Spike: a simple program to explore potential solutions. Pair programming: program creation where two people working together at the same computer in order to increase quality

15.3.4 Lean Product Development

With the approach of lean product development (LPD), parts of the approaches of lean production (that have profoundly changed the automotive industry) are transferred[13] to product development. The first question is whether this is possible at all, because product development deals with unique and innovative projects (Fig. 15.2) in which iterations and the risk of failure occur, while in production the same products are always manufactured with precisely defined and reproducible processes in order to e.g. achieve always the same level of quality.

Due to the different nature of the processes, LPD is not a process model. The focus is not on how product development is carried out in a company. For this reason, no (quasi-) standardized procedure is specified as for example in VDI guidelines 2221 and 2222 (Sect. 1.1.2). Instead, it is an optimization approach that primarily aims to reduce or eliminate non-value-adding activities, since these activities generate unnecessary effort (comparable to waste in production)[14]. This includes such activities that

- are necessary to develop a product, although they do not generate any direct added value for the customer. This includes, for example, maintenance and updating of CAx systems.
- can be removed immediately without negative effects, such as waiting times due to poor organization of project work or boundaries between departments.

For all other activities, a case-by-case examination is necessary to identify and reduce unnecessary effort.

To identify non-value-adding activities, all activities and areas involved in the creation of a product are subjected to a value-stream analysis.

- In this context, value is defined as the ability of the company to offer a product to a customer at the right time and at a reasonable price that generates added value for the customer (Chap. 2, see also Chap. 16).
- The value stream consists of those activities with which the product can be developed, manufactured and made available from concept to market launch. The value stream should be able to flow continuously and without interruptions.
- The value-stream analysis provides a representation of the information, material and financial flows in the value stream under consideration. The outcome of this analysis is the potential for improvement.

The analysis allows finding those activities that fulfil the respective task with a minimum of resources and processing time. Their total expenditure is compared with the value of the product as well as the attainable profitability of the product for the company is determined. All other activities, if not needed or required, can be reduced or avoided [Walt-1999]. This leads to the following characteristics of LPD:

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[13] However, the different meanings of the term *lean* are *thin, undernourished, unhealthy* and *scarce.*

[14] This approach is not new: As early as 1915, Lillian M. GILBRETH focused her consulting work in companies on the avoidance of waste in a physical and a figurative sense [Lanc-2004].

- Demand-driven focus on customer wishes and on the resulting tasks as the customer specifying the processing cycle (in the sense of a positive "customer pull").
- Appropriate support measures and information are provided in the right formats, sizes and qualities, in the right place, but only during the periods in which they are actually needed. They are not available in other periods.
- A continuous evaluation of the activities for target achievement is carried out.

Thus, LPD is primarily a collection of proven activity patterns, such as the *9P model* by PRINZLER [Prin-2011]. This model consists of the following instructions:

- Positioning: Finding the most suitable strategy to meet market requirements.
- Prioritization: Definition of suitable and achievable goals for the company on the basis of customer requirementsor of the market, respectively.
- Projection: Define and set up a project with a clear focus and clear objectives.
- Product Classification: Find and use existing part families, modules and standard parts that can be used for the product to be developed.
- Product development: Develop products according to the criteria of Six Sigma [DaHa-2009].
- Process standardization: Use of defined development processes.
- Product Lifecycle Management (PLM): Benefits of computer support covered of PLM (e.g. PDM systems, Chap. 18).
- Project controlling: Evaluation with key figure systems.
- Project feedback: Use of rules for experiences and lessons learnt from them to expand knowledge storage in the company with explicit knowledge (Fig. 12.2).

In an LPD environment, especially in the development of software, there are a number of the so-called agile methods that are specialized for certain applications. Characteristic of all these methods are teamwork, self-organization, flexibility, delegation of responsibility to the performers, joint responsibility and intensive personal communication, which is not necessarily subject to clear sequences and rules, but is spontaneous and disordered, so to speak as being in a scrum[15]. The flexibility of these methods allows the process to be changed. In order to reduce the risk of failure, products are developed using partial results in short periods of time, known as "iterations". Each iteration includes design, development, testing and documentation of the resulting product. The intermediate or partial results document the current progress and are released incrementally by the team. Therefore, robust partial results of the project are already available after a few iterations [OtKo-2017].

With the tools of the LPD and its various features, the efficiency of the activities can be noticeably increased on the one hand. On the other hand, by focusing on

[15]The colloquial British English term for "crowd" (both in public and in sport) is "scrum". This name became a generic term for a certain form of quick daily exchange and consolidation of information on the results achieved since the last Scrum, especially in software development projects (see Sect. 15.3.3.2).

customer wishes (which can usually change at short notice) and by concentrating on avoiding (superficially) superfluous activities, creativity and thus the innovative ability of product development can be equally noticeably hindered.

15.4 Dynamic Product Development

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The scientific basics of Dynamic Product Development (DPD) were presented in Sect. 1.4. This Section at hand describes how the dynamic principles of DPD can be applied in strategies, processes, and activities within product development. These principles were boiled down to useful rules of thumb for everybody doing some kind of development. Although difficult to make comparing studies, using dynamic development principles indicates that they can cut down development time and development costs at the same time as the user satisfaction and pleasure can increase [Björ-2009].

For organizational purposes also two opposite management strategies can be used for the development—the classic or the dynamic. The classic strategy works well for a slowly changing and predictable world. The dynamic strategy is well suited for rapidly changing situations and for innovative activities. Therefore, Dynamic Product Development (DPD) uses the dynamic management strategies represented as the Planetary Organization, that can be seen as a combination of the linear organization and self-organization (see Sect. 1.4).

Dynamic models, such as DPD, Lean Product Development (LPD) and Agile Product Development, are designed to handle unstable conditions and increasingly complex developments typical of New Product Development (NPD) projects. DPD is the sole PD model designed for want- and wish-based PD of all types of products. The research on DPD has mainly been done as Insider Action Research (e.g. [Björ-2003]) or more specifically Participation Action Research (e.g. [Otto-2003]).

Possible triggers for the start of a product development in DPD are either a concrete need with a short-term realization horizon and a low level of innovation, a need with a medium-term horizon and incremental innovation or a wish with a long-term horizon that can lead to radical innovation or even a disruptive solution (Sect. 1.4).

One very special and important rule for DPD is not to list many demands and then to solve them as for the classic start. Instead one should not have more than a few demands to solve when the appointment of the project team leader takes place. Important is also that the project leader has the responsibility for appointing her/his team and not the reverse way typical for the classic way of working.

The principle of finding and reducing the number of remaining demands to solve for the two principles is shown in Fig. 15.14. Working in the dynamic way has shown to reduce the time to ready product considerable. It is not uncommon that the number of demands to solve in the traditional way of working can be 100. The number of

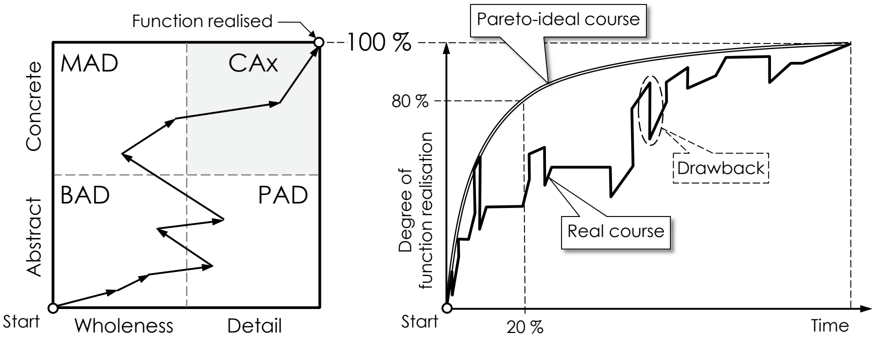

Fig. 15.15 Left side: developing a product concept applying BAD (Brain-aided design), PAD (Pencil-aided design), MAD (Model-aided design), and CAx (Computer support for all kind of activities in product development; see also Sect. 1.4). Right side: Deviation from the ideal project course due to dysfunctions in the project flow [Otto-2016]

remaining demands to solve for the dynamic way of working should not be more than four at any time in the development process.

Wish-based PD—and partly also want-based PD—starts with developing a concept product that is converted into a product concept when a functional design has been developed (see left part of Fig. 15.15). For the development of a concept product the market connection is rather weak while it is important for the development of a product concept. The time it will take to reach a functional level is dependent on many factors. Often disappointments and drawbacks will be felt when a promising solution shows up not to hold. The right part of Fig. 15.15 shows a principle example of this.

Contradictory to what is taught in general—that all demands must be set before the creation of a concept starts—we have found that one shall start only with one primary demand and 2–3 secondary demands and then start to create concepts and solutions to satisfy them. When one or more concepts & solutions have been found, more demands are added for each of them. These demands can result in that new solutions must be found. If a solution does not hold in the test and evaluation it is stopped from further development and documentation is done of the findings and experiences. Using this principle, which is shown in Fig. 15.16, the work can go ahead at a high speed to end up with a final concept and solution that is well documented.

When one or more basic concepts—independent of concept type—have been agreed upon as interesting to make further development on, it is time to take on the concrete and detailed development of the product concepts. Initially—and when problems occur later in the development process—BAD, PAD, MAD (Model-Aided Design) and tests of the models in general show to be a fast and efficient way of working until detail engineering design can be done (see Sect. 1.4).

To make MAD means to make simple models in as soft materials as possible so as to quickly understand the effects of the solutions with the help of as many of our five senses (See, Hear, Taste, Touch, and Smell) as possible. For the shaping and the

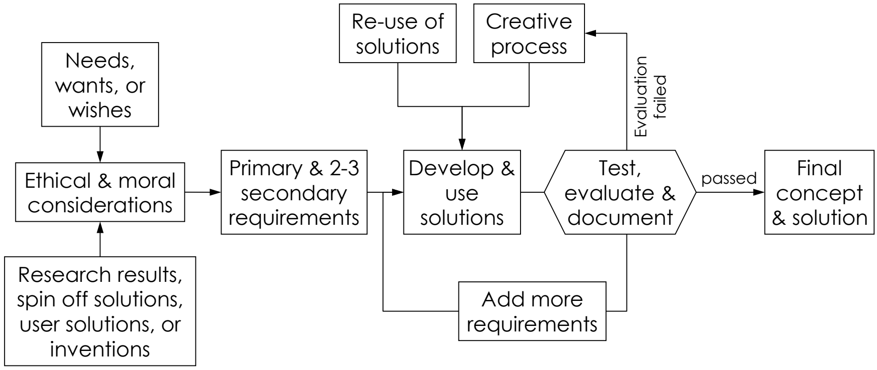

Fig. 15.16 The concept development is an iterative process in DPD [Otto-2018]

changing of hardware models in their soft material, in principle a multifunctional Swiss Army knife in most cases is the only tool needed. Techno LEGO® can also be used to find out the mechanical functions of possible solutions. When solutions have been found one can benchmark other solutions before it is time to apply computer support to as much development activities as possible (CAx; Figs. 1.31 and 15.16).

Efficient hardware development of different parallel activities can be performed as Simultaneous Engineering. As DPD is a user centred development model, DfU (Design for Usability) comes first in the development when a functional concept principle has been found. All the time until the project is finished, checks must be made that the demands on DfU are not violated e.g. when DfMA (Design for Manufacture and Assembly) shows that a more efficient production will be possible making changes on the design, Fig. 15.17 (further DfXes are explained within this figure).

Thus, DfU should be present from the start to the end of the development (grey area in Fig. 15.17). Therefore, of great importance for the product developers is to get to "know the user" and the use of the product. She/he also needs to realize that users are not possible to collect in homogenous groups, which is why they request solutions on individual basis. Age, experience from usage of similar products, or other relevant experience, financial situation, and life situation are just a few of all aspects that influence the user of a product. Therefore, the product developer's ability to empathize, participate and understand user situations is critical for the analysis of how new products can support e.g. disabled people and offer adequate usability.

Several principles or rules of thumb are used in DPD for practical work. These are the principle of flowing water, the change between activities, the application of the Pareto principle (Chap. 1), the principle of preliminary decisions and the principle of making many small and few large decisions.

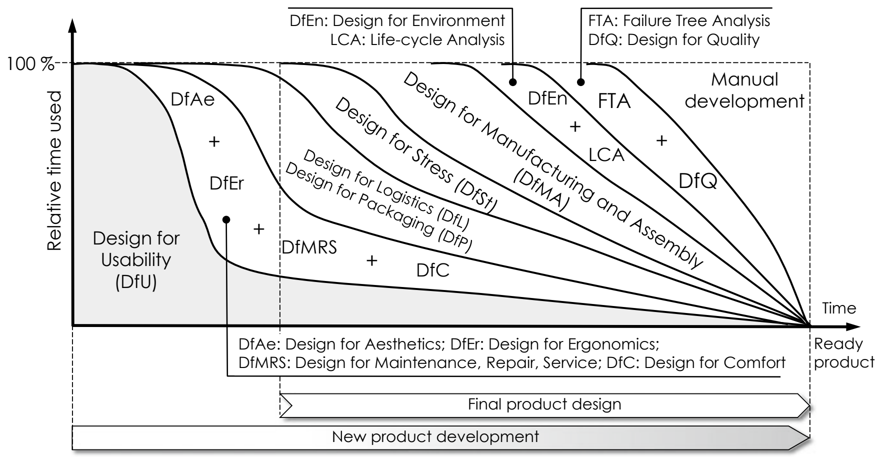

Fig. 15.17 Application of DfU and further DfX methods in the development of a mechanical product after the creation of the functional concept [Otto-2018] (see also Chap. 14)

15.4.1 Principle of Flowing Water

During the technical development it is essential to always look for emerging main problems and to attack them immediately with as much forces as needed. When the main problem has been solved it is often easy to solve the lesser problems. For smaller problems the principle should be to go around them and to leave the solution of such problems to a special task (or cleaning up) force. Thereby the progress of the total process is not slowed down by the small problems.

This way of working when the main problem has been solved is called the *Flowing Water Principle*. This as it has similarities to how water flows around obstacles, Fig. 15.18. The important characteristic is the flexibility of flowing water and its momentum. If the obstacle is massive, water accumulates and eventually finds a

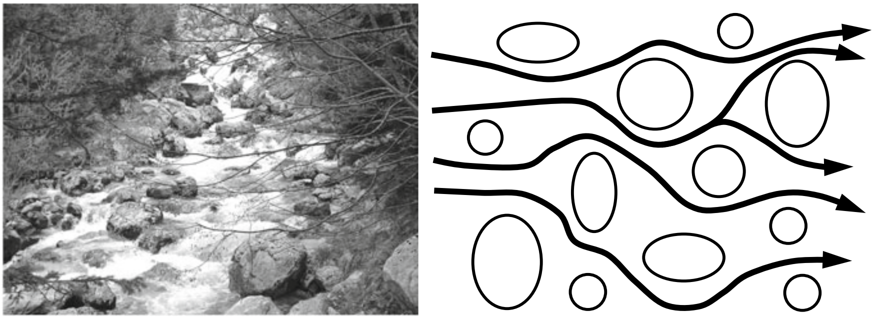

Fig. 15.18 The metaphor of flowing water is used to solve problems without losing momentum (photograph by the author and sketch from [Holm-2007])

weak point and breaks through. In the same way larger, perhaps critical problems are attacked and resolutely solved with the combined force of team members and project resources.

15.4.2 Principle of Switching Between Activities

Since speed, initiative and money can be reduced or lost when people spend their time waiting (c.f. e.g. [Bjoe-2009]), it is important that they have many activities to switch between. So if for some reason one can't continue at a particular point, one should document the interim result and work on the next most important activity or task until one can return and continue with the previous activity or task. By following this step-by-step procedure, the solutions will become better and better. It has also been found that the creative abilities of humans benefit from switching between different activities if there are not too many at once (their number should be between six and seven parallel activities, as this number covers the so-called control span that a brain can handle in parallel, see also Fig. 15.18). It has also been found that the more experienced and competent a product developer is, the greater the ability to switch and iterate between activities [AdTA-2003], and that this principle also reduces waiting times and costs.

Often it is not necessary to follow a specific task, if different subtasks are processed to get the overall solution, Fig. 15.19. In this example, five tasks have to be processed to get the overall solution. The task processing starts in the centre with the first subtask. As soon as a workable intermediate result has been achieved and documented for this subtask, you can switch to the next subtask, and so on. When acceptable solutions have been found for each subtask (the markings on the respective task arrows), the task processing ends.

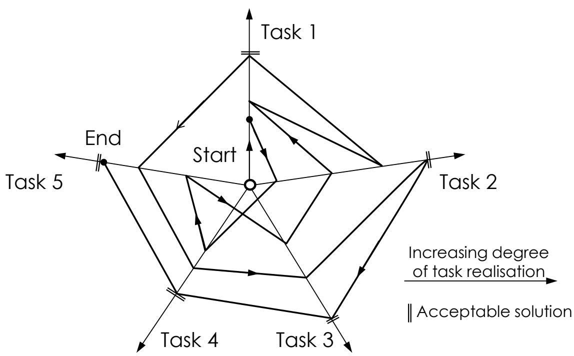

Fig. 15.19 Random shift between tasks

15.4.3 Application of the Pareto Principle

There is a proverb: "Perfection is the enemy of the good". Good enough is the solution to that. This guiding principle can be called the Pareto Principle (see Chap. 1). It says that when working in product development one shall test a solution as soon as it is "good enough". Based on the results the solution is improved to another "good enough" level after which a new test takes place. After three such cycles an almost 100% solution has been reached in a very short time. If one instead tries to reach 100% directly it in reality shows that the time it will take to reach that level will be much longer.

In the 1940s, J. M. JURAN introduced the 80/20 rule as the *Pareto principle* [Jura-1951]. He found out that this principle should be a very effective management instrument, since it can be applied to almost anything, from scientific management to activities in the physical world[16].

In product development, a solution should always be re-tested if it is "good enough". Based on the test results, the solution is taken to a higher level of "good enough", whereupon the next new test is performed. After three such cycles, an almost 100% solution can be achieved in a very short time. If instead one tries to achieve the same solution directly, the industrial reality shows that the time required for this will be much longer.

15.4.4 Principle of Preliminary Decisions

In traditional management literature a constant piece of advice is to make decisions as early as possible. By doing so, it is thought, the decisions will help to provide orientation for people working in the development process. For management that also means that it is easy to follow up on decisions that have been put in action. Thus, by taking one step at a time it is believed that the development will be safe and efficient[17].

However, in reality it shows that the opposite way of acting—making early preliminary decisions and late final decisions—gives a safer and more efficient result [Holm-2007]. This does not mean that one shall not set deadlines (milestones at specified completion time) as people tend to work harder close to the deadlines than when

[16]This principle is also known in Sweden as the "Lagom" principle. For this term there is no direct translation in German, it can mean for example "good enough", "not too little and not too much", "just right", "fair share". The term refers to a balance of requirements and it neither has a negative meaning, nor does it claim perfection.

[17]This assumption should not be confused with the recommendation to work on only one thing at a time (and not several at the same time). Processing only one task at a time allows you to concentrate fully on that task and thus complete it with an appropriate result in an acceptable time. In contrast, in multitasking about 2/3 of the available human concentration power is consumed by switching between the different tasks and, before the actual processing begins, restoring the respective processing states of the individual tasks [KuSe-2008, Schw-2012].

there is plenty of time to next deadline. That is connected to the principle of "Make many small and few large decisions".

One important reason for the principle of as late final decisions as possible is that it is impossible to know in detail what will happen in the context of the development project. Having made a fixed early decision, therefore, means that the flexibility of the project is taken away as new information cannot be taken into account during the process. Going back on a decision is frustrating and is often seen as bad management. Changing direction more than once often means that the confidence in the project leader is deteriorating with every step.

Explaining the reasons for going back on a final decision and motivating the team members for a new decision is a difficult process in general and especially difficult if hard facts do not exist as to why a new orientation is needed. When hard facts exist to make a new decision—and not only gut feelings—it often is too late to make the change causing the project to fail anyway.

Thus, in DPD, one as a general rule makes final decisions as late as possible. Instead of taking early fixed decisions one makes preliminary decisions that are easy to change when required without mental blocks. This general rule of course must be applied cautiously. It doesn't mean e.g. not ordering models and prototypes on which to make tests, or not hiring the competences necessary to speed up the pace. Needed investments must be taken but e.g. scrap material can often be used for initial tests, which is cheaper and faster than buying new test material.

Taking preliminary decisions means maintaining the flexibility to make changes and take shortcuts when needed without causing mental difficulties. This principle is connected to the next rule—to make many small and few large decisions.

15.4.5 Principle of Making Many Small and Few Large Decisions

For any type of development, it may be necessary from time to time to change the direction of the project due to external and internal influences, which may lead to unforeseen changes (for influences of these on a team see Sect. 15.6).

- External influences from the development and application environment of the product are, for example, additional requirements and expectations of the customer for the product during project processing or new laws and changed technologies. Depending on their effect, these can be positive (such as the introduction of a new technology such as additive manufacturing, which leads to lower manufacturing costs) or negative (such as additional requirements without allocating the necessary additional budget or a longer processing time).
- Internal influences are unforeseen problems in project execution. A positive influence is the possible shortening of project execution due to other organizational forms, which reduces processing time and costs. Negative influences are often the lack of personal, organizational, technological or financial resource.

If such influences occur, the basic strategy is to deal with these issues immediately and not to decide them too long after their appearance (although of course an appropriate occupation with a topic must not be neglected). A reasonable response time promotes many small decisions with little (and controllable) impact on the project, while a long response time (e.g. by accumulating a number of problems before processing or a general departure from decision making) forces a large decision with different consequences for many other issues and areas, which (due to fragmentary control possibilities) can lead to significant difficulties in the project, until the failure of the project. In any case, any decision must take into account possible alternatives to be tested according to DPD principles[18].

A metaphor for this principle is the steering of a small boat that has an autopilot but is sensitive to fast flowing water or strong wind. In order to achieve a goal, every time an external or internal influence occurs, a new direction must be taken, as well as when the skipper feels that an increasing problem should be avoided.

15.4.6 Further Principles

There are further principles and useful rules of thumb that are summarized as follows:

1. The focus of new developments and innovation projects is on fulfilling relevant and well-founded requirements from within the company, from users and from society (the so-called CUS requirements). Compile these requirements, as they serve as a reference for recording and measuring development progress. Add new requirements when agreed.
2. Allocate a preliminary budget and estimate the development time for each project. Monitor both cumulative development costs and the technical status of each project on a weekly basis.
3. Each new development and innovation project should be built around an entrepreneurially minded project manager, who in turn will recruit motivated and qualified team members who not only share the CUS requirements, but also have high moral and ethical standards of their own.
4. Each development project is organized as a planetary organization (see Sect. 1.4). The (entrepreneurial) project leader is at the centre of this organization. Self-organizing teams (the so-called planets) do the preliminary work. The teams are preferably supported by experienced mentors (the so-called comets).
5. Development work starts with the identification of the most important requirements for the product to be developed. Afterwards, a first model of the product, which fulfils these requirements, is developed and tested with creativity methods. The next development loop begins by identifying the next most important requirement, which is processed in the same way as the first development.

[18]Further testing and assessment options are discussed in Chap. 25.

6. Many different product properties must be met during development. In IDE, these are described by the six product attributes (Chap. 2). In DPD, functional fulfilment is the most important property that must not be overridden by other product properties. The different product properties require special knowledge and experience covered in the methods of Design for X (DfX), where X covers a specific area such as DfU (Design for Use) and DfAe (Design for Aesthetics).
7. The order in which the individual DfX methods are applied depends on which product is to be developed. However, DfU always comes first in the development chain and must be checked in all new development steps (cf. Fig. 15.17).
8. New inputs and requirements are welcome in the iterative development work, which can lead to more work than expected after completion of the respective DfX method.
9. If the development project is an innovation project, commercial development must also take place parallel to technical development.
10. Visualize the solution under consideration before you start creating a physical model or programming software.
11. Document the development simply and clearly with sketches, photos and videos, so that you can understand logic and order of the development work at any time. Ensure that the documentation is complete and consistent in the event of any future litigation. Distribute the documentation to everyone involved in the project.
12. The most efficient and effective way to deliver information to and within a development team is always to talk in person, followed by video conversations. Respond quickly through any channel when someone requests answers or assessments.
13. Achieving and maintaining simplicity[19] is essential throughout the development process. If for any reason a standstill occurs, you should work on a different task, such as documenting, recapitulating the work already done, etc.
14. Ensure that other team members and (future) users can test the developed solutions. Provide structured feedback. Weekly discussions on the current status of the project serve to keep all project participants informed about progress and possible problems. Keep the customer and the next level of management in the company up to date as well.
15. At regular intervals, both team and project management will reflect on how to become more effective. The team then agrees on the new approach and adapts accordingly.
16. Create the documentation for use and service of the product and test it with the help of key people.

Basically, it is important and helpful to know, to understand and to apply these dynamic rules of thumb in order to accelerate development and improve results.

[19]"Simplicity" in this context means the art of minimizing the amount of work done without compromising the agreed results (c.f. also Sect. 1.8).

15.4.7 Comparison of Development Methods

Based on information from [Otto-2018], comparisons between different development methods can be made, Table 15.1. As seen Table 15.1, there are many similarities between the methods of Agile Development, Lean Development, and Dynamic Product Development (DPD). What is most dominant is that DPD™ has more defined work principles. It has also a theoretical background that is valid also for the other two methods.

Table 15.1 Some important differences of characteristic between the dynamic development methods Agile development (Sect. 15.3.3), lean product development (15.3.4), and dynamic product development

	Agile development	Lean product development	Dynamic product development
Background	Best practice	Best practice	Best practice + theory
Theoretical support	No theoretical foundation	No theoretical foundation	Quantum physics, chaos theory, complexity theory, innovation theory
Main research methods	Case studies (interviews)	Case studies (interviews)	Insider action research
Beneficiaries	Users, business	Customers, business	Users, business, and society
Leadership	No formal leaders	MBWA (management by walking around)	MBWA
Manning principles	Teams set up first	Teams set up first	Successive manning
Planning	Weekly individual planning	Weekly team planning towards a target	Weekly team planning towards a vision
Budgeting	No principles known	Traditional budgeting	A total amount and weekly check-ups of accumulated costs
Decision principles	Late final decisions	Late final decisions	Early preliminary and late final decisions
Documentation	As little as possible	A3 paper formats with curves, sketches, pictures, stories	Curves, sketches, pictures, log-books, e-mails, stories, etc.
Location	Colocation	Colocation	Both colocation and distributed location

(continued)

Table 15.1 (continued)

	Agile development	Lean product development	Dynamic product development
Work principles	– Iterations – Incremental steps – Frequent tests	– Iterations – Minimize waste – Quality assurance – Value streams	– Universal design – DFX order – Iterations within and between incremental work packages – Traffic light metaphor – Rules of thumb (e.g. BAD-PAD-MAD-CAD, Flowing water principle, switch between topics, for example, to reduce waiting time, apply the Pareto Principle, few demands to meet in each loop, and so forth)
Follow ups	Weekly meetings Performance, time (PT)	Weekly meetings Quality, cost, time (QCT)	Weekly meetings in the war room Performance, cost, time (PCT)
Comparing scientific studies with other PD methods	Nothing found	Nothing found	Yes, from hardware development, software development and organization studies

15.5 A Visual Understanding of the Product Development Process Based on Recurring Patterns in the Problem–Solution Space

Stefanie Rothkötter

In the development process, a product idea passes through various stages of increasing detail in order to be turned from an initial inspiration into a usable, producible and competitive product via concepts and prototypes. However, this path from the abstract to the concrete [HuEd-2002] can only be represented insufficiently in linear form [GeKa-2004, Laws-2004]. Especially models of the traditional development process that are based on a division into defined sections (e.g. [Coop-1986]) are hardly applicable at the beginning of a product development process (also called *Fuzzy Front End* in view of its fuzziness and uncertainty [DeCo-2007, SaSt-2008].

This challenge is particularly evident in a context where the goal of developing a product is not defined or not yet recognized as such by the parties involved. For example, product development theory in the area of innovation by individual *lead users* [LeHG-2008] describes inventive users who solve a problem in their daily working environment pragmatically by means of their own designs without initially pursuing the goal of product development. These users are in the midst of an intuitive, informal development process, which can create the basis for a later formal development process within IDE based on derived requirements. In order to allow the creativity of inventive users to be integrated into product development, communication and close cooperation between developers and users is advantageous, for example in the sense of co-creation (see Sect. 15.9).

In this section, a project-related visualization of product ideas and concepts is introduced to support this type of cooperation. The visualization is independent of a representation in stages and instead works with recurring patterns in the development process. Here, these patterns are not represented along a temporal dimension, but are regarded as movements in a problem–solution space that can be identified gradually. This approach is based on various product development and innovation theories in which the problem–solution space is described as a hilly landscape [VCJB-2005, NoVe-2014]. In an analogy to the so-called *fitness landscapes* from evolutionary biology [BBEG-2007], the development team moves, figuratively speaking, in a concept landscape and climbs mountains that correspond to the product ideas and concepts as shown in Fig. 15.20 (right). The higher the mountain, the more suitable the concept is as a solution for the development problem.

The first essential pair of patterns to be considered within this landscape is *divergence* and *convergence* [Simo-1999]. These terms are used to describe ways of thinking and acting which, on the one hand, contribute to a broad observation and the emergence of many alternative solutions (divergence) and, on the other hand, bring about a focus and decision on alternatives (convergence). These patterns are described in product design literature (e.g. [Lase-1986, DeCo-2005]) as well as in engineering design literature (e.g. [Fric-1996, VDI-2222/1997]).

Another essential pair of patterns is the contrast between *cumulative design* and *conceptual reorientation* [Cril-2010]. Cumulative design describes an incremental, iterative refinement of product concepts, whereas conceptual reorientation often involves a sudden change of direction [Cril-2010]. The combination of these

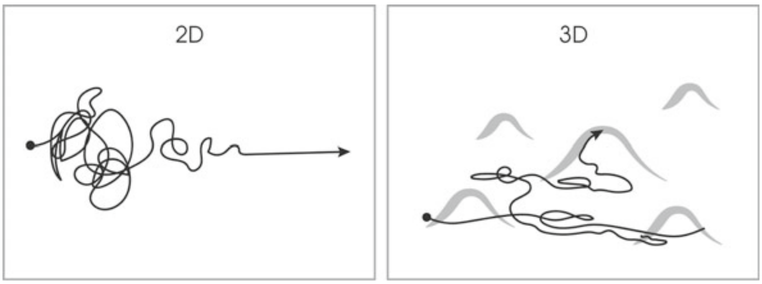

Fig. 15.20 Transferring the general design process (left, based on [Newm.-n.d., Sand-2019]) into a 3D landscape (right)

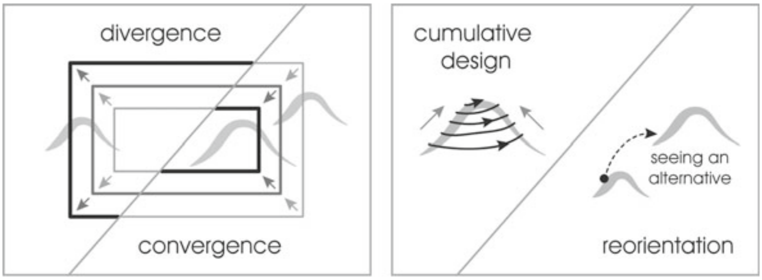

Fig. 15.21 Visual understanding of product development patterns in the problem–solution space

general patterns in product development as movements in the concept landscape of the problem–solution space is shown in Fig. 15.21.

The graphical representation of product concepts allows developers and users of the product to reflect on their common understanding of the development process. Users can test the solutions proposed by the development team and identify development potential that meets the users' immediate needs. At the same time, the development team can recognize the innovation potential or existing "blind spots" in user ideas and, using clever design, make the product experience tangible at an early stage of development by materializing or "manifesting" it [Moul-2015]. This approach does not only refer to physical objects, since the repertoire of design methods especially in prototyping is also suitable for other types of products such as services and spatial environments.

If the concept landscape is used as a visualization tool in the development process, individual rules for the spatial arrangement of ideas and concepts can be created. For example, it may be useful to cluster similar or related concepts and to map them in the same region of the landscape representation of the problem–solution space. It can also be helpful to exclude areas of the landscape from consideration if they are unsuitable for the solution search e.g. from a financial or regulatory point of view. These so-called *taboo zones* have already been described in the literature [VaKB-2010]. As shown above, the parallel processing of many concepts with different levels of detail can thus be captured without requiring a linear sequence of product development phases.

15.6 Teamwork

The work in the team contains elements of the structural and the process organization. In a team, a group of employees works together for a limited time to implement a specific project (see Sect. 15.2.3) or for new and complex tasks across hierarchical and departmental boundaries. As a rule, the employees are interdisciplinary in composition, complement each other with their respective knowledge, cultivate mutual relationships, have (despite different social competences, working and communication styles, reaction patterns and motivation structures) a strong cohesion and common goals. The work in the team is carried out as a joint procedure (without hierarchies) with as few formal regulations as possible. Members come from those areas of the company that are needed to work on a particular project. The team thus contributes to area integration (Chap. 14). The number of team members should be between five and eight (leadership range or span of control, respectively) and should not exceed ten persons, so that each member can communicate with all other members, work together and assess their tasks and activities, Fig. 15.22 (see also Sect. 14.2).

In the composition of a team, it must be ensured that a sufficiently large area of common knowledge exists as a basis for work and communication among the experts in all fields of knowledge required for the project, Fig. 15.23.

Working in a team is the working form of choice in IDE. The hallmarks of this are commitment to the common cause and the pursuit of common performance

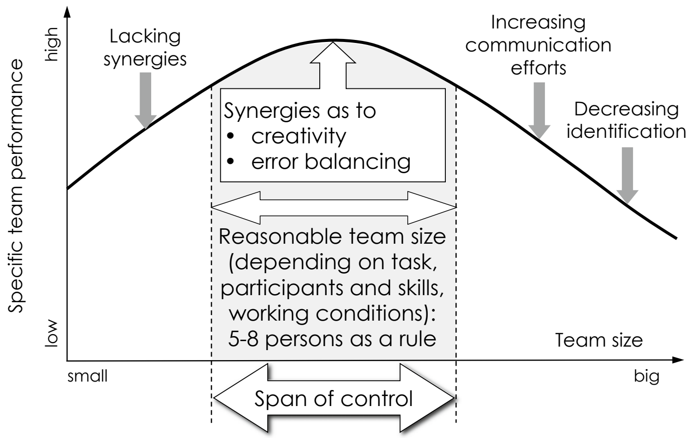

Fig. 15.22 Criteria for the size of a team (according to [Lind-2009])

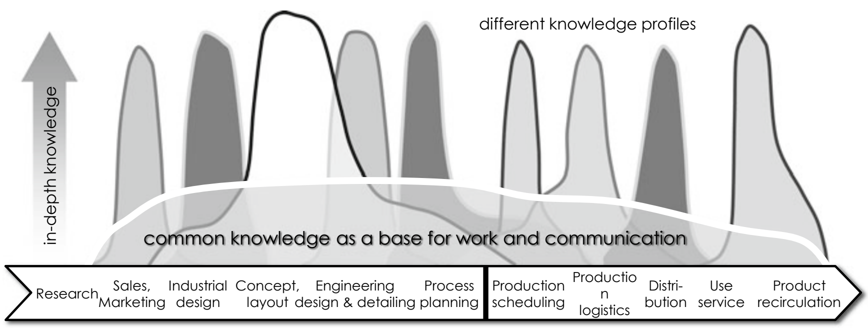

Fig. 15.23 Shared knowledge as a basis for team work and communication

goals through joint action and a high level of motivation. This is only possible with independent and responsible action.

15.6.1 Structure of the Team

A team can only work successfully for all participants in the project environment (clients, team members) if the participants are able to work in a team and are team-minded, because this is the only way to achieve team success outwards and team satisfaction inwards.

The ability to work in a team basically includes the ability to work together, to discuss with the willingness to be convinced without recklessly leaving one's own point of view, and to be able to deal with critical questions objectively and not personally. This requires a high degree of mental flexibility and the willingness to learn from mistakes.

In IDE, the members of a team come not only from different areas of a company, but also from different personality types (initiative, dominant, constant and conscientious), whose cooperation is promoted by a meaningful and skill-oriented distribution of roles, so that the synergy of the different characteristics as well as strengths and weaknesses of the team members leads to team success.

Teams need a certain time to grow together. There are four phases called forming, storming, standardization and performing, which are passed through [Tuck-1965], Fig. 15.24.

- Forming: Orientation or test phase with mutual scanning. No team member wants to be naked, so that everyone acts politely, impersonally and carefully, and nobody gets out of cover.
- Storming: Either team members fight for the respective position in the team or subliminal conflicts build up. There may be confrontations and the first formation of groups within the team. After some successes, the team goes through the first

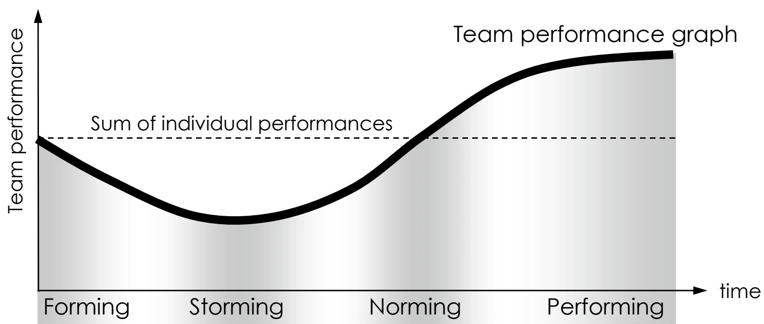

Fig. 15.24 Development of team performance

phase of frustration (up to a feeling of hopelessness). The team performance falls below the level of the sum of the individual performances of the team members.

- Norming: The team members start to move towards each other and the team begins to organize itself. Confrontations on points of view are conducted openly and receive increasing feedback. In this way, team-oriented manners and behaviours can develop.
- Performing: The team is now integrated. Team members working on the project are fully motivated. They work imaginatively, are open and helpful with each other and react flexibly to changes in requirements and environment. Due to the synergy of the cooperation, the team performance is higher than the sum of the individual performances.

Under certain conditions (long-running project, project team remains unchanged even for a follow-up project) the phase of dissolution of the team (adjourning) may be added. However, this is not relevant in IDE, since IDE projects end with their completion and a new project does not resemble a previous one, so that a new team must be put together in any case.

15.6.2 Teamwork in IDE

An IDE project team consists of the core team (Sect. 15.2.3) and the extended team with temporary team members (see also Fig. 15.8). Depending on the task at hand, the core team is made up of representatives of the specialist areas required for each core task. The extended team includes experts who only work in the team temporarily or in certain project phases. If technical experts are needed from customers, partners, suppliers or other external parties, they are integrated into an external team, Fig. 15.25.

Teamwork in IDE comprises pro rata temporis forms of individual work and joint work, whereby individual work is carried out in parallel. The appropriate time portion is determined depending according to the work task. The team works independently and autonomously in an interdisciplinary environment. Decisions are made together in the team and all members are jointly responsible for the decisions. The personal

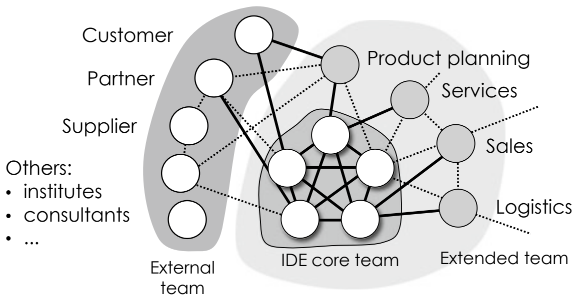

Fig. 15.25 25 composition of IDE team [Ehrl-2007, Burc-2001]

goals of the individual and the performance goals of the team do not contradict each other. The project manager takes on a coordinating, moderating and mediating function. All team members are responsible for achieving the goals. In the IDE teamwork, the following approach has proven to be viable and economical (see also Sect. 14.2):

- Things that have a fundamental character or that affect all areas of the product life cycle are determined at the earliest possible time jointly by all parties involved. If fundamental changes occur, all parties involved have promptly to create the resulting specifications.
- The results following from the specifications and suitable alternatives to these are simulated, calculated and evaluated using preliminary information and feedback from the product life cycle.
- The resulting decisions and selections are made as late as possible, but before the product and its documentation are released for production, so that any further changes can be taken into account with little effort.

This leads to the following general procedure pattern of teamwork in IDE, Fig. 15.26.

After the start of the project, all participants agree on the basic tasks of the project (large circle with a black border). The work takes place predominantly as parallel work of all team members with or without formation of partial teams with their respective meetings (small grey circles). Whenever there is a need, everyone involved agrees on the new situation (large circle with grey border). If there is a fundamental change in requirements or the environment, the current activities are stopped and documented. Once again, all parties involved agree on the changed situation and an adapted planning of the project (large circle with a black border). Finally, at the end of the project, the final presentation is given and the project results are handed over to the client.

In project work in IDE, type and number of team meetings between the start and the end of a project are basically not fixed, but are agreed according to an emerging need for coordination. The project team or the client can also agree on points in time at which specific and previously agreed results are to be delivered. Such events

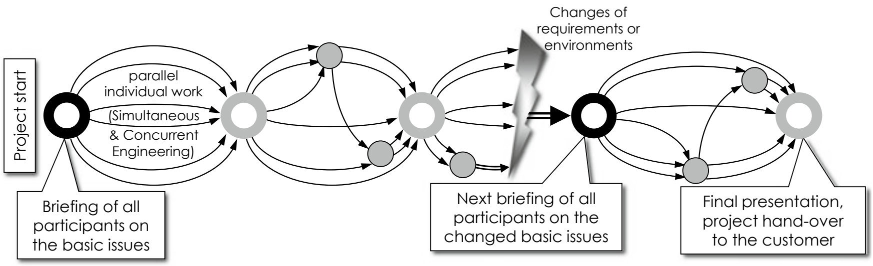

Fig. 15.26 Teamwork procedure in IDE (large circles: meeting of all team members, small circles: meeting of some team members)

can be realized either with gates from the stage-gate process (Sect. 15.3.1) or with milestones (Sect. 15.3.2).

15.6.3 Advantages and Disadvantages of Teamwork

Teamwork offers significant advantages over collaboration in workgroups, which are of particular importance for IDE. These include:

- An interdisciplinary team forms an extensive pool of know-how. Through the effect of synergies, the knowledge of an interdisciplinary team is greater than the sum of the knowledge of the individual team members [Hock-1997].
- The multitude of different experiences and skills within the team is an essential prerequisite for the synthesis of innovative ideas. In doing so, questioning and uncovering contradictions offer an effective control of tasks.
- In a joint interdisciplinary work, different perspectives show up through a holistic task processing. Accordingly, the solution is developed holistically [KaBT-1993].
- Teamwork promotes the knowledge growth of team members. Mutual suggestions (as a result of synergy effects) generate additional knowledge that can be used, for example, for innovations [Otto-2013].
- Group-dynamic methods, for example brainstorming or Failure Mode and Effects Analysis (FMEA) increase the quality of results [Pahl-1997].
- Working in the team leads to a higher motivation of the participants. It is supported by direct participation, direct transfer of information and independent work of the team members [Dörn-1994].
- Due to the lack of hierarchies in IDE, the team leader is primarily both moderator and coach, as the team organizes itself. Thus, activities are not only carried out together and on an equal footing, but immediate action is also possible without hierarchical decisions.

However, there are also disadvantages when working in a team. During the formation of the team, it is often difficult to overcome the barriers from different trainings, objectives, experiences and conceptual worlds. Not every employee is team-minded or a team player. In contrast, some want to distinguish themselves at the expense of the other members or profit from their results without any personal effort. Efficiency and results of the team depend essentially on the composition of the team (e.g. expertise and willingness to cooperate), the leadership and motivation behaviour of the project manager and the dedication and enthusiasm of the team members. If the team works well together, an exaggerated but unjustified self-confidence can develop after a long period of successful time, which often occurs together with a self-censorship of the team to maintain team harmony.

Despite the high proportion of self-organization of the team, the organization of teamwork requires an increased need for coordination, for example when finding decisions, which are often lengthy due to tough voting discussions driven by the same right of each team member to have a say [Land-1989].

The result of the entire team is presented to the client, but internally the individual performance of each team member must be appropriately evaluated. Here it can come to difficulties, since shy team members can bring in their ideas only with difficulty and therefore their contribution is not always easy to recognize within the team result. But if individual team members deliberately do not contribute anything to the fulfilment of the task, this so-called social laziness is at the expense of the team result [Pahl-1997].

15.7 Dynamic Process and Project Navigation

At the beginning of this chapter it was already stated that the activities in IDE are usually complex and dynamic (mainly due to external influences). As a rule, development projects cannot be processed in an undisturbed way, because in addition to the emergence of new findings during this processing, changes in the project goal often occur due to changed requirements from the customer or new conditions from the project environment. Figure 15.27 shows the typical course of such a project.

- The doubled curve shows the originally planned course of the project with the corresponding project goal 1.
- Strong lines symbolize undisturbed phases of project work.
- Arrows pointing up document additional findings in the work, which led to the fact that the work could be continued with a higher goal achievement, whereby the project target did not change.
- Arrows pointing downwards show findings from the processing, which led to the fact that parts of the previous work could no longer be used and therefore

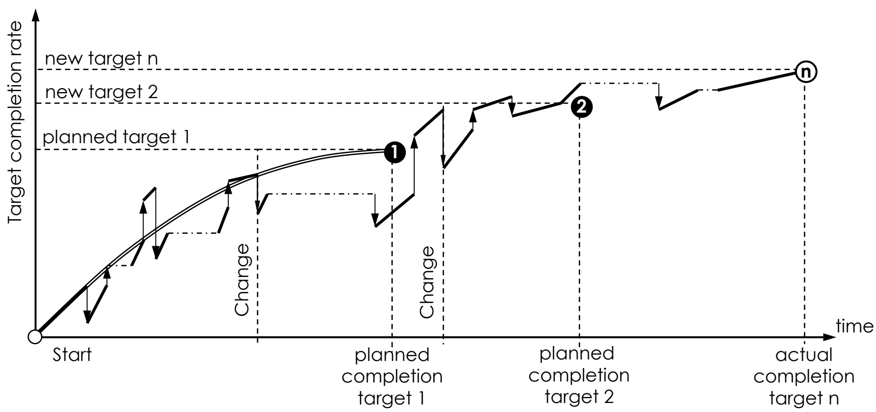

Fig. 15.27 Originally planned and actual course of the project (double line curve: planned course of the project; filled circle: planned project goal; strong lines: processing phases; arrows: New findings; dotted lines: waiting phases; after [Otto-2004])

the processing had to be continued at a lower degree of target achievement. The project objective remained unchanged.
- External changes (e.g. changes in customer requirements or the environment, new framework conditions) led to a changed project goal and thus also to a lower degree of target achievement because part of the previous work could no longer be used. The first change in Fig. 15.18 modified the projected target 1 to the new target 2. Shortly before reaching this target, a second change moved it to target n.
- Dashed lines indicate delays in processing. These were triggered by factors outside the project, such as problems with resources, waiting times for interim results from external sources, additional test phases and changes in corporate strategy.

Usually, external changes cannot be foreseen in a project. In this specific case, however, the way and sequence of project processing were updated for both changes without adapting them to the changed targets (e.g. by increasing parallel processing of activities). After all, the client had not pressed for the originally planned processing time to be adhered to. It would also have been desirable to compensate for the delays caused internally by a different sequence of processing. Up to the actual end of the project, the total expenditure for project processing increased by about 14% (only).

Due to its high degree of integration and the simultaneous development of the six product attributes, however, IDE requires processes that can be flexibly planned and smoothly running projects that can balance out changes as well as internal and external disturbances. This cannot be achieved with the classic linear procedures of project management, but only with the approach of *dynamic process and project navigation.*

The basic idea of dynamic process and project navigation can be, for example, described with the metaphor of playing chess. In this game, both players make plans for their own moves and take into account possible alternatives of different risks, depending on the (expected or actual) moves of the respective opponent. As long as the opponent behaves according to one's own plan, the own plan does not have to be changed. If the opponent acts differently, however, a new situation arises, to which immediate and flexible reaction is required. This leads to the adjustment of one's own plan and to the consideration of other alternatives than previously. Neither the timing for the occurrence of a new situation cannot be predicted, nor can the extent of the necessary changes to one's own plan.

The two chess players in IDE are the customer for a product and the contractor (manufacturer or provider) of this product. The customer's plan is to get the product as soon as possible and as cheap as possible. The plan of the manufacturer/provider consists of the individual processes and projects for the realization of the product. A new situation arises, among other things, if the customer suddenly changes requirements during the product realization or if disturbances of any kind occur spontaneously at the manufacturer/provider during this realization, which hinder the planned realization.

Dynamic behaviour in IDE means that actions are always performed exactly when they are needed (whether due to changes or malfunctions), even if there is only little and/or uncertain information available for processing and decision making at this point in time[20]. The results and decisions made in such a way do not have to be complete, because the Pareto rule (80% of the later solution is created with 20% effort, Chap. 1) allows them to be checked for their usability at an early stage. Regardless of whether the action with the uncertain basis was successful or not, additional knowledge of action is built up. In unpredictable and critical situations, dynamic behaviour is often the only way to get better results and to make better decisions about the changed environment.

A dynamic and flexible process and project management serves to control ongoing activities, even if they are characterized by changes and disturbances. It can react immediately to current circumstances without neglecting the goals regarding task fulfilment and adherence to time, cost and resource frameworks. Rigid schedules or binding reference processes used in the areas downstream to IDE (Fig. 15.2), however, offer no possibilities of reacting flexibly and dynamically to unforeseen disturbances and changes.

The IDE process and project management must be able to point out possible bottlenecks in the project at any time (and, if possible, in advance), suggest alternatives in the event of faults and evaluate the various proposals in advance. However, the final decision on how to proceed with the project is always made by the employee, who must be informed of the possible consequences of her or his decision.

The procedure described below is a *navigation*, since it not only documents events (such as an open-loop controller) or reacts to events (such as a closed-loop controller), but also can also identify and evaluate additional alternatives.

Navigation originally meant the continuous determination of location and course (including possible alternatives) of vehicles on land, on water and in the air [Wahr-1978]. The same approach can also be applied to the management of processes and procedures as well as to processes and projects. The navigation can

- create and evaluate alternative activity threads based on the process element s used when modelling a process.
- ensure that all necessary working steps in the project resulting from the process are executed in the correct context.
- also identify and evaluate alternatives for further action at any time during project processing. Such a point in time results either from the user's desire for more efficient processing or from a disturbance. In the event of a disturbance, the alternatives are used to check whether and how the project specifications can still be achieved.

In all cases, the employee selects the best alternative and continues to work with it.

The prerequisites for successful navigation are flexible organization and project structures typical for IDE, an easy combination and configuration of process alternatives as well as their simple and fast evaluation.

[20]This is the case, for example, with an unplanned transfer of unfinished results within the framework of Simultaneous Engineering (see Fig. 17.4).

Process and project navigation in IDE is based on the assumption that every process in product development can be built up from small, essentially indivisible units that can be configured and combined depending on the task and requirement. This smallest unit is called process element, based on the *Therblig* approach developed since 1915 by the couple Lillian M. and Frank B. GILBRETH. The Therblig[21] in its original version first defined a standardizable and completed activity as an element of an action to be performed in production with clearly defined interfaces to other Therbligs (see also Sects. 4.1 and 22.2). From 1924 Lillian GILBRETH transferred the Therblig approach to any production and planning activities, not only in companies, but above all to domestic work and work with the disabled[22] [Lanc-2004].

Following the Therblig approach, a process element describes an activity, an activity or one or more work steps, initially independent of the respective application. It is started by one or more events (e.g. results of upstream process elements) and ends with a work result (e.g. a created or changed CAD model) as well as one or more events (e.g. specifications or decisions on further procedure), Fig. 15.28.

The process element also contains extensive knowledge, for example

- the qualification profile required for processing the process element (differentiated according to formal education level of the agent and the current knowledge level required), in order to exclude both overstraining and under-challenging of the employee,

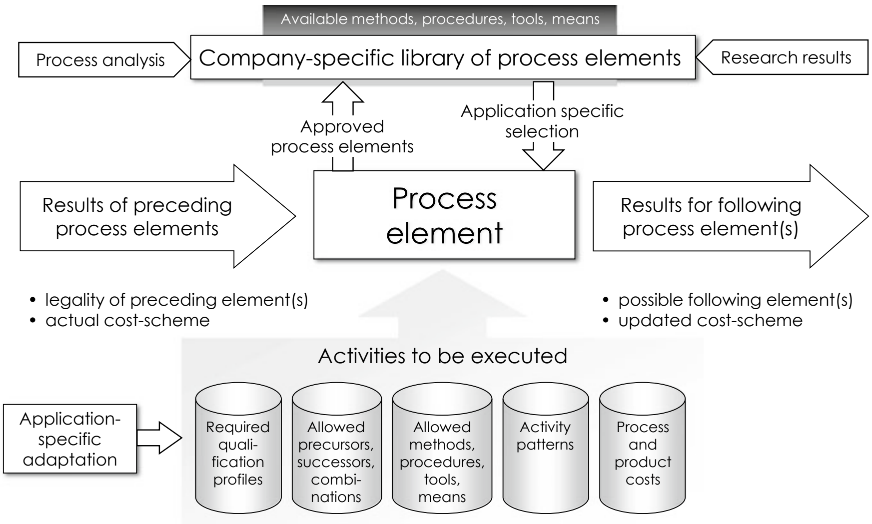

Fig. 15.28 Basic structure of a process element

[21] This name originated from the last name of the GILBRETH couple read backwards.

[22] The works of the GILBRETH couple can be viewed at Purdue University (West Lafayette, www.purdue.edu) and in part at the Boston Public Library (www.bpl.org). They are also available from the American Institute of Industrial Engineers, IIE (http://www.iienet2.org/Default.aspx).

- knowledge of upstream and downstream process elements and permitted (serial and parallel) combinations with other process elements, so that “impossible” combinations can be avoided (but, in the sense of navigation, can still occur if necessary),
- the most suitable or possible and available methods, procedures, aids and tools for the respective process element,
- best practice patterns for problem solving, and
- cost systems that can determine both the product costs (costs for the manufacture of the product) and the process costs (costs for the respective development activities), so that full cost transparency is ensured at all times as well as cost-related development (design-to-cost, Sect. 14.1.1.4) is made possible.

All contents can be adapted to specific applications.

Company-specific process elements are determined on the basis of analyses of typical processes in the company, configured according to the basic structure shown in Fig. 15.9 and stored in a library. Methods, procedures, tools and utilities available in the company are assigned to the respective process elements, whereby assignments to more than one process element are also possible.

The basic structure allows the configuration of further process elements at any time. The library can also be extended by frequently and successfully used variants of a process element. Similarly, subprocesses can be created and preconfigured, for example, proven combinations of process-elements and workflows (see Sect. 15.1). Other sources include best practices, external applications and research results.

For a powerful support a large number of different process elements is not necessary at all, because (almost) any processes can be modelled by clever configuration and combination of relatively few process elements[23].

The structure of the contents in the company-specific library is shown in Fig. 15.29.

The first column contains the freely configurable company-specific process elements. Preconfigured variants of this process element follow in the respective lines. In addition, there are proven or defined subprocesses. Overall, the structure of the library, combination of process elements and evaluation of these combinations are based on the principles of the *Morphological Box*[24] by ZWICKY [Zwic-1966].

To model a process, a process element or a subprocess is selected from the library for each activity. These can be reconfigured if necessary, because the adaptation to

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[23] In her doctoral thesis, FREISLEBEN uses a knowledge-based procedure model with only 51 process elements to model new design from any industry branch. Accordingly, even fewer process elements are required for modelling adaptation design or variant design. Almost 100 methods, procedures, tools and aids are provided for the process elements [Frei-2001].

[24] In the morphological box (also called morphological matrix)a task is divided into subtasks. These are entered in the first column of the box. Solution alternatives are developed for each subtask and entered in the respective line. To create a new solution, individual solution alternatives are combined for each subtask. Only those combinations are possible in which the respective material, energy and information flows are compatible between the two meeting solution alternatives. The combinations can be evaluated in different ways, for example with the connection matrix according to Roth [Roth-1982].

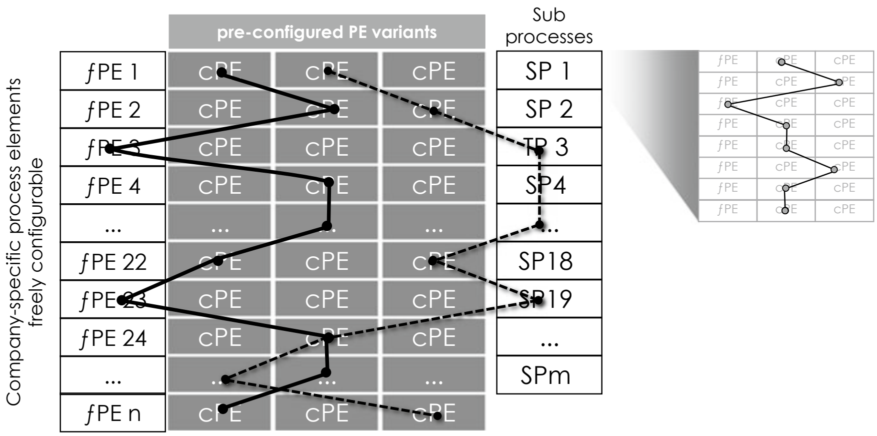

Fig. 15.29 Structure and content of the company-specific library for process elements based on the morphological box of ZWICKY [Zwic-1966] (*f*PE: freely configurable process element, vPE: preconfigured-process element, TP: preconfigured subprocess) with two process combinations

the concrete application case takes place by taking into account the type of data to be processed, the selection of the methods and procedures, tools and aids used in each case and the knowledge required for their application.

Once all activities have been taken into account, the selected process elements are linked to a process model in accordance with combination rules (e.g. compatible design spaces with defined interfaces or specifications for material, energy and information flows between the process elements). The links between the process elements are stored as rules to which certain properties (e.g. a time-limited validity) can be assigned. If one repeats this process with different combinations of process elements (Fig. 15.20 shows two examples), one obtains alternative process models for the process one is looking for, whose respective value results from the individual values of the process elements and the value of their interaction with regard to lead time, resource consumption, etc. [Scha-2001].

When combining process elements, not only linear connections are possible, but also parallel connections of different types (for Simultaneous Engineering or Concurrent Engineering, Sect. 15.1), branching's (division of action threads or alternative procedures), adaptations (the further procedure is decided based on current circumstances) and repetitions (loops), so that any operational situations can be simulated. This produces the model of the process under consideration, shown here, for example, in BPMN notation[25] (Figure 15.30).

The theoretical foundation for dynamic navigation is the knowledge-based procedure model for product development processes according to FREISLEBEN [Frei-2001], Fig. 15.31.

[25] BPMN is the abbreviation of Business Process Model and Notation. This specification language is used to model and graphically represent workflows and processes. An extensive symbol library and rules for linking them are available for this purpose [FrRH-2010, SzSV-2013].

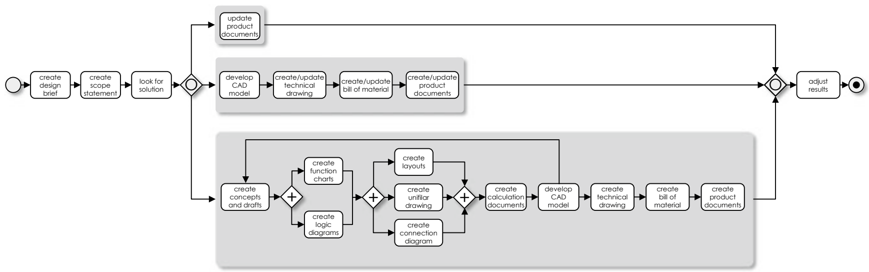

Fig. 15.30 Example of a process model in the BPMN notation [SzSV-2013]

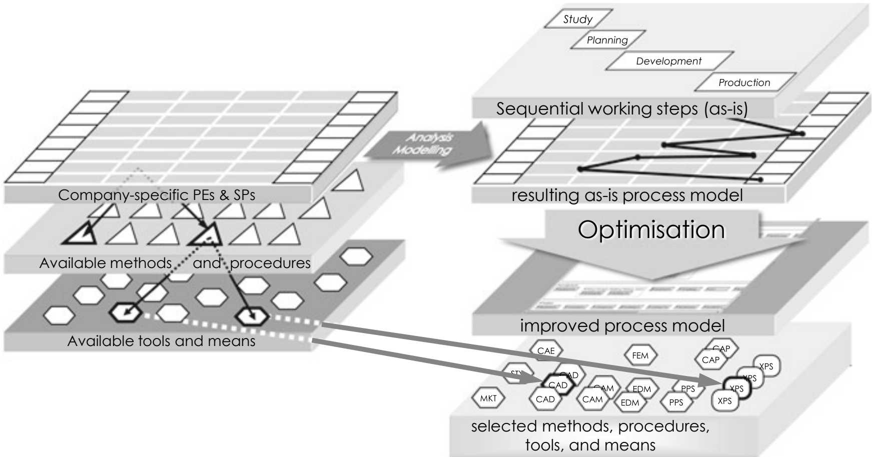

Fig. 15.31 Modular and knowledge-based procedure model for product development processes ([Frei-2001]; left half: company-specific process elements, subprocesses, methods and procedures as well as tools and aids, right half: modelling and optimization)

In this procedure model, the respective methods and procedures are assigned to a process element on the left middle level and the tools and aids on the left lower level. In current modelling, the actual process (first level at the top right) is analysed and modelled with the existing process elements (second level from the top right). With simulation and evaluation of the modelled as-is processes and their structures, bottlenecks in resources, problems with deadlines and milestones or processes that cannot function in practice are identified.

The actual process can be optimized, for example, using the process improvement model (Sect. 15.1 and Fig. 15.3). If simulation and evaluation of the improved process correspond to the ideas, the currently required methods, procedures, tools and aids (lowest level right in Fig. 15.31) are linked with the individual process elements.

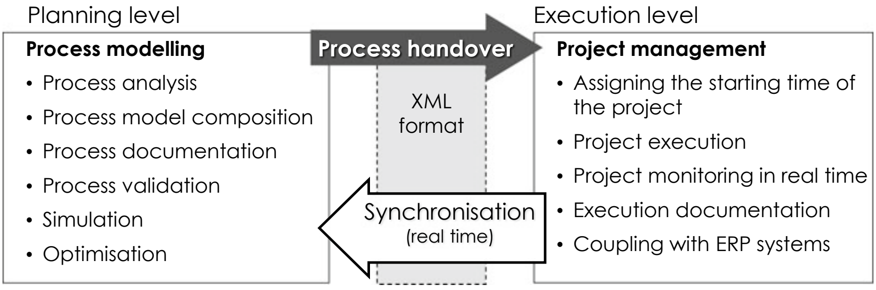

Fig. 15.32 Simplified presentation of dynamic navigation [Vajn-2009]

For a specific order, the process is transferred to a system for project processing via a neutral format (e.g. XML), the starting time is assigned and the project is started, Fig. 15.32.

During execution, the required documents and tools that were assigned to the respective process element during modelling are made available in a context-sensitive manner. The process navigation ensures that all required work steps are meaningfully processed independently of a sequence (i.e. also “chaotically”). Today, project management systems enable continuous monitoring of an active project as well as coupling with and transferring relevant results to ERP systems. In addition, all current activities are fully documented, making it possible to understand and evaluate procedures and decisions at a later time (e.g. in the case of product liability).

If there are changes in the environment or disturbances in the course of the project (see Sect. 15.8), the current project is stopped and the current status of the project is promptly returned to process modelling via synchronization. Now the changes of the process can be realized in the procedure model (Fig. 15.31, left side) by modelling, simulation, optimization and evaluation. If the simulation of the updated process fulfils the changes, the resulting new process model is transferred back to the project processing system. There, the project continues with the updated process from the point at which it was stopped. In this way, the current status of the process is mapped dynamically.

The updated process model now also exists at the planning level. At the end of the project, therefore, not only the original process model, but also all changed process models and the project states at the time of the respective change or disturbance are available, so that all changes remain traceable both in terms of their occurrence over time and their scope[26].

[26]This traceability plays an important role in questions of product liability. The company must be able to prove that it has not made any mistakes in the development, manufacture and sale of the product (proof of relief in the Product Liability Act [EU-85/374]).

15.8 Handling of Dysfunctions in the Project Workflow

Julie Stal-Le Cardinal

Two aspects will be presented in this section. The first (and most important) one is the systemic approach of handling dysfunctions[27] that may occur during the processing of a project due to unforeseen changes in e.g. requirements, resources, and time-frames, as dysfunctions have to be analysed and solved, when an organization has to be improved. Then a method to reduce risks in decision-making within a project concerning the choice of actors called SACADO[28] [StLC-2009] will be described.

So as to be able to handle disturbances in the project workflow, it is necessary to understand the context of any kind of project, the expectations of its stakeholders, and the history of the organization, in which the project is embedded, or the history of the project itself. This is the purpose of the systemic approach presented here.

The systemic approach considers the human behaviour (c.f. Chap. 4), the enterprise that runs the project, the economy, in which the enterprise is working, and the ecosystems that influence the enterprise and the processing of the project. It allows to organizing the necessary knowledge to be effective in the realization of projects. The SACADO approach is suitable for complex systems and projects. A complex system can be defined in comparison to simple or complicated one. Although a simple problem can be solved by almost anybody, a complicated problem needs an expert of the discipline to solve it whereas a complex problem requires the collaboration of several experts of different disciplines. Thus, a project with several people in charge can be defined as a complex system, with a need of collaboration of the various stakeholders to achieve one common goal. This is the reason why the systemic approach is suitable in a project environment, Fig. 15.33.

- When launching a systemic analysis in a project (Fig. 15.33), one starts with the Genetic axis, which considers the further development (evolution) of the system, its subsystems, and its phases over time. Understanding from where the system comes from and where it is going is the key issue before going on. The main output of this activity at the beginning of the analysis is to identify the phase in which the project is actually in (planning level or execution level). An efficient tool used for this step could be Risk Analysis in order to clarify possible constraints and obstacles as much as possible within the given situation.
- Once the phase is identified, the objectives of the project in question can be discussed and detailed (Teleological axis). All stakeholders in this particular

[27] A dysfunction is a disturbance or a malfunction that leads to an impaired or abnormal function and/or behaviour of a creature or an artefact.

[28] Abbreviation of **S**ystème d'**A**ide au **C**hoix d'**A**cteur et aux **D**écisions d'**O**rganisation (supporting system to select actors and to support decisions in organizations).

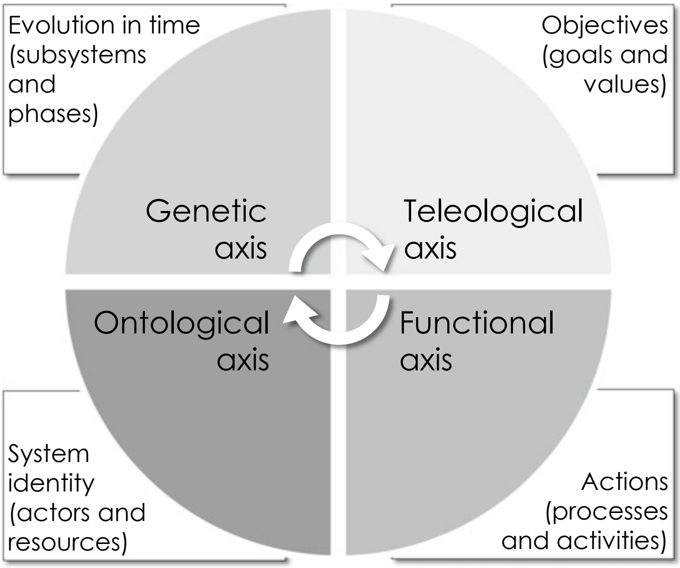

Fig. 15.33 Systemic vision of a complex system, based on Le Moigne 1990 [LeMo-1990]

context have given goals and value creation expectations. The output of the Teleological axis is to define for each stakeholder the respective goals and value expectations (positive and negative ones). A tool used for this step could be project specifications (context, stakeholders, objectives and deliverables…).

- Next, the activities along the Functional Axis are covered, which deals with actions, processes, activities and organizations. The main question is what is the ideal organization to fulfil the expectations of the stakeholders (defined in the Teleological Axis)? A tool used for this step could be to set up a Work Breakdown Structure [PMIW-2019] to define the main actions to be done in the project.
- At last, the Ontological Axis deals with the identity, i.e. the capabilities, behaviour, and characteristics typical of the specific system. The main purpose here is to define the just necessary resources to accomplish the actions in the pre-defined organization. A tool used for this step could be the Responsibility Assignment Matrix [PMIR-2013] to assign resources to tasks.

As projects run in complex and dynamic environments, it has to be checked in a reverse way that the defined resources (ontological axis) are just necessary to accomplish the actions in the organization and that the goals and objectives will be fulfilled for all stakeholders. If this is the case, the project can evolve to another level, to another phase, and the same reflexions have to be repeated.

The description above covers the main tools and methods that are usually used in systemic analysis for any of the four axes. In the following, the focus will be on SACADO in the Ontological Axis.

The choice of appropriate actors is crucial for the success of a project, as they influence the whole value performance of the project and the design of the product itself. The challenge is to offer help to make the right decisions when choosing the actors in order to improve decisions in product development and design.

This decision support is provided by two components of SACADO:

- The Target Process to be followed to avoid dysfunctions (Fig. 15.34), and
- The Decision Card for choice of actor that helps to approach the Target Process and allowing a capitalization of the processes and the decision taken (Fig. 15.35).

Due to these tools, SACADO is useful when decisions have to be taken.

The main steps of the Target Process correspond to the following six questions:

1. What are the tasks to be performed by the actor to be chosen and in what environment?
2. What are the necessary skills and competencies?
3. Which skills and competencies are available?
4. For the choice of actor: What is the best compromise in terms of quality, cost and time?
5. What are the risks (quality, cost, time) that the actor to be chosen could cause to the project?
6. Is there a process for controlling the actor chosen in relation to these risks or a risk eradication action plan to be put in place?

To help the decision maker to follow the Target Process, a decision card to support the decision process, Fig. 15.35. The decision card contains the key information that characterize a project:

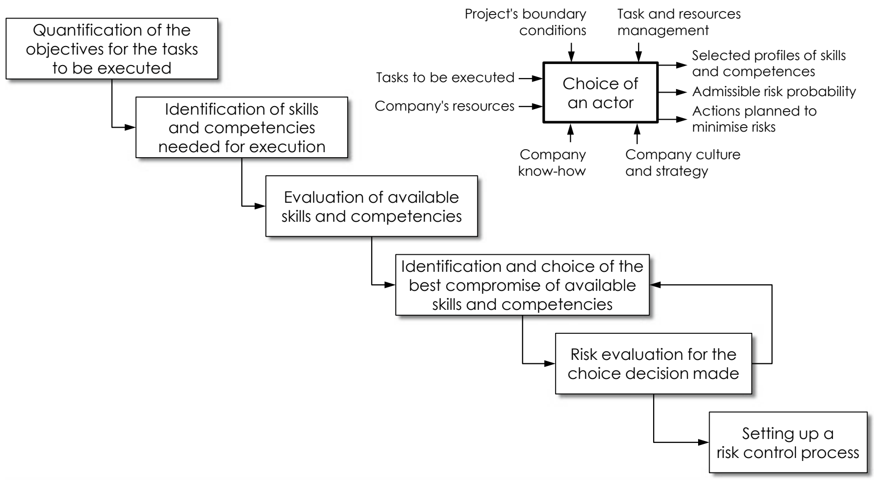

Fig. 15.34 Target process [MeSC-2005]

<table>
<tr><td colspan="6">Context</td></tr>
<tr><td colspan="3">Who asks (customer)?</td><td colspan="3">Who chooses (contractor)?</td></tr>
<tr><td colspan="3">Question Date</td><td colspan="3">Choice Date</td></tr>
<tr><td colspan="3" rowspan="2">Tasks to perform</td><td colspan="3">Objectives</td></tr>
<tr><td>Quality</td><td>Costs</td><td>Schedule</td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Required Competencies</td></tr>
<tr><td colspan="2">Knowledge</td><td colspan="2">Know-how</td><td colspan="2">Attitude</td></tr>
<tr><td colspan="3">Potential Actors</td><td colspan="3">Selected Actors (and reasons for selection)</td></tr>
<tr><td colspan="3" rowspan="2">Risk Evaluation</td><td colspan="3">Action Plan</td></tr>
<tr><td>What</td><td>Who</td><td>When</td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Dysfunctions (what went wrong in the decision process)</td></tr>
<tr><td colspan="3" rowspan="2">Results</td><td colspan="3">Gap</td></tr>
<tr><td>Quality</td><td>Costs</td><td>Schedule</td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Recommendations</td></tr>
</table>

Fig. 15.35 Decision card for the choice of an actor [MeSC-2005]

- The project context,
- Who is the customer at which date and who is the contractor at which date?
- The tasks to be performed, quantified in terms of quality objectives, cost and time,
- The skills required (knowledge, know-how and attitude) for these tasks,
- The potential actors and the chosen actor with the reasons of the choice,
- The risk assessment depending on the skills of the chosen actor in relation to the skills required and the tasks to be performed. If a plan of actions is set up, it appears here. The responsible actor and the date of completion are specified for each risk and for each action,
- A quantified assessment of the results, with the gaps in terms of quality, cost and time of the various actions carried out.

This card also makes it possible to analyse a dysfunction that appeared in a past decision.

In order to obtain a global vision of the dysfunctions in the process of choice of actor of a company, it is recommendable to widen, in a second time, the analysis of a dysfunction with the analysis of a series of dysfunctions and to deduce from it a recurrence or a typology. The study of all the projects of a company, or at least of a part, makes it possible to determine the main and most influential categories of dysfunctions corresponding to the problems related to the organization of the company.

15.9 Co-Creation: A Catalyst to the IDE Development Process

Juan Carlos Briede-Westermeyer, Elizabeth B.-N. Sanders and Bélgica Pacheco-Blanco

In order to systematize and optimize the product development process from an IDE point of view, it is necessary to articulate and to integrate both human and material resources, processes and results as well as the complete life cycle of the product. IDE's potential to systematize and to articulate the product development processes is undeniable. IDE also identifies and articulates the resources of the people within these processes. But what is the input at the beginning of IDE? How do the processes get started?

15.9.1 Co-Creation as Input to Integrated Design Engineering

Current trends, including global interconnections, the flow of information, and the speed with which things are changing in a VUCA[29] context [BeLe-2014], challenge whether the procedures of IDE are sufficiently flexible and well-aimed to be competitive and to generate benefits not just in the marketplace, but also for making improvements in the quality of people's lives.

In this sense, it is not enough to design a product correctly (effectivity), but rather one has to endeavour to design the right product (efficiency). As Buxton stated *"There is an emphasis on balancing the back-end concern with usability and engineering excellence (getting the design right) with an up-front investment in sketching and ideation (getting the right design)"* [Buxt-2007, Meer-1994]. To design the right product, it is not enough to focus on traditional design processes, but in fact it is necessary to explore the input to a traditional design process. The pre-design stage, also known as *Front End Innovation* (FEI) or the *Fuzzy Front End* (FFE) [HRSM-2016], is the place where ideas are generated first, and then design

[29]VUCA is a combined acronym for **V**olatility, **U**ncertainty, **C**omplexity and **A**mbiguity. The same acronym also serves for describing a strategy to overcome the problems of volatility, uncertainty, complexity, and ambiguity. In this case VUCA reads as **V**ision, **U**nderstanding, **C**larity, and **A**gility.

Fig. 15.36 The fuzzy front end and the traditional design development process (based on [Sand-2019])

opportunities are identified, evaluated and chosen, before the concept that is to be developed is selected [StMS-2016], Fig. 15.36.

In the pre-design stage, the purpose is to actively integrate the future users of a product and the key stakeholders (clients, providers, suppliers, etc.) in the development of the product in a joint exploration process in order to identify problems and possible solutions and to explore opportunities for future products. In the pre-design stage, the use of co-creation approaches, tools, and activities allow future users to be aware of and reflect upon their daily lives in order to express their ideas [MoTo-2013] regarding what their future lives might entail.

In this context, co-creation is an approach that facilitates acts of creation to be experienced simultaneously by designers in collaboration with non-designers. This approach changes the paradigm from "designing for people" to "designing with people" and it changes the designer's role from the expert to the facilitator of the creativity of others [Sand-2019]. It is a special case of collaboration where the intention is to create something new [SaSi-2009], with the goal of meeting both needs and dreams of the future users [SaSt-2008]. In doing so, it is necessary to be guided by the doubting users, the unadjusted, the uncomfortable among them as well as by all those who ask questions and who do not avoid them [Lott-2019]. In this way, the results of a co-creation process may result in a product, service, interface or perhaps something else, where the ideas of all participants are integrated so that everyone is able to participate from a perspective of horizontality[30] [SaSt-2008]. This can be seen in the definition of co-creation developed by Ramaswamya and Ozcan

[30]Horizontality is a structuring principle that doesn't come from hierarchical (i.e. vertical) structures, in which the hierarchy regulates access to information, resources, positions of power, etc., but from flat and equivalent (network) structures, in which the principle of diversity applies to all participants and in which there is no centre, no single individual or organization that may speak in the name of the whole network and in which the only decision-making process is consensus [Wain-2007].

[RaOz-2018]. This definition describes co-creation as a level of "enactment of interactional creation across interactive systems-environments (afforded by interactive platforms) entailing and agencing[31] engagements and structuring organisations".

Co-creation is also promoted by the dematerialization/virtualization of processes, prototypes and products resulting and increasing from digitalization. This allows product development to be accelerated in such a way that feedback from those involved can be implemented without (major) delay and the new results can be assessed immediately, so that one can claim that the logic of the beta version is transferred from the software to the hardware [Jans-2019].

Three main methodological approaches are defined for the implementation of a co-creation process:

1. *Making (M) techniques and tools* enable people to give shape to their ideas and to make the process tangible. For example, one can use blocks, clay, and pipe cleaners to create simple prototypes of future products.
2. *Telling (T) techniques and tools* enable people to talk about what they make. For example, people can tell stories about how they would like to live in the future by using their simple prototypes of future products.
3. *Enacting (E) activities* enable people to show how they would use their future prototypes [SaBB-2010]. For example, people can role-play or use improvisation to enact their dreams for future ways of living.

Studies like those of Orcik et al. [OrTA-2013] and Hesmer et al. [HTWB-2011] identified key elements of the co-creation process in different phases of the product's life cycle, together with groups of co-creators that are most relevant in different product development phases. Due to the complexity of addressing these different scenarios, development environments (e.g. large and small companies, investment goods and consumer goods, etc.), and types of co-creators the focus in this section will be on the pre-design stage where co-creation can be used to conceptualize the input to the IDE process, Fig. 15.37.

There are many similarities between the IDE approach and the approach of co-creation. Most notably are the facts that both are human-centred approaches that are described in processes that apply at all stages of a product, a system or a service life cycle. Both approaches are based on experiences that derive from a large number of projects and relationships that have taken place over the years in industry. Where co-creation differs from IDE is in its focus on the very early front end of the innovation process from a participatory perspective.

In this conceptualization, the attributes that are in play are not addressed like a checklist but rather as options that invite the future users to explore those attributes that are significant for them. Following this line, Russo-Spena and Mele [RSMe-2012] describe the first stage of their co-creation model as "co-ideation", and this is developed in the conceptual phase of the product's development, looking to

[31] The meaning of "agencing" (based on the French word "agencer", of which the English translation can be "to contrive" or "to arrange" something) is both "organizing" and "giving agency"; it thus designates a process by which various entities are connected, coordinated, and put in motion [Oxfo-2019].

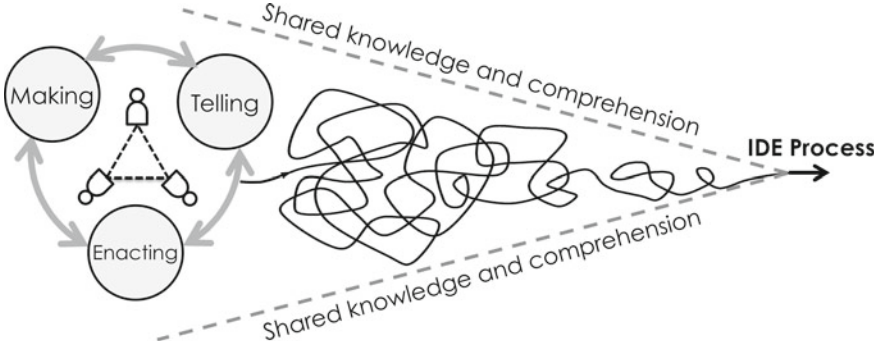

Fig. 15.37 The co-creation journey within the fuzzy front end (FFE)

innovate through an external network of players who include not only leading users, but also "consumers, fans, customers, partners, professionals and intermediaries who actively participate in idea generation and shaping".

15.9.1.1 The Relationship Between the IDE Product Life Cycle and the Co-creation Approach

The connection between the IDE product life cycle (PLC) and the co-creation approach is shown in Fig. 15.38, where it can be seen that, on the one hand, the co-creation process intersects the IDE model at the very beginning of the product life cycle. It provides the conceptualization that serves as the input to the activities

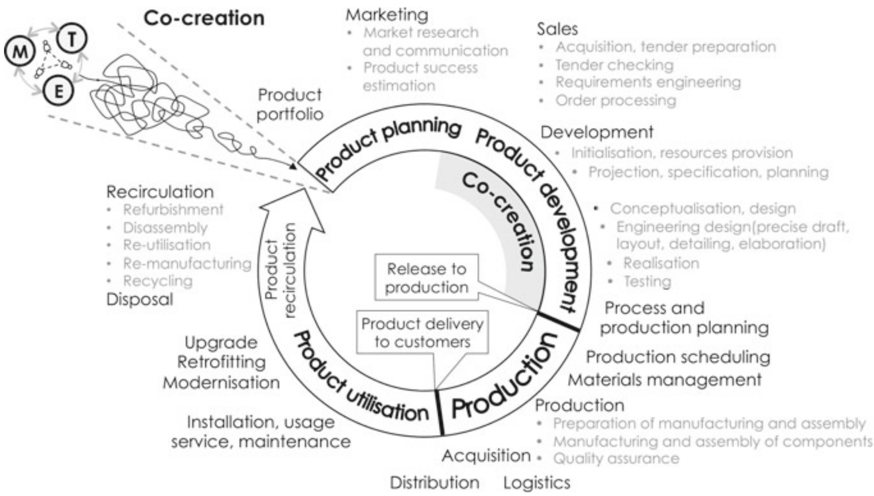

Fig. 15.38 Co-creation within the IDE product life cycle (c.f. Fig. 2.2)

within the product life cycle. On the other hand, it can be applied when necessary at any time throughout product development. One can say that the co-creation process is the catalyst to IDE.

15.9.1.2 The Role of the IDE Attributes in the Co-creation Process

The consideration of the attributes that describe a product is addressed in Chap. 2 that describes six product attributes, three fulfilment attributes, and two economic attributes, which all together describe the performance of the (future) product and the behaviour, with which the performance can be applied. How do these IDE attributes connect to the characteristics that are relevant in the pre-design stage during the co-creation process?

The three product attributes that make up Suitability (Product Gestalt, Functionality, Usability) are most often explored in the pre-design stage where co-creation activities are introduced to facilitate the codesigner's explorations of opportunities for better ways of living in the future. For example, making techniques and tools are used to enable the codesigners to explore Product Gestalt questions such as "What might the product or service look like?" and perhaps "What perceivable information is offered?" Telling techniques and tools as well as enacting activities are used to facilitate the codesigner's exploration of Functionality. For example, they might demonstrate what they have made by telling how it works or by presenting how to use it in its targeted environments. Codesigners do not usually address Usability in the Fuzzy Front End but they may begin to address usability issues once there is a working (or semi-functional) prototype later in the IDE process.

Additional product characteristics that are usually explored in the front end of design include Usefulness and Desirability. Usefulness addresses a codesigner's questions such as: Does the product solve my problem? Does it address my unmet needs? Does it offer new opportunities for living? Desirability addresses questions such as: Is the product attractive? Do I like it? Do I want to own it? Do I want to use it?

The fulfilment attributes (Safety, Reliability, Quality) might also be explored in the front end of the co-creation process although they are more likely to be explored in the later stages of the design and development process, because the co-creation process is a pre-requirement stage where some of these attributes are not yet relevant. The remaining attributes (Producibility/Availability, Maintainability, Sustainability, Added Value and Return on Investment) are also relevant later in the design and development process once the thing that is to be designed has been conceptualized through front-end activities.

The purpose of the iterative process within co-creation is on defining and simulating the required or anticipated "product experience" (and thereby an important component of the customer demands) rather than on defining the attributes and requirements of the solution.

15.9.1.3 Identification of Participants in the Co-creation Process

In order to initiate the co-creation stage, the co-creators must be identified. It is particularly important and challenging to consider, who the future users might be, since it is not yet known how the product requirements will be approached by which concepts, kinds, and types of design. Who will they be? Are they common users? Will they become involved in the product's entire life cycle or will they just play a big role in the front end? Answers to these questions will be defined depending on the scope and scale of the project. For example, in processes that are running on Web platforms without time and space restrictions, any stakeholder whose ideas can be filtered can take part [RSMe-2012]. However, a project-dependent series of restrictions must be considered when seeking high quality (i.e. new) needs at a low cost [OrTA-2013].

The selection of codesigners is important since it is with the greatest diversity of participants that the most useful results emerge in the generative phase of co-creation. In addition, it is needed to prepare the codesigners for their involvement in the co-creation process. This is usually done in the form of "homework" that is to be addressed by the participants before the co-creation session begins.

It is important for the designers to know the people who will become codesigners. It is necessary to understand their points of view. Only if "we put ourselves in their shoes", it is possible for the designer to understand what is important to them. This may seem to be impossible, but it is this empathy of the designer that allows generating new possibilities. The ability of the designers to connect with the people who are the codesigners goes hand in hand with handling the informal and formal processes that are developed within the teams. In this sense, co-creation has to be spontaneous and any attempt towards formalization might cause a certain degree of stress.

Commitment between the designers and the codesigners and commitment to the co-creation process involves generating almost emotional bonds with the problem/need being resolved/satisfied. This bond is achieved by the motivation coproduced among those involved. It does not always involve signing a document with deadlines and attending meetings. It can be more of a feeling that is necessary to solve the problem or need.

15.9.2 The Co-creation Process

The co-creation process in the pre-design stage takes place in three main stages, Fig. 15.39.

- **First stage: Capacity building**. In this stage both designers and the codesigners (as well as the other stakeholders in the process) get to know each other socially. This does not need to take a long time but it does need to be carefully orchestrated. The first stage will take more time and effort if the cultures of the designers and the

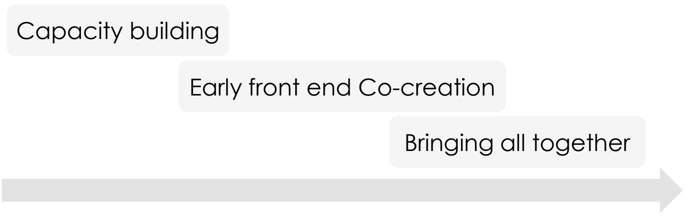

Fig. 15.39 Stages in the co-creation process at the fuzzy front end of design

codesigners are different from each another. Once they have had the opportunity to get to know each other, they can begin to explore how to work together. The designers serve as facilitators of the process of working together[32].

- **Second stage: Early front-end Co-creation**. In this stage, designers and codesigners are engaging together in the participatory activities of Making, Telling and Enacting. The order of these activities will vary but what makes it important is that all three types of activities are used iteratively during the early front-end co-creation process. The designers may ask the codesigners to do some “homework” in preparation for the engagement. The results of the homework are then shared at the beginning of the meeting.
- **Third stage: Bringing everything together**. The iterative activities of Making, Telling, and Enacting give continuity to the work and involve the participants directly in the design process. This allows the design team to adjust and to specify the frame of the project and to facilitate the generation of ideas. The team then creates a presentation covering the idea that is being developed, which describes this idea and the reasons why the idea is meaningful to the codesigners. The team also describes both questions and challenges that lie ahead. Finally, this output of the co-creation process within the FFE serves as input to start the product’s life cycle.

15.9.3 Case Study[33]

This example of a co-creation process in the FFE of design a co-creation approach for elderly users was applied as a way to address one of Chile’s most concerning issues, the ageing of the population, which reflects a series of challenges that only can be solved by an interdisciplinary approach, keeping also in mind the cultural particularities and demands [BPBB-2017] and the bio-psychosocial changes of this population segment [BWLP-2017]. The objective of this co-creation process was to

[32]For more about Creative Capacity Building, see e.g. [DrSG-2017].

[33]This description is based on results from the User Centred Design Workshop 2018 at the Universidad del Bío-Bío (Chile). the student team to perform this case study consisted of N. Olivera, C. Crino, and R. Valladares. the study was a part of a research work supported by the CONICYT FONDECYT 1171037 project.

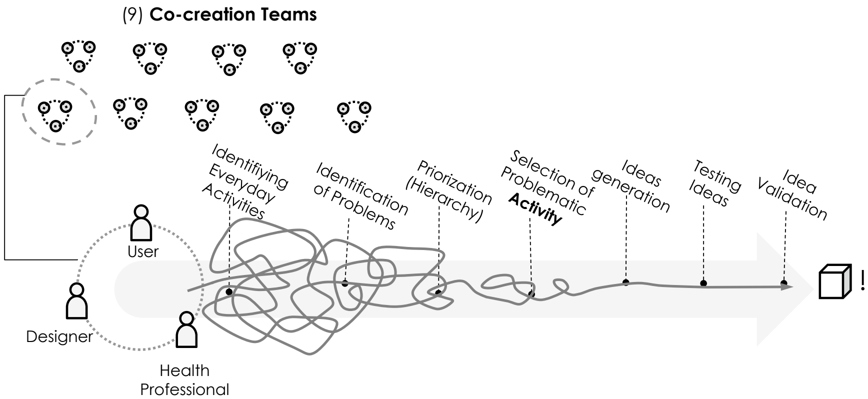

Fig. 15.40 The co-creation process that was used in the case study. Nine teams of students and elderly codesigners took part simultaneously in this process. The case study describes the work of the marked team

understand the difficulties in the day-to-day activities of the elderly so that one could know, prioritize and select the most relevant issues and then engage in the co-creation of valid solution alternatives, Fig. 15.40.

The design students, after having received in-depth insights about the reality of the elderly nowadays, started the investigation by getting to know their elderly participant, including learning about her daily routines (*everyday activities*) and the problems that arise for her (*identification of problems*). This took place in face-to-face meetings that allowed the students to get to know their elderly codesigner before beginning to co-create with her. Together they identified and prioritized the impact of her routine activities that were associated with problems. The outcome of this process was the *selection of the main problematic activity.*

For example, they learned that their elderly codesigner had great difficulties bending down and getting back up again when cleaning inside her home. The students met with other project stakeholders from health institutions at the university to obtain the biomechanics knowledge needed to address such issues. They determined that the limited pushing ability to be able to stand up was caused by lumbago with sciatica that generated pain in her entire lumbar area. This area placed greater stress on her body, thus it took more time than usual for her to complete the action. Reasons for this were her spinal column that failed as the third point of support, as well as a lack of musculature, which is typical of this age and which added to arthritis and back pain.

During the ideation phase, the students created *provotypes* (a combination of *provo*cative and proto*types*, i.e. a prototype made to provoke reactions). The elderly participant's reactions helped the students to make assumptions in terms of functionality and comfort. In this way they developed with her a shared understanding of the problem and possible solutions.

The students then generated a co-creation toolkit containing alternative components of varying sizes (e.g. parts and pieces with different setups or possibilities) from which their codesigner could chose, combine, and adjust. Along with this, they presented her with 3D drawings showing possible final appearances of this type of product, to get to know which one presentation she would judge as aesthetically pleasing.

The next step in the process was to prototype and to test ideas. The students learned that the provotype , in order to provide support, must be a rigid cylinder. They used the provotype for testing, which allowed them to understand and to see the implications of how the body of their elderly codesigner moved when bending down. This allowed the students to explore and to test different alternatives, considering the nature and fluidity of her movements. This iterative process took place over time, involving several sessions which gradually sensitized the elderly codesigner to have a greater state of awareness about the problem being worked on, making her an integral part of the team. In this way she had a very high degree of empowerment and trust in the process, not only to validate the idea being developed but also in the generation of this joint space for creation.

The co-creation team envisioned and made an extendible free walking stick. They explored several possibilities or principles for shortening or telescopically extending it. For example, could this be realized by analysing existing walking sticks? What was about the great collateral issues of how easy it is to carry the stick? Where would the elderly codesigner leave it when not using it? Starting from there, they looked again at her natural body reaction and analysed the moment of getting back up after bending down. They created an accessory that was anchored in the shoe at the heel area and provided, through an extendable bar complement, knee support to the elderly codesigner when she was bending over. Figure 15.41 shows some impressions of the work during the case study.

Fig. 15.41 Impressions from the case study. *Left*: Co-creation of prototypes and model making with basic materials (i.e. rough mock-ups) to quickly generate multiple ideas focused on solving the primary problem. *Middle*: the most appropriate prototype. *Right*: practical validation of the most appropriate prototype by the elderly codesigner/future user of the product

15.10 Conclusion

The final provotype is not a designed product. It is a concept that was embodied and visualized so that the elderly codesigner was able to participate in its creation and to test out the implications for her being able to use it in the future. By using the co-creation process, the team created a provotype that addresses the IDE attributes Product Gestalt, Functionality, and Usability together with Usefulness, Desirability and Preliminary Usability. As such, it is a conceptualization approach that can well serve as a catalyst to the IDE development process.

References

[AdTA-2003] Adams, R.S., Turns, J., Atman, C.J.: Educating effective engineering designers: the role of reflective practice. Des. Stud. **24**(3) 2003

[Agil-2019] Manifesto for Agile Software Development. 2001, https://agilemanifesto.org. Access Jan 2019

[BBEG-2007] Barton, N.H., Briggs, D.E.G., Eisen, J.A., Goldstein, D.B., Patel, N.H.: Evolution. Cold Spring Harbor Laboratory Press, Cold Spring Harbor (2007)

[BeLe-2014] Bennetta, N., Lemoine, G.J.: What a difference a word makes: understanding threats to performance in a VUCA world. Bus. Horiz. **57**(3), 311–317 (2014)

[Björ-2003] Björk, E.: Insider action research applied on development of assistive products. Ph.D. thesis, Otto-von-Guericke-University, Magdeburg, Germany (2003)

[Björ-2009] Björk, E.: Why did it take four times longer. Int. J. Technol. Disabil **21**(4), 159–170 (2009)

[Boeh-1988] Boehm, B.: A spiral model of software development and enhancement. IEEE Comput. **21**(5), 61–72 (1988)

[BPBB-2017] Briede-Westermeyer, J.C., Pérez-Villalobos, C., Bastías-Vega, N., Bustamante-Durán, C., Olivera-Morales, P., Parra-Ponce, P., Delgado-Rivera, M., Cabello-Mora, M., Campos-Cerda, I.: Interdisciplinary experience for the design of health care products. Rev. Med. Chile 145, 1289–1299 (2017)

[Burc-2001] Burchardt, C.: Ein erweitertes Konzept für die Integrierte Produktentwicklung. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[Buxt-2007] Buxton, B.: Sketching user experiences: getting the design right and the right design, 448 pages. Morgan Kaufmann Burlington, MA (2007)

[BWLP-2017] Briede-Westermeyer, J.C., Leal-Figueroa, I., Pérez-Villalobos, C.: Designers, are they stars of facilitators of interdisciplinary work? The co-creation and consensus in the design of products for elderly. Revista **180**(40), 20–29 (2017)

[ClCY-2018] Clarke, P.M., O'Connor, R.V., Yilmaz, M.: In search of the origins and enduring impact of Agile software development, ICSSP '18, Gothenburg, Sweden (2018)

[Coop-1986] Cooper, R.G.: Winning at new products. Addison-Wesley Pub. Co., Reading (1986)

[Coop-2002] Cooper, R.G.: Top oder Flop in der Produktentwicklung - Erfolgsstrategien: Von der Idee zum Launch. Wiley-VCH-Verlag, Weinheim (2002)

[Cril-2010] Crilly, N.: The structure of design revolutions: Kuhnian paradigm shifts in creative problem solving. Des. Issues 26(**1**), 54–66 (2010)

[DaHa-2009] Dahm, M., Haindl, Chr.: Lean management six sigma—Qualität und Wirtschaftlichkeit in der Wettbewerbsstrategie. Schmidt Verlag, Berlin (2009)

[DeCo-2005] Design Council: The design process. The 'double diamond' design process model. 2005. http://webarchive.nationalarchives.gov.uk/20080821115409/designcouncil.org.uk/en/about-design/managingdesign/the-study-of-the-design-process/, Zugriff 5. Juni 2016

[DeCo-2007] Design Council: Eleven lessons: Managing design in eleven global companies. 2007. https://webarchive.nationalarchives.gov.uk/20080821071149/http://www.designcouncil.org.uk/Documents/About%20design/Eleven%20Lessons/Desk%20Research%20Report.pdf, Zugriff 4. Juli 2019

[DIN-69901] DIN 69901, Projektmanagement – Projektmanagementsysteme. Beuth, Berlin (2009)

[Dörn-1994] Dörner, D.: Gruppenverhalten im Konstruktionsprozess, In: VDI-Berichte Nr. 1120, VDI-Verlag Düsseldorf, Seite 27–38 (1994)

[DrSG-2017] Drain, A., Shekar, A., Grigg, N.: Involve me and I'll understand: creative capacity building for participatory design with rural Cambodian farmers. CoDesign, https://doi.org/10.1080/15710882.2015.1399147, (2017)

[EhMe-2013] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, fünfte überarbeitete und erweiterte Auflage. Carl Hanser Verlag München (2013)

[Ehrl-2007] Ehrlenspiel, K.: Integrierte Produktentwicklung, dritte aktualisierte Auflage. Carl Hanser Verlag München (2007)

[EU-85/374] Richtlinie 85/374/EU des Rates der Europäischen Union vom 25. Juli 1985: Haftung für fehlerhafte Produkte. Erlassen am 25. Juli 1985. Inkrafttreten als Bundesgesetz in der Bundesrepublik Deutschland am 01. Januar (1990)

[Frei-2001] Freisleben, D.: Gestaltung und Optimierung von Produktentwicklungsprozessen mit einem wissensbasierten Vorgehensmodell. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[Fric-1996] Fricke, G.: Successful individual approaches in engineering design. Res. Eng. Des. **8**(3), 151–165 (1996)

[FrRH-2010] Freund, J., Rücker, B., Henninger, T.: Praxishandbuch BPMN 2.0, 2. aktualisierte Auflage 2010, Hanser München, pp. 8–17, 28 (2010)

[GeKa-2004] Gero, J. S., Kannengiesser, U.: The situated function–behaviour–structure framework. Des. Stud. **25**(4), 373–391 (2004)

[Groc-1983] Grochla, E.: Unternehmensorganisation: neue Ansätze und Konzeptionen. Westdeutsche Verlagsgesellschaft, Hamburg/Opladen (1983)

[Hash-2019] Extreme-programming. https://www.slideshare.net/bilalhashmishah/extreme-programming-12836919. Access 18 Juli 2019

[High-2004] Highsmith, J.: Agile project management: creating innovative products. Addison Wesley, USA, 2004 and 2009

[Hock-1997] Hock, T.: Integrated product development. In: Proceedings in Engineering Science 22. Seite 189–198. Indian Academy of Science, Bangalore (1997)

[Holm-2007] Holmdahl, L: Complexity aspects of product development, Ph.D. thesis, Otto-von-Guericke-University, Magdeburg (2007)

[HoSG-2018] Hoda, R., Salleh, N., Grundy, J.: The rise and evolution of Agile software development. IEEE Softw. (2018)

[HRSM-2016] Heck, Rittiner, Steinert, Meboldt Iteration-based performance measurement in the fuzzy front end of PDPs. Proc. CIRP 2016, Elsevier 50(**2016**), 14–19 (2016)

[HTWB-2011] Hesmer, A., Trebels, J., Wiesner, S., Brenken, B., Thoben, K.-D: Introducing a co-creative innovation environment for extended products. In: 17th International Conference on Concurrent Enterprising, pp. 1–8, Aachen (2011)

[HuEd-2002] Hubka, V., Eder, W.E.: Theory of technical systems and engineering design synthesis. In: Engineering Design Synthesis, pp. 49–66. Springer, London (2002)

[Jans-2019] Jansen, St. A.: Die Enkel-Tauglichkeit kommt wieder. Interview in brand eins 21(2019)11, S. 100–101 (2019)

[Jura-1951] Juran, J.M.: Quality Control Handbook. McGraw-Hill, New York (1951)

[KaBT-1993] Kannapan, S.M.; Bell, D.G.; Taylor, D.L.: Structuring information and coordinating teams in product development. In: 5th International Conference on Design Theory and Methodology, Seite 233–242, Albuquerque (1993)

[Kshi-2015] http://kshitijyelkar.blogspot.com/2015/11/the-agile-scrum-framework.html. Access July 17 2019

[KuSe-2008] Küstenmacher, W.T., Seiwert, L.J.: Simplify your life. Knaur München (2008)

[Lanc-2004] Lancaster, J.: Making Time. Lillian Moller Gilbreth – A Life Beyond "Cheaper by the Dozen". Northeastern University Press, Hanover, USA (2004)

[Land-1989] Landgraff, R.L.: The Cross Functional Team Approach to Product Development. Conference on Managing in a Global Competitive Environment, Seite 45–48, Pittsburgh (1989)

[Lang-1998] Lange, K.W.: Das Recht der Netzwerke - Moderne Formen der Zusammenarbeit in Produktion und Vertrieb. Verlag Recht und Wirtschaft, Heidelberg (1998)

[Lara-2019] Day to day life on an XP team. https://www.laramind.com. Access July 18, 2019

[Lase-1986] Laseau, P.: Graphic Problem Solving for Architects and Designers. Wiley, New York (1986)

[Laws-2004] Lawson, B.: What Designers Know. Routledge, New York (2004)

[LeHG-2008] Lettl, C., Hienerth, C., Gemuenden, H.G.: Exploring how lead users develop radical innovation. Opportunity recognition and exploitation in the field of medical equipment technology. IEEE Trans. Eng. Manag. **55**(2), 219–233 (2008)

[LeMo-1990] Le Moigne, J.L.: La modélisation des systèmes complexes, Dunod Ed., France (1990)

[LiFu-2018] Lindlöf, L., Furuhjelm, J.: Agile beyond software—a study of a large scale Agile initiative, DESIGN 2018, Dubrovnic Croatia (2018)

[Lind-2009] Lindemann, U.: Methodische Entwicklung technischer Produkte – Methoden flexibel und situationsgerecht anwenden. Springer, Heidelberg (2009)

[Lott-2019] Lotter, W.: Der Durchblick – die alte Welt wollte Komplexität immer nur reduzieren. Die neue erschließt sie. brand eine **21**(7), S. 34–39 (2019)

[Meer-1994] Meerkamm, H.: Integrierte Produktentwicklung im Spannungsfeld von Kosten-, Zeit- und Qualitätsmanagement. VDI-Bericht 1136 VDI-Verlag Düsseldorf, S. 1–13 (1994)

[MeSC-2005] Mekhilef, M., Stal Le Cardinal, J.: a pragmatic methodology to capture and analyse decision dysfunctions in development projects. Technovation **25**(4), 407–420 (2005)

[MoTo-2013] Møller, L., Tollestrup, C.: Creating shared understanding in product development teams. How to 'Build the Beginning', 134 pages. Springer, London. https://doi.org/10.1007/978-1-4471-4180-8 (2013)

[Moul-2015] Moultrie, J.: Understanding and classifying the role of design demonstrators in scientific exploration. Technovation **43–44**, 1–16 (2015)

[Neut-2010] Neutschel, B.: Adaption des generischen Prozessmodells der Integrierten Produktentwicklung für den Industrieeinsatz. Interner Bericht LMI (2010)

[Newm.-n.d.] Newman, D.: The Process of Design Squiggle. Nicht datiert, ca. https://creativecommons.org/licenses/by-nd/3.0/us/legalcode. https://thedesignsquiggle.com/, Zugriff 26. Mai (2019)

[NoVe-2014] Norman, D.A., Verganti, R.: Incremental and radical innovation. Design research vs. technology and meaning change. Des. Issues **30**(1), 78–96

[OrTA-2013] Orcik A., Tekic Z., Anisic Z.: Customer co-creation throughout the product life cycle. Int. J. Indus. Eng. Manag. (IJIEM) **4**(1), 43–49 (2013)

[OtKo-2017] Ottosson, S., Kolla, S.S.V.K.: Which product development method is best for need-based new product development? In: Vajna, S. (ed.) 11th International Workshop on Integrated Design Engineering, pp. 145–155, Magdeburg (2017)

[Otto-2003] Ottosson, S.: Participation action research—a key to improved knowledge of management. Technovation—Int. J. Technol. Innov. Entrepreneurship **23**, 87–94 (2003)

[Otto-2004] Ottosson, S.: dynamic product development—DPD. Technovation—Int. J. Technol. Innov. Entrepreneurship 24, 179–186 (2004)

[Otto-2013] Ottosson, S.: Frontline Innovation Management (zweite Auflage). Tervix Göteborg (2013)

[Otto-2016] Ottosson, S.: Developing Sustainable Product Innovations. Tervix Göteborg (2016)

[Otto-2018] Ottosson, S.: Developing and Managing Innovation in a Fast Changing and Complex World: Benefiting from Dynamic Principles. Springer Nature (2018)

[Oxfo-2019] Oxford Handbooks online, Chapter "A Theory of 'Agencing': On Michel Callon's Contribution to Organizational Knowledge and Practice" (by Franck Cochoy). http://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199671083.001.0001/oxfordhb-9780199671083-e-006. Access 2 Apr 2019

[Pahl-1997] Pahl, G.: Neue Organisationsformen mit Teamarbeit. 21. Kolloquium Konstruktionstechnik: Zeitgemäßer Produktentwicklungsprozess, Magdeburg (1997)

[PHSA-2008] Pikkarainen, M., Haikara, J., Salo, O., Abrahamsson, P., Still, J.: The impact of agile practices on communication in software development. Empirical Softw. Eng. 303–337 (2008)

[PMIR-2013] Project Management Institute, Inc. (ed.): A Guide to the Project Management Body of Knowledge (PMBOK Guide), 5th edn. Project Management Institute, Inc., Newtown Square, PA, USA (2013)

[PMIW-2019] Project Management Institute, Inc. (ed.): Practice Standard for Work Breakdown Structures, 3rd edn. Project Management Institute, Inc., Newtown Square, PA, USA (2019)

[Prin-2011] Prinzler, H.: Lean Development—Das 9 „P"-Modell. Zusammenhang zwischen den wesentlichen Prozessschritten im Produktenstehungsprozess. In Marcus Evans (Herausgeber): Optimierung des Engineering-Prozesses in produzierenden Unternehmen, Düsseldorf (2011)

[RaOz-2018] Ramaswamya, V., Ozcan, K.: What is co-creation? An interactional creation framework and its implications for value creation. J. Bus. Res. **84**(2018), 196–205 (2018)

[Roth-1982] Roth, K.: Konstruieren mit Konstruktionskatalogen. Springer, Berlin (1982)

[Royc-1970] Royce, W.: Managing the development of large software systems: Concepts and techniques. Western Electric show and Convention Technical Papers, (1970)

[RSMe-2012] Russo-Spena, T., Mele, C.: "Five Co-s" in innovating: A practice-based view. J. Service Manag. **23**(4), 527–553 (2012)

[SaBB-2010] Sanders, E.B.-N., Brandt, E., Binder, T.: A framework for organizing the tools and techniques of participatory design. In: Proceeding PDC '10 Proceedings of the 11th Biennial Participatory Design Conference Sydney, pp. 195–198, Australia (2010)

[SAGS-2019] Schmidt, T.S., Atzberger, A., Gerling, C., Schrof, J., Weiss, S. Paetzold, K.: Agile development of physical products: an empirical study about potential transition and applicability, ISBN: 978-3-943207-38-5, Available at: www.unibw.de/itpe, Report 2019, University of the German Federal Armed Forces, Munich, Germany (2019)

[Sand-2019] Sanders, E.B.-N.: Is sustainable innovation an oxymoron? In: Stebbing, P., Tischner, U. (eds.) Changing Paradigms: Designing for a Sustainable Future, Birkhäuser Publishers (BIRD Series) (2019)

[SaSi-2009] Sanders, L., Simons, G.: A social vision for value co-creation in design. In: Open Source Business Resource (2009)

[SaSt-2008] Sanders, E.B.-N., Stappers, P.J.: Co-creation and the new landscapes of design. Co-Des. **4**(1), 5–18 (2008)

[Scha-2001] Schabacker, M.: Bewertung der Nutzen neuer Technologien in der Produktentwicklung. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[Schw-1995] Schwaber, K.: SCRUM development process. In: 10th Annual Conference on Object-Oriented Programming Systems, Languages and Applications (1995)

[Schw-2012] Schwartz, T.: The magic of doing one thing at a time. In: Harvard Business Review. March 14, 2012. https://hbr.org/2012/03/the-magic-of-doing-one-thing-a.html#, Zugriff 13. April 2019

[Scru-2019] www.scruminc.com. Access 17 July 2019

[ScSc-2019] Scrum-Scrum.: https://www.scruminc.com/scrum-of-scrums/. Access Apr 2019

[Simo-1999] Simonton, D.K.: Creativity as blind variation and selective retention. Is the creative process Darwinian? In: Psychological Inquiry, pp. 309–328 (1999)

[SlXP-2019] https://slidemodel.com/templates/extreme-programming-powerpoint-templates. Access 18 July 2019

[StLC-2009] Stal-Le Cardinal, J.: Approche systémique de la prise de décision en entreprise. Thèse de Doctorat, École Centrale Paris (2009)

[StMS-2016] Stevanović, M., Marjanović, D., Štorga, M.: Managing the process of preparation for product development - ideas assessment and evaluation. In: Marjanovic, D., Storga, M. (eds.) Proceedings of DESIGN 2016 Dubrovnik, Zagreb 2016 (DS 84), pp. 1155–1164 (2016)

[StVa-1996] Stark, J., Vajna, S.: Business Process Reengineering vor der Einführung eines EDM-Systems. Océ GmbH Mülheim (1996)

[SuNa-2018] Surendra, N.C., Nazir, S.: Agile development: exploring what practitioners want to know. J. Softw. Eng. Appl. **11**, 1–11 (2018)

[SzSV-2013] Szélig, N., Schabacker, M., Vajna, S.: Suitable methods for process modeling and process optimization. In: Lindemann, U., Venkatraman, S., Kim, Y.S., Lee, S.W. (Herausgeber): Proceedings of ICED 13, Seoul Korea, Vortrag 176 (2013)

[Tuck-1965] Tuckman, B.: Developmental sequences in small groups. Psychol. Bull. **63**, 348–399 (1965)

[Vajn-2009] Vajna, S.: Dynamic process navigation. In: Penninger, A.: Proceedings of 9th International Conference on Heat Engines and Environmental Protection, Seite 229–240 (2009)

[VaKB-2010] Vajna, S., Kittel, K., Bercsey, T.: Designing the solution space for the Autogenetic Design Theory (ADT). In: Marjanovic, D., Storga, M., Pavkovic, N., Bojcetic, N. (Eds.): Proceedings of DESIGN 2010, the 11th International Design Conference. Dubrovnik, pp. 1441–1450 (2010)

[VCJB-2005] Vajna, S., Clement, S., Jordan, A., Bercsey, T.: The autogenetic design theory. An evolutionary view of the design process. J. Eng. Des. **16**(4), 423–440

[VDI-2222/1997] VDI-Richtlinie 2222 Blatt 1: Konstruktionsmethodik – Methodisches Entwickeln von Lösungsprinzipien. VDI, Düsseldorf (1997)

[Vier-1996] Vier, C.: Unternehmenstransformation und Netzwerkorganisation. Verlag Paul Haupt, Bern (1996)

[VWZH-2018] Vajna, S., Weber, C., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S.: CAx für Ingenieure, eine praxisbezogene Einführung, 3. Auflage. Springer, Heidelberg (2018)

[Wahr-1978] Wahrig, G.: Deutsches Wörterbuch. Bertelsmann Lexikon-Verlag Gütersloh (1978)

[Wain-2007] Wainwright, H.: Prinzipien und Herausforderungen. Rosa Luxemburg Stiftung 2007, https://www.rosalux.de/publikation/id/1460/prinzipien-und-herausforderungen. Access 28 July 2019

[Walt-1999] Walton, M.: Strategies for Lean Product Development. Lean Aerospace Initiative, MIT Boston, Center for Technology, Policy, and Industrial Development (1999)

[Wien-2014] Wiendahl, H.P.: Betriebsorganisation für Ingenieure, 8. überarbeitete Auflage. Hanser (2014)

[XP-2019] XP.: http://www.extremeprogramming.org/ Access Apr 2019

[Zwic-1966] Zwicky, F.: Entdecken. Forschen im morphologischen Weltbild, Droemer Knaur Verlag München Zürich, Erfinden (1966)

Chapter 16
Holistic IDE Procedure Model

Sándor Vajna

A solution usually emerges in an iterative process between development and evaluation. The development itself is as well an iterative process that takes place between an idea, a suitable concept and the solution derived from the concept. Each solution must be evaluated, whereby each evaluation leads to an improved development, which in turn goes through the cycle of ideas, concept and development, is re-evaluated and so on. This process can be described with the TOTE scheme (Sect. 1.2.3.2). As shown in Sect. 2.2.2 and Fig. 2.4, it is triggered by various forms of customer demand, the general market situation and market opportunities, whereby different conditions, requirements, constraints and standards in different areas have to be considered. The entire iteration loop has the course of an "8", in which the generation between an idea, the resulting concept and the actual solution development and solution evaluation take place[1]. The individual product attributes are successively developed, their fulfilment determined by the attributes Safety, Reliability and Quality safety, Reliability and Quality, and their economic performance measured by the attributes Added Value and Profitability Added Value and Profitability, Fig. 16.1.

As shown in Sect. 1.2.3.2, the TOTE scheme is a self-similar process that can be applied to different tasks and thus can serve as a guideline for a high variety of activities. Such a guideline is then called a *procedure model* when it proposes, (but not necessarily prescribes) a meaningful sequence of organizational, methodical and technically meaningful activities and processes (with the use of the associated methods, procedures and tools) for the development of products.

A procedure model covers all activities involved in processing processes and objects as well as related activities, such as to manage a project. The procedure

[1] A lying "8" is the sign of infinity and so there are product developments in all industries which (despite the knowledge of the Pareto rule described in Chap. 1) would never end if there were no end dates or financial limits.

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model defines all relevant activities and (expected) results as well as their logical interdependencies with each other and with the external framework conditions. The procedure model provides a formal framework for processing tasks, for example, to plan the development of a product. It can map the current dynamic state of a process, e.g. that of product development, and realize further steps by applying Dynamic Navigation (Sect. 15.7). The procedure model can also assume the function of a checklist for the timely completion of activities, clarify the expenditure for a task to be solved or already been solved and reflect the results of a completed project [Frei-2001] [PoLi-2011].

16.1 Basics and Structure of the IDE Procedure Model

The loop depicted in Fig. 16.1 can be identified at every level of abstraction and concretization of product development, as has been shown by corresponding research on the *Autogenetic Design Theory* ([VaKB-2011] and Chap. 1.1.5). It thus forms a self-similar activity pattern within IDE and therefore serves as the basis for the holistic procedure model of Integrated Design Engineering. However, the model shown in Fig. 16.1 is neither comprehensive, nor detailed and diverse enough to

- cover all requirements for structuring, modelling, navigation and completeness of the development within IDE. These requirements result essentially from the interdependent attributes and their fulfilment levels, the necessity for parallel processing of tasks, the numerous integrations within IDE (Fig. 3.2 and Chap. 14) and the restrictions and limitations in project work (Sect. 15.2.3).
- ensure that the procedure model can be applied not only to the creation of arbitrary objects (Sect. 2.1), but also to the creation of their preliminary stages (ideas, concepts, designs, approaches, trials and errors, etc.).

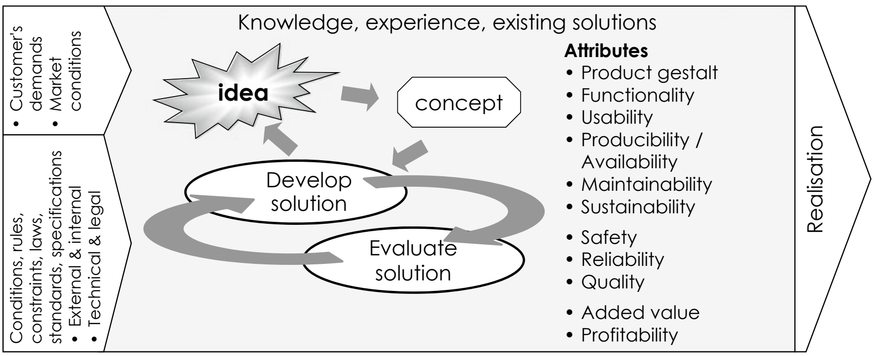

Fig. 16.1 Iterative preparation and evaluation of a solution (using Fig. 2.4)

- consider all problems arising from the dynamization of requirements (in the broadest sense) and changes both in the development and application environments (Sect. 15.7).
- enable that the knowledge required for IDE can be made available in a context-sensitive way.

The holistic IDE procedure model picks up the basic idea of the self-similar activity pattern, which can be used at any concretization level of product development, on a large scale as well as in detail, and for any product and application domains as well as application disciplines, Fig. 16.2.

The procedure model with its eleven activities arranged in five groups can be used for all objects that can be handled within IDE, i.e. any ideas, concepts and problem solutions from any disciplines and for any markets, in all possible combinations, development stages and implementation states. The procedure model does not specify a specific processing sequence (completely in accord with Dynamic Navigation, Sect. 15.7), since a subsequent processing step can only result from the results of the current step and the conditions prevailing at this point in time from requirements and the internal and external environment (for restriction options during processing, see Sect. 16.3).

The IDE procedure model consists (from left to right) of the activity groups Research; Develop | Design | Integrate; Evaluate | Compare | Select; Model | Configure | Synthesize; and Complete, all of which are accompanied by ongoing documentation of (intermediate) results. Conception, selection and configuration of these activities and their respective groupings are based on the work of FREISLEBEN [Frei-2001], on the results of industrial development projects in the IDE Master's study course IDE

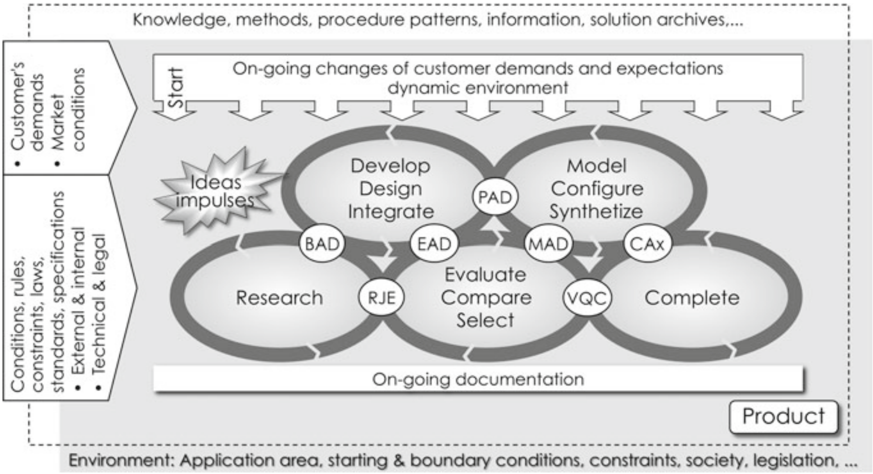

Fig. 16.2 Holistic procedure model of Integrated Design Engineering

at the Otto von Guericke University Magdeburg[2] [IDEP-2019] and on the work of NEUTSCHEL [Neut-2017].

- *Research* with its various measures enables the procurement of required information and knowledge for the other activities in the procedure model in the required quantity and quality at the respective points in time. It can be carried out as a rough or a fine search.
- *Develop* encompasses a wide range and variety of the emergence of an object, but predominantly in small or rudimentary stages of concretization. *Design* serves to successively work out the geometric-material totality of the object in the sense of solving the aesthetic design problem according to the product requirements formulated via the attributes in the respective environment (design thinking). *Integration* complements, completes and merges, where appropriate, the solutions that have been developed so far (including fragmentary solutions), so that the essential characteristics and features of the later product can be identified.
- For the *evaluation* of the current work status as well as for both *comparison* and *selection* of alternative objects according to arbitrary criteria, various procedures are used for the evaluation, calculation, simulation, animation and testing of objects as well as the determination of economic aspects, all at arbitrary times.
- Both for the easier evaluation of the object and its preliminary stages, as well as for development and interpretation, it is helpful to work with a growing numerical representation (model) of the object, in which the essential characteristics of this object, its components, its behaviour and its interaction, which all contribute to the object performance, can be *modelled* in the respective current development stage. The modelling also includes the representation of the object in different forms of illustration. Such a representation can be a more or less complete product model (a so-called digital twin[3]). According to the stage of development, it can be a digital prototype (digital mock-up), a technical drawing and a more pictorial representation, which aims, for example, at the shape, impression and surface quality of an object. *Configure* basically contains the same activities as Develop, but prefers to use these for the concretization and dimensioning of (emerging) objects. It does not matter whether it is a new or an adaptation development of an object or a variant design. With *synthesizing,* the emergence of a superior solution (synthesis) in the sense of HEGEL's philosophy is promoted from previously competing and/or contradictory solutions (thesis and antithesis). At the same time, a meaningful reduction of the variety of solutions without loss of solution quality is achieved.

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[2] In the 2000s, the editor and assistants of his Chair of Information Technologies in Mechanical Engineering developed the IDE Master's study course. Teaching started in the winter semester 2011/2012, since then, the master course has been transferring research results on IDE into university teaching.

[3] A digital twin accompanies a product throughout its product life. It digitally maps the current state of the product (how it was developed, delivered and installed, updated, etc.), its history and the associated structures, processes, calculations, simulations (of behaviour and strength), etc. at all times.

- C*omplete* ensures that all necessary activities are done in order to complete the current development step.
- Continuous *documentation* of each activity takes place until the product documentation is complete.

The abbreviations BAD, PAD and MAD (adapted after [Otto-2013], see also Sect. 1.4) as well as EAD, RJE, VQC and CAx summarize suitable support and linking measures for the activities in the IDE procedure model at the points of contact of the circles in Fig. 16.2.

- Within IDE, brain-aided design (BAD) comprises such procedures and methods that take place on abstract levels and serve to round off possible solutions at an early stage, for example, the most varied thinking and creativity techniques as well as their appropriate application. BAD promotes thinking on abstract levels in order to be able to better grasp the contexts in a task. Thus, it serves the collection of requirements, the compilation of the required knowledge, the definition of the required support and last but not least the preparation and execution of the development work.
- Pencil-aided design (PAD) comprises the fast creation, visualization and fixing of solution variants with their essential characteristics as sketches on paper (also called the "language of the product developer", see also Sect. 6.2), without having to carry out a complex modelling at an early time. This allows an initial check to be carried out on the fulfilment of specifications and the feasibility of a solution. In addition, a continuously growing repository with solution ideas is created, with which a fast identification of the currently best possible solution can be achieved with little effort.
- Model-aided design (MAD) is preferably used for "thinking with the hand," as a first impression of form, impression and dimensions of the resulting product can be gained from a physical model of any complexity. This allows not only the haptics of the object to be tested and optimized, but also its shape. At an advanced stage of development, MAD also includes virtual models in suitable CAx systems and virtual reality systems as well as the rapid creation of prototypes with classical materials (light metals, plastics, wood) and by additive manufacturing (e.g. with photopolymers or sintered materials; Sect. 9.2).
- Evaluation-aided design (EAD) summarizes all measures for verification and evaluation of (interim) results.
- RJE (Rate, judge, estimate) is used to classify search results in terms of usefulness, plausibility, consistency and coherence.
- VCQ (Verify, quantify, check) is applied to check and evaluate the results and solutions that have been achieved so far before the documentation is completed.
- Computer-aided everything (CAx) is the generic term for any type of computer-aided system support for the most realistic modelling and simulation of product alternatives possible (see also Chap. 18).

The holistic nature of the procedure model results first of all from the IDE attributes, which originate from all phases of the product life (except product development) and thus enable the holistic consideration of all influencing variables. In addition, the currently reached fulfilment levels of each attribute control the flow through the procedure model. In conjunction with the Dynamic Navigation procedures (Sect. 15.7), it is ensured that none of the activities required for a project can be omitted.

Equal goals are the achievement of the specified or required product quality during the processing of all activities and the fulfilment of customer demands. Therefore, the IDE procedure model uses diverse knowledge, methods, tools, procedures, information and solution archives, etc. to work with the activity groups. The procedure model is subject to the influences of the environment, consisting of the application environment in which the product is used, boundary, initial and mandatory conditions as well as constraints, laws and society, etc. The adaptation to a concrete problem is carried out exclusively by the information used and the knowledge applied. All activities also make use of the existing explicit and implicit knowledge of employees and the company, consisting of knowledge and experience, methodologies, best practices, information, solution archives, etc. (see also Chap. 17).

Three structures can be identified in the holistic IDE procedure model, Fig. 16.3:

- Based on the customer demand and the possibilities in the market as well as the consideration of possible limitations, the Research activity, the activity group Develop | Design | Integrate as well as the activity group Evaluate | Compare | Select provide the continuous development of the application scenario of the resulting product take place.
- In the activity group Develop | Design | Integrate, the activity group Modelling | Configure | Synthesize as well as in the activity group Evaluate | Compare | Select the essential activities of IDE take place within the genesis of the product and its preliminary stages. The genesis can also be supported very effectively with the methods of the Autogenetic Design Theory (Sect. 1.7). For this purpose, the specifications for the fulfilment levels of the individual attributes are integrated to form a common target function. The genesis then proceeds analogously to the procedures described in Sect. 1.7.1 and shown in Fig. 1.32.

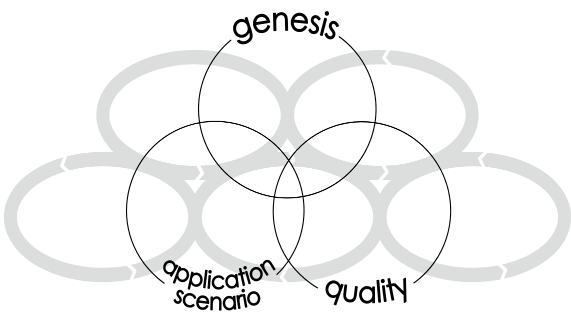

Fig. 16.3 Structures in the holistic IDE procedure model

- In the activity group Modelling | Configure | Synthesize, in the activity group Evaluate | Compare | Select and in the activity Complete, the essential steps for consolidating all possible quality aspects (e.g. usage, production and re-utilization quality) are carried out before the product is released for production.

The three structures are sufficiently interlinked to ensure that they cooperate and do not compete against each other and that a product can be developed that meets the requirements and is continuously adapted to new influences.

In the IDE procedure model, each activity is basically connected to all others (forming a mesh). However, a connection is only activated when required and becomes inactive again after the end of the respective requirement. The procedure model does not contain a time axis, because when processing in a dynamic environment, there is neither a previously definable time sequence nor a preferred direction for the activities. Only when editing a concrete project does a sequence emerge step by step from the current editing and its progress in comparison to the current fulfilment levels of the attributes. Further effects result from current knowledge, internal and external influences and the resulting work progress. The concrete chronological order in a project can therefore only be determined afterwards.

- Internal influences arise from problems with project resources or missing or incomplete input from the extended or external teams (Sect. 15.6.3).
- External influences essentially include changes in customer requirements and expectations as well as changes in the environment of the IDE, in particular from the application scenario and environment, as well as the boundary, initial and mandatory conditions.

As mentioned above, the TOTE scheme is the basic structure for describing possible patterns of individual activities. In the procedure model, the activity group Evaluation | Compare | Select corresponds to the TOTE function “Test”, while the other activity groups implement the TOTE function “Operate”, Fig. 16.4.

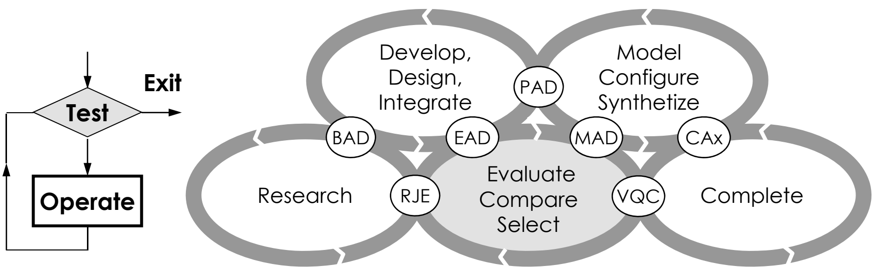

Fig. 16.4 TOTE scheme as basic pattern for the holistic IDE procedure model (grey areas: Realization of the function “Test”, white areas: Function “Operate”; after [Neut-2017])

16.2 Application of the IDE Procedure Model

Due to its self-similarity, the IDE procedure model can be used for modelling purposes at the top level of the product development process as well as at any level of detail below. It also supports the development of any objects from any disciplines (Chap. 2), mechanically oriented products as well as those with an emphasis on electronics or software (Mechatronics: Chap. 23). The activities contained in the procedure model always remain the same. Therefore, the procedure model can be used just as well to develop a concept as, for example, to develop detailed solutions for a specific product.

In the sense of Dynamic Navigation (Sect. 15.7), each of the activities listed in Fig. 16.2 can be regarded as a process element with a corresponding set of methods and tools, suitable procedural patterns (e.g. from [EhMe-2017] or [HaGo-2004]) and structuring rules for the structure of the network of activities. During the modelling of the process by configuring and combining process elements, these are adapted to the current conditions. Depending on the situation of a company, sub-processes from several process elements can also be applied instead of individual process elements, for example, in the activity *Compare,* since these are usually reproducible activities. Figure 16.5 shows further possible decompositions of the process elements at the top level of the IDE procedure model, as they can be used in an IDE project to form the activity pattern[4].

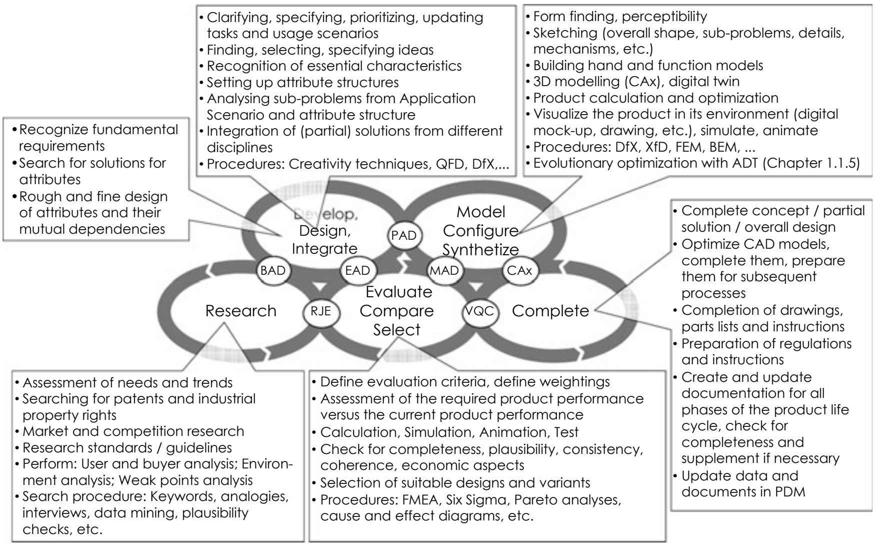

Fig. 16.5 Selection of the stored methods, procedures and procedures for each activity group in the holistic—IDE procedure model (Selection)

[4]A detailed description of the activities resulting from decomposition is not given here, because such activities can be found in the Engineering Design Methods and VDI guidelines discussed

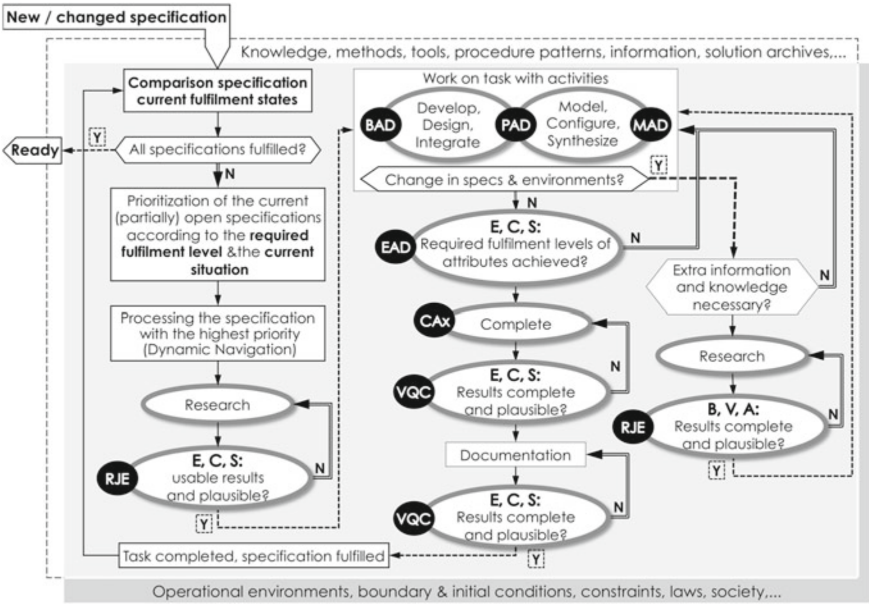

Fig. 16.6 Basic pattern for processing all activity groups within the IDE procedure model (dashed line: Positive result of a query "Y". Solid line: Negative result of a query "N")

Although the IDE procedure model does not fix a specific processing sequence, one can define a neutral basic pattern for the activities with which, for example, an (as yet) inexperienced product developer can work with the procedure model. In addition to the processing of all activity groups and the seven support and connection measures, the essential elements of this basic pattern are the on-going comparisons of the results of each processing step and its progress compared to the respective required fulfilment levels in the respective specifications, Fig. 16.6. Processing starts with the step "Comparison of specifications of ⇔ current fulfilment status" (top left in Fig. 16.6). It ends when all specifications and their fulfilment levels have been reached and the product thus exhibits the required performance capability with the corresponding performance behaviour.

If the actual sequence of activities is to be recorded in a concrete IDE project (e.g. because of product liability), this can be done using the documentation options of Dynamic Navigation (Sect. 15.7). During the processing of the project, the network of activities forms and changes successively. Using the project example presented in Fig. 15.27, the resulting network is shown in Fig. 16.7. The small white circles

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in Chap. 1 as well as at large number and variety, e.g. in [HaGo-2004] [Otto-2013] [EhMe-2017] [PBBG-2020]. However, it should be noted that the sequences of activities described in the individual sources cannot be valid in the IDE procedure model, since possible sequences in the activity strands only form and change during current processing.

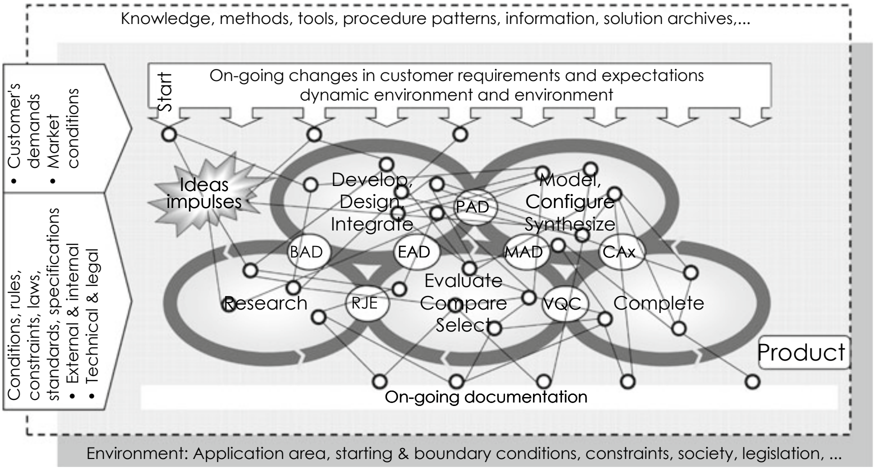

Fig. 16.7 Network of activities in the concrete project processing within IDE procedure model

represent individual activities or groups of activities, which are connected with each other according to the respective context.

The network in Fig. 16.7 shows (as expected) an accumulation of activities in the three activity groups of the product genesis (Fig. 16.3), but also the fact that the customer changed the requirements twice (circles below the arrows above). The circles in the "on-going documentation" field only show the consolidations of the product documentation carried out for certain events, for example when a certain development status (or milestone) has been reached.

Because during the processing of all activities both the respective start and end dates as well as the results of each activity are documented with regard to the achieved fulfilment levels of the attributes, the activity network from Fig. 16.7 can be related to the time axis. Each activity group of the procedure model becomes a strand running in parallel to the other strands. All strands are framed, on the one hand by activities to secure and update the current projects, on the other hand by the creation and updating of the documentation. Figure 16.8 shows this transition for the project from

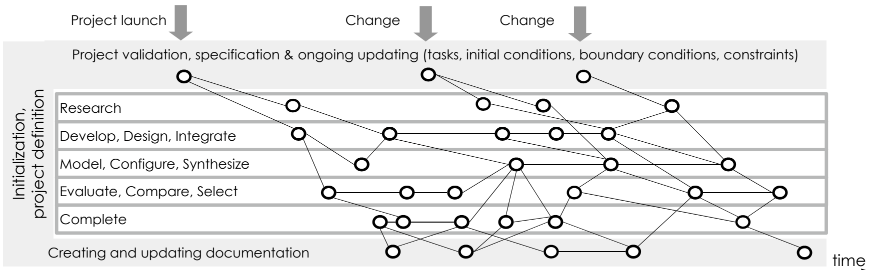

Fig. 16.8 Network of activities of the concrete project along the time axis

Fig. 15.27 and the resulting network of activities.

The small white circles in Fig. 16.8 show (as in Fig. 16.7) individual activities from a certain activity group in a certain chronological order, beginning with the project launch and depending on the task as well as on changes in the requirements (there were two changes in this project). Usually the last activity before the transfer of the project result is the documentation of the last achieved results.

Indeed, Fig. 16.8 shows the individual interconnected activity groups, but not how these activities were distributed over the genesis of the six product attributes. The attributes must be developed with a view to predefined degrees of fulfilment and economic specifications. Since they influence each other, a processing order cannot be specified here either. If one now, in analogy to the documentation of the activities, wants to represent the sequence of the genesis of the six product attributes in retrospect, then the logged results of the respective activity and their respective time window of the treatment (see above) can be used for this. Figure 16.9 shows this process for the project from Fig. 15.27 in a spider diagram which was rotated by 30° compared to Fig. 3.11 for better representation. As pointed out in Fig. 3.11, the individual fulfilment heights increase from the inside out. Consequently, the processing starts in the middle of the spider diagram, where at the beginning of the processing there are no fulfilments. The genesis of the product attributes forms a comparable network to that of the activities in Fig. 16.7. They end as soon as the specifications of each attribute have been reached, with the preparation for market launch. Accordingly, this node is associated with the highest fulfilment of each attribute.

As with the network of activities in Fig. 16.7, the activities in Fig. 16.9 can be projected onto the time axis. Figure 16.10 shows for the same project the network of activities for the genesis of product attributes over time.

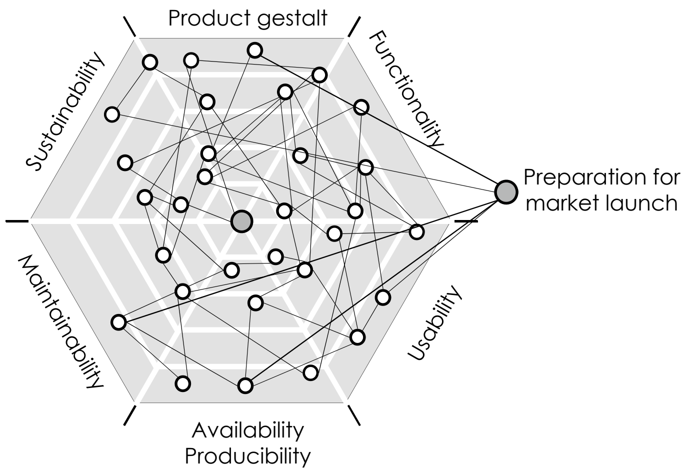

Fig. 16.9 Networked activities in the genesis of product attributes

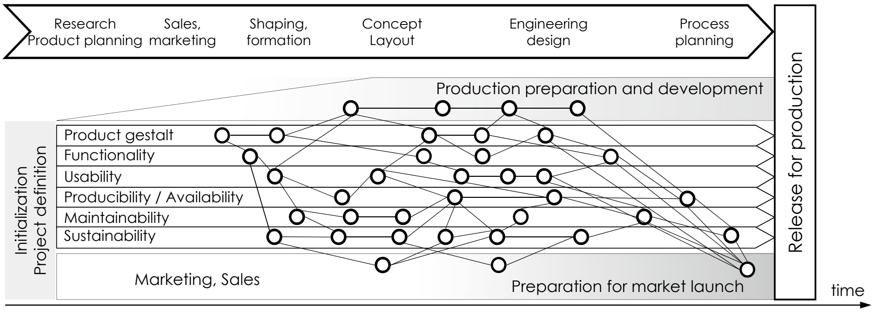

Fig. 16.10 Genesis of product attributes over the time axis

Provided no changes occur during product development, it can also be assumed that the fulfilment levels of an attribute increase from left to right. If, however, changes occur that are reflected in a change in the requirements, then it is quite possible that the fulfilment level of an attribute is "thrown back" and must be redeveloped and concretized again.

During processing, both the documentation of the respective start and end dates (Fig. 16.8) as well as the documentation of the results of the respective activity with regard to the resulting fulfilment levels for each attribute (Fig. 16.10) are carried out for all activities. Thus, with the help of the activities, the current processing status of the product development can be determined at any time. Should deviations from the project specifications occur, these can be corrected and compensated using the Dynamic Navigation procedures (Sect. 15.7).

16.3 Adaptability of the IDE Procedure Model

As already mentioned, the actual processing sequence in the IDE procedure model can only be determined after completion of a project. If, however, a company develops, a number of similar products, the quintessence of the stored networks of activities can be derived as so-called pattern networks (i.e. best practices), which can be used as possible initial configurations for similar development tasks. In order to represent such a sample network in the form of a bar chart for a project, the time windows[5] intended for editing are used. The determination of a time window is based on a network of activities selected as a pattern. The duration of a time window is basically determined by the time interval between the first and the last activity from the same activity group. In Fig. 16.11, this is executed using the concrete example from Fig. 16.8.

[5]The time window determines when the activity under consideration can begin at the earliest and when the subsequent activity requires the result of the activity under consideration at the latest. It is therefore longer than the actual processing time of the activity itself.

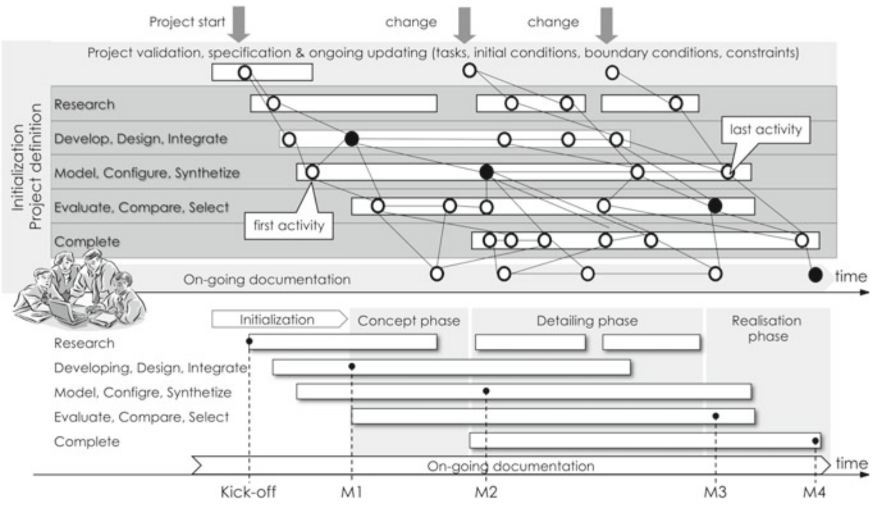

Fig. 16.11 Fixed time windows and content properties in the IDE procedure model as well as transfer to a time bar chart (white bars: Time windows for the respective activity groups. Black filled circles: Milestones)

- In the time bar chart, the project is divided into the processing tasks initialization, concept phase, detailing phase and realization phase ([HaGo-2004], see also Sect. 1.1.2).
- The beginning of the initialization is scheduled with a time lead in which the project can be conceptualized, structured and planned through with regard to project members, tasks, resources, budget and processing times (see Sect. 15.2.3).
- With project start (kick-off), a larger time window is assumed for the Research activity based on project experience than can be derived from the individual activities in the concrete example. Further Research time windows arise when there are changes in requirements or conditions of the environment (in the broadest sense).
- Milestones (Sect. 15.3.2) take place at the beginning of each editing phase and at the end of the project (see also Sect. 22.2.2).

From the time windows, a time bar chart (Gantt diagram[6]) is created, which can be edited with the known methods of project management (for example [Hahn-2001] [Neut-2017]), whereby of course the dynamics and flexibility inherent in the IDE procedure model can no longer be used.

[6]Named after Henry L. GANTT (1861–1919), American mechanical engineer, founder of Scientific Management together with Frederick W. TAYLOR and Frank B. GILBRETH [Lanc-2004].

16.4 Summary

The holistic IDE procedure model provides such activities, with which most different products (material and non-material as well as combinations from it, Chap. 2) can be developed. It applies the findings of the Dynamic Navigation of processes and projects to the development of a product. It gives the product developer (or the IDE team) at any time the necessary freedom to develop the product as it appears best at the time of processing. It dynamically maps the current status of product development and thus provides an up-to-date overview of the processing status at all times. From a successful project, the activity network (or parts of it) can be used as a model for further projects.

The eleven activities of the process model, their grouping as well as the procedures, methods and tools associated with each activity (Fig. 16.5) as well as the resulting possibilities of predictive engineering and reverse engineering ensure that in the case of a development task the maximum possible number of work and decisions can be moved forward to the area of product development (Fig. 16.1). If one works with the IDE procedure model and plots the expenditure for the product development against the time, then the front-loading of activities within the product development becomes visible, Fig. 16.12.

In order to develop viable solution concepts, four of the five activity groups in the IDE procedure model are applied from the phase of Shaping and formation to the phase of Engineering Design. Only when viable solution concepts have been developed can the final details be detailed and completed.

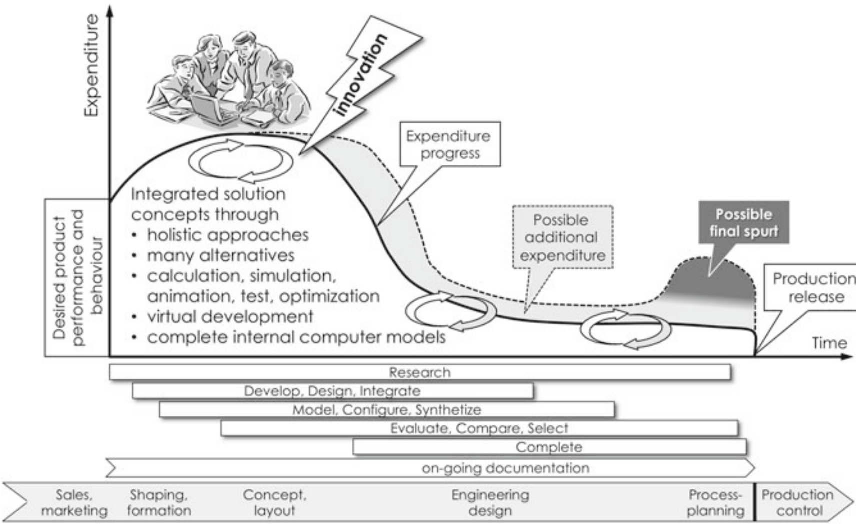

Fig. 16.12 Changed procedures in product development using the IDE procedure model. *Source* This illustration uses research results that were kindly provided by Dipl.-Ing. B. Jörg, Vibracoustic KG

If there are changes during project processing, then the Dynamic Navigation methods (Sect. 15.7, Fig. 15.30) must be used to achieve these changes primarily by changing the configuration and combination of the process elements. If this is not or only partly possible, additional effort (agreed in advance with the client) is required to achieve the changed project objective in order to achieve the changed specifications. This is highlighted and marked in light grey in Fig. 16.12. It is also possible that changes made shortly before the end of the project may result in further expenditure in the form of a final spurt (marked in dark grey), which can be realized, for example, in the form of a sprint (Sect. 15.3.3.2).

By specifying logical and temporal restrictions of the IDE procedure model, it can be converted into a static procedure model if required. Although this can be used to specify a target procedure (which may also be necessary for certain types of process, such as stage-gate processes, Sect. 15.3.1), it no longer makes it possible to permanently monitor and evaluate the stage of development.

References

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung. Sechste grundlegend überarbeitete und erweiterte Auflage, Hanser München (2017)

[Frei-2001] Freisleben, D.: Gestaltung und Optimierung von Produktentwicklungsprozessen mit einem wissensbasierten Vorgehensmodell. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[HaGo-2004] Hales, C., Gooch, S.: Managing Engineering Design, 2nd edn. Springer, London (2004)

[Hahn-2001] Hahn, R.: Projektmanagement für Ingenieure. Wiley VCH Verlag, Weinheim (2001)

[IDEP-2019] Projektarbeit im Masterstudiengang Integrated Design Engineering (IDE) an der Otto-von-Guericke-Universität Magdeburg, http://ide.ovgu.de/ide-projektarbeit.html. Zugriff am 14. 11. (2019)

[Lanc-2004] Lancaster, J.: Making Time. Lillian Moller Gilbreth—A Life Beyond "Cheaper by the Dozen". Northeastern University Press Hanover (USA) (2004)

[Neut-2017] Neutschel, B.: Parallelisierung von Produktentwicklung und Businessplangestaltung—ein Beitrag zur Schaffung von regionalem Wachstum durch universitären Wissenstransfer. Dissertation Universität Magdeburg (2017)

[Otto-2013] Ottosson, S.: Frontline Innovation Management (zweite Auflage). Tervix Göteborg (2013)

[PoLi-2011] Ponn, J., Lindemann, U.: Konzeptentwicklung und Gestaltung technischer Produkte, zweite Auflage. Springer Heidelberg (2011)

[PBBG-2020] Pahl, G., Beitz, W., Bender, B., Gericke, K: Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung 9. Auflage. Springer Heidelberg (2020)

[VaKB-2011] Vajna, S., Kittel, K., Bercsey, T.: The Autogenetic Design Theory—Product development as an Analogy to Biological Evolution. In: Birkhofer, H. (ed.) The future of design methodology. Springer, London (2011)

Chapter 17
Knowledge Integration

Sándor Vajna

The success of and within IDE is essentially based on the knowledge, experience, creativity, and competence of the people working in IDE. They have to acquire new knowledge continuously and with each project, i.e., eventually they have to learn lifelong, since new knowledge is continuously generated by high innovation speed and (natural) decay of factual knowledge through technical progress (decreasing half-life period of knowledge). The lifespan of methods and procedures within IDE is similar, even if the half-life period here is many times longer than for factual knowledge[1].

Knowledge is needed and used for every activity and for every result within IDE. However, it is not immediately visible and retrievable everywhere and therefore cannot be applied everywhere and easily. This raises the question of what knowledge actually means in this context: Is it the knowledge of the product developer and his ability to create and apply rules (acquired from outside or based on experience, in both cases supported by trust), i.e., his distilled or refined (in the sense of refined) or neutralized or abstracted knowledge and experience, or is it more?

The ephemerality of knowledge, which is based on the one hand on the processes of thinking, learning and forgetting [Vest-1998], and on the other hand, promoted by information overload, is not a phenomenon of today. As early as 1808, Johann Wolfgang von GOETHE stated in *Die Wahlverwandtschaften* ("Elective Affinities") that "it is bad enough that you can no longer learn anything for your whole life. Our ancestors kept to the lessons they received in their youth—but now we have to relearn every five years if we don't want to go out of style." [Goet-2006]. The couple Lillian M. GILBRETH and Frank B. GILBRETH already proved 1908 in *Field System*, the

[1]For example, the half-life period of IT expertise is currently between two and three years of technology knowledge between five and ten years. For methods and procedures, it is about 15–20 years.

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manual for rational procedure for bricklayers in their own construction company[2], that the most important factors are committed employees and the application of knowledge to make the success of the company possible [Gilb-1908].

Knowledge (whether self-generated or acquired from third parties) is an essential part of a person's intellectual capital (mental capital, intellectual property). The mental capital exists only in his head. In addition to knowledge, this includes:

- Wisdom and knowledgeability,
- Motivation, talent, abilities (aptitude, ability, efficiency), and skills,
- Analytic thinking,
- Creativity as ingenuity, heuristics, and creative power to gain new insights into the novel formation, configuration, and combination of objects of thought,
- All experiences gathered so far (the knowledge you have experienced yourself),
- Competence as the ability to use existing knowledge of different characteristics and fields of application expediently and also in analogies, and
- Loyalty to other persons, to certain organizations or institutions.

Knowledge consists of self-made discoveries and experiences as well as acquired knowledge and experience of third parties. As already mentioned, it basically belongs to particular individuals. It can therefore only be created, acquired, used, improved and expanded, passed on, bought and sold ("specialist," "consultant") by individuals.

Knowledge is today (after man, machine, material, financial resources, and information) the sixth production factorto which 60–80% of the total value added of a company is attributed[3]. However, only 20–40% of company knowledge is actually used[4]. Non-human systems such as computer systems cannot (yet) generate knowledge[5], but can store and manage it in suitable forms, for example, as rules or algorithms.

The term *knowledge integration* within IDE means the provision of the complete knowledge about

- the product,
- the associated design, development, machining, manufacturing, distribution, utilization, and re-circulation processes,
- the associated methods, procedures, and technologies, and
- the environments in which the life cycle of the product takes place.

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[2]Among other things, GILBRETH invented a mortar mixer and a scaffold that grew with the wall, on which bricks and mortar were placed in such a way that a bricklayer could grasp the trowel with mortar with one hand and the brick with the other hand without bending down, and immediately install it. Thus, the number of movements to set a brick could be reduced from 18 to four and the quality of bricklaying could be significantly increased [IWSI-1968].

[3]Source: Spath, D (ed.): Wissensarbeit: Zwischen strengen Prozessen und kreativem Spielraum, GITO Gesellschaft für Industrielle Informationstechnik und Organisation mbH Berlin 2011

[4]Even to find and use this, a product developer spends about 22% of his working time.

[5]Ray KURZWEIL wrote in 1999 that it would still be possible at the beginning of the twenty-first century to completely reproduce brains on computers and then have them generate knowledge [Kurz-1999].

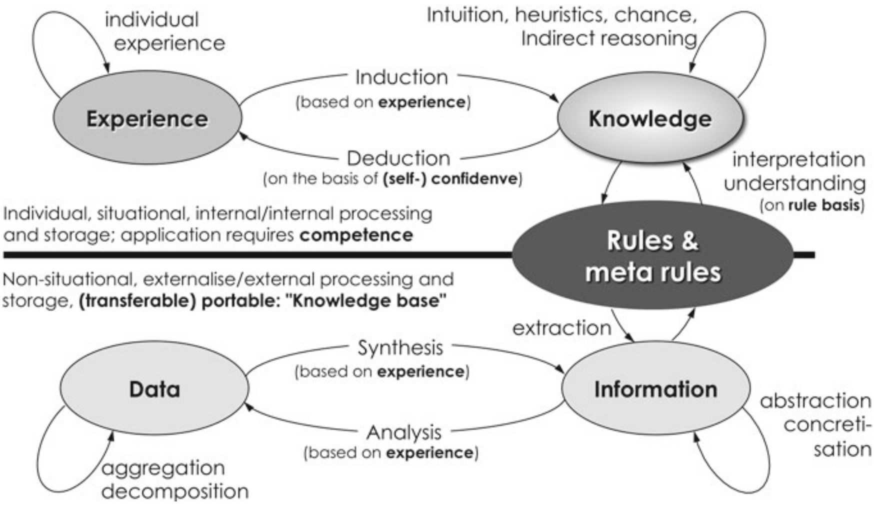

Fig. 17.1 A possible knowledge taxonomy [Vajn-2001]

The provision is to take place in a holistic and uniform knowledge base to which every user can have access at the required time.

However, knowledge manifests itself outside the human being only indirectly, either through communication between people or on external media, in both cases usually in the form of signs, data, information and rules, alphanumeric or graphical representations. Since knowledge is usually passed on ("externalized") only after it has been checked for stringency and consistency and for correctness and usefulness, knowledge stored externally is not a priori obsolete, but it is not necessarily always up to date.

Possible connections between data, information, knowledge, and experience as well as their connection by rules and meta-rules are shown in the knowledge taxonomy in Fig. 17.1 [Vajn-2001].

The taxonomy is divided into two parts. The upper part contains experience and knowledge. Both exist only in humans, are individual, either related to a certain situation or transferable as analogy to comparable situations. The lower part contains data and information that can be stored and processed externally and that can be used both neutrally and for a specific situation. The two parts of the taxonomy are connected by rules and meta-rules.

- Information technology data can be in numerical form as numbers, in alphabetical form as letters, or in a mixed form as alphanumeric characters. These characters stand in a certain sequence and structure, the syntax. The syntax gives data a meaning (semantics). Data can be combined (aggregation) and split (decomposition).
- Information arises from data that has been contextualized and synthesized to a higher meaning. The focus is on the structure and connections of the data contained

therein, so that the meaning of the information arises primarily from the order of the signs contained therein, less from the signs themselves. Information can be generalized (abstraction) or illustrated (concretization). The analysis of information can generate data again. In order to carry out a synthesis or an analysis, appropriate experience is required, which can be acquired, for example, in training or in daily work.

Data is the medium used to display information. Information contains the actual message, which can, however, be interpreted differently by each recipient. This means that the same data can provide different information for different recipients.

- Rules are predetermined guidelines, methods, or regulations, usually confirmed by experience. They are used to describe contexts, meanings, purposes, actions, etc.
- Meta-rules are rules about the application of rules. They also describe the relationships between rules.

If information is networked and linked with rules or meta-rules, then knowledge can arise for a human being by linking interpreted information with the individual knowledge and experience of this human being. The emergence also depends on how this person's point of view and understanding of a particular topic is. Therefore, the resulting knowledge is always individual.

- Knowledge arises both from the induction of experience and continuous engagement with a subject, as well as from intuition, spontaneous knowledge (heuristics), random observations, and indirect conclusions[6]. Knowledge is taken from other sources if it seems plausible and trustworthy and can contribute to solving a current problem. From this knowledge, personal experience can be derived again through deduction, provided there is sufficient (self-) confidence that this derivation can deliver the desired results.
- An experience arises from personal experience in the application of knowledge and as a quintessence of success and failure, which can serve as a basis for analogy conclusions. Especially for the latter, self-confidence in one's own judgement and the right conclusion are necessary. Experiences are always individual and related to a certain situation. If, however, it is possible to generalize an experience, then new knowledge can emerge from it through induction.
- The activities in the environment of knowledge and experience regarding selection, linking, and application require competence. This is divided into meta-knowledge, i.e., knowledge about contents, meanings and links of experiences and knowledge, and action knowledge for implementing and applying experiences and knowledge ("know how," "know what," "know why," "know where," and "know when").

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[6]It comes to an indirect conclusion when an unpredictable phenomenon occurs surprisingly within a harmonious environment, which, due to its apparent otherness, becomes so important that within the environment a reason is sought and "constructed in" (which is actually not possible in this environment) which can confirm this phenomenon [Stang-2012].

In today's language, links of data, information, and rules or meta-rules are also referred to as "knowledge" (although this does not apply in the sense of the taxonomy in Fig. 17.1). Systems that generate, link, manage and store data, information and rules are therefore referred to as "knowledge bases." There are proven approaches in information technology with which such knowledge bases can be established.

Even if there are other forms of knowledge description in the literature, the taxonomy used here has the advantage that it does justice to the human-centered approach of IDE, because it leaves the sovereignty over possession, interpretation, generation, acquisition, application, storage, and passing on of knowledge to the human being.

17.1 Types of Knowledge and Knowledge Structures

Knowledge can first be divided into explicit knowledge, knowledge for action, implicit knowledge, and obsolete knowledge, Fig. 17.2.

- Explicit knowledge is knowledge that everyone formulates, expresses, and explains to others in a comprehensible way, about which they can talk: "He knows that he knows, and he can explain". Such knowledge can easily be stored in external media. It consists of data, information, and rules as well as meta-rules, which are interlinked in many ways.
- Active knowledge or action knowledge is the knowledge that becomes effective during a work or action, which can be retrieved from memory and used in a targeted manner. It has a three-level structure and consists of target units, condition units,

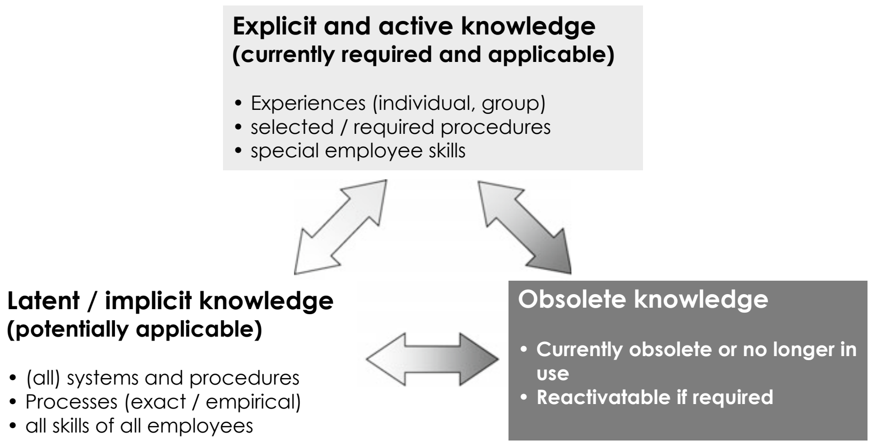

Fig. 17.2 Types of knowledge

and the resulting measure units[7]. Knowledge of action only leads to successful action if the actor pursues a clear goal, intelligently seeking conditions for the realization of the goal, adequately assessing and controlling any existing risk, and knowing and applying appropriate measures to successfully complete his action. Therefore, in addition to knowledge, action also requires suitable goals and motivations, the necessary intellectual abilities and basic intelligence as well as sufficient knowledge and facts about the methods and procedures to be used [Hack-2002]. The storage of active knowledge on storage media is most likely to succeed in connection with explicit knowledge.
- Implicit, latent, or tacit knowledge is not readily available. It is usually acquired unconsciously through practical and repetitive work in a similar task environment. Implicit knowledge usually does not determine individual action, but is always present and can usually be explained by humans. It is "stored" in people in the form of diverse experience and competence. Storage on external media is difficult, because knowledge carriers are only rarely able to describe the underlying (essentially fuzzy) rules and the manifold interconnections of the information in a way that is comprehensible and reproducible for third parties. A certain part of the latent knowledge cannot be explained by many bearers of knowledge, "it's just like that", "you have it in your little finger" [Hack-2002].
- Obsolete knowledge is (currently) out-dated or no longer used knowledge. In order to state obsolescence, appropriate rules, procedures, and metrics are required. However, obsolete knowledge should not be deleted, but better archived in such a way that it does not affect the current development process, but can still be made available again if necessary, for example, in the case of new findings and product liability issues.

A further subdivision is possible according to declarative knowledge or object knowledge and procedural or process knowledge. The types of knowledge described so far can be both object knowledge and process knowledge.

- Declarative knowledge includes the description of objects and the relationships between objects. This includes documents on any storage medium (see Fig. 18.17, Sect. 18.5), such as reports (e.g., on trade fair visits, conferences, etc.), analyses, specialist books and component catalogues, rules (instructions for use, assembly instructions, etc.), rules of thumb [Otto-2018], and standards. Structured minutes of meetings[8] play as well as the documentation of decisions (including the reasons that led to the rejection of alternatives) play a special role. Declarative knowledge can be retrieved and made available to others at any time.
- Procedural knowledge places the objects of declarative knowledge in a problem-specific context. It cannot be represented directly, but essentially in formulas

[7] Action knowledge without a risk component is therefore similar to a condition rule (If-Then-Else) for branches in the flow of a program.

[8] Meeting minutes have a great value as a source of knowledge. However, this source is currently neither fully understood nor properly exploited. This is in the way meetings are logged, what information is contained in the logs, and how it is then handled.

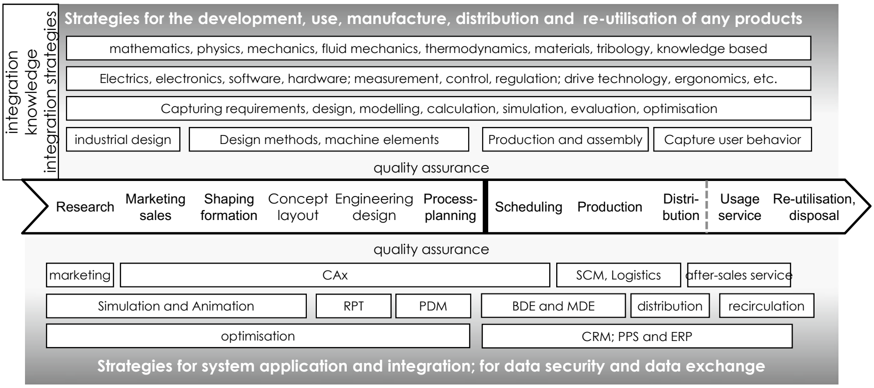

Fig. 17.3 Knowledge along the product life cycle

and/or rules. By storing processes and their documentation, the knowledge of how a problem was handled and solved and the difficulties encountered is preserved. Preconfigured templates facilitate daily work and ensure that only those methods and procedures are used that are approved by the company and lead to useful results[9]. In many cases, process knowledge is more valuable than pure factual knowledge because it stores the know-how of the company.

Knowledge integration within IDE combines the experience and competence of the employees with the declarative knowledge and procedural knowledge available in the company. This also contributes to added value for the customer and profitability for the company.

From the perspective of IDE, knowledge along the life cycle of a product can be exemplarily displayed as shown in Fig. 17.3.

- In the upper part of Fig. 17.3, knowledge is embedded in integration knowledge and integration strategies of IDE. It is structured in a subject specific way, starting from basic knowledge up to special knowledge. The individual fields of knowledge are primarily embedded in strategies for the development, use, production, distribution, and recycling of products and services.
- In the middle, there are procedures for the quality assurance of those results which are achieved in the fields of knowledge on the one hand with the development, use, production, distribution and feedback, and on the other hand, with the application of systems.
- In the lower area, the computer-aided tools necessary for the application of knowledge are embedded in strategies for system application and integration as well as for data security and data exchange.

[9]These include, for example, "intelligent" factory standards for such tasks in which empirical knowledge is predominantly used.

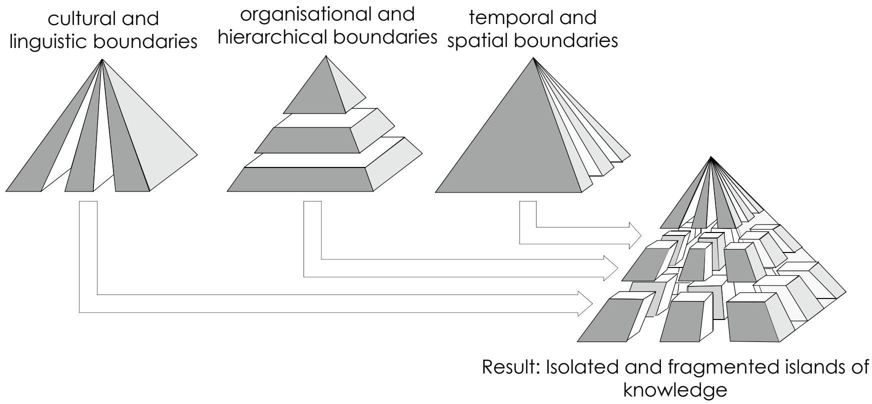

Fig. 17.4 Fragmented knowledge in a company [METO-2008]

In a global enterprise, knowledge is usually not integrated, but rather present in numerous isolated and fragmented islands of knowledge, Fig. 17.4. These are initially created by (inter-) cultural and linguistic barriers, which manifest themselves in particular in the different interpretation of knowledge. In addition, there are organizational and hierarchical barriers as well as temporal and spatial barriers, especially if a company has subsidiaries in several countries with different cultures. This not only leads to significantly more difficult internal communication, for example, in project work in international teams but also to difficulties in identifying knowledge sources and in acquiring, recording and absorbing, i.e., acquiring knowledge.

Within IDE, communication difficulties can lead to cultural and linguistic differences in cross-border networks of companies. However, the different ethical and cultural values and characteristics of the employees involved contribute to an increase in the quality of the solutions. Problems arising from organizational and hierarchical barriers are reduced through process orientation and teamwork. Temporal and spatial boundaries can become more permeable in terms of information technology through the possibilities of e-collaboration (Sect. 18.2).

With today's diversity and scope of knowledge, it has become impossible for a single person to master all knowledge alone[10]. Knowledge fragmentation is therefore the current state of the art. Knowledge is therefore divided into sub-areas of such size that can be mastered by the respective experts. Since projects within IDE are predominantly carried out by teams, the composition of a team must ensure that both experts from all required fields of knowledge are available and that a sufficiently large area of common knowledge exists between these fields as a basis for work and communication, Fig. 17.5.

[10]Because of this diversity and the quantity, there are no more universal geniuses. One of the last was OTTO VON GUERICKE from Magdeburg. With his hemispherical experiment to demonstrate the vacuum in 1654, the age of experimental physics and thus the exploitation of new technologies [LSA-2012] started.

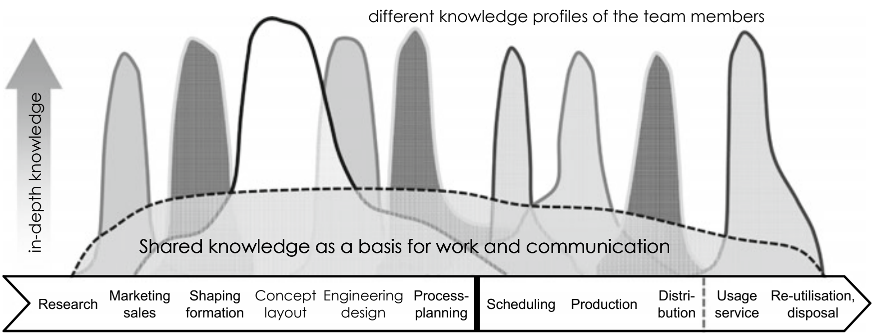

Fig. 17.5 Shared knowledge as a basis for work and communication

17.2 Knowledge Lifecycle

Knowledge, like every product, also has a life cycle, Fig. 17.6. For most phases in the life cycle of a product (Fig. 2.10), there are analogous phases in the life cycle of knowledge, but not for the disposal activities, because knowledge itself can be obsolete, but not destroyed—only the media on which it is stored can be destroyed.

The knowledge life cycle starts with the identification, acquisition, and development of knowledge. It arises during the confrontation with a task, either from different (external) knowledge sources, from the life cycle itself or (in the form of reuse) from the local knowledge archive, whereby this archive can also be, for example, the collective implicit knowledge of all employees. For a concrete application, knowledge is selected, limited if necessary, shared with other employees

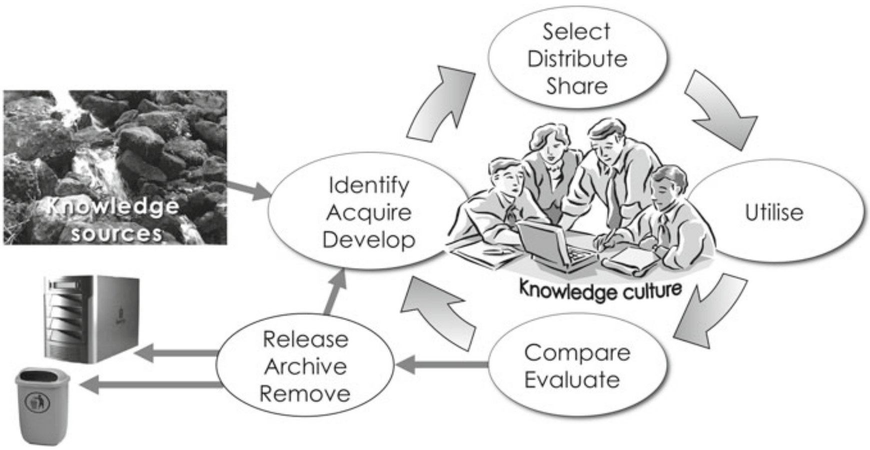

Fig. 17.6 Life cycle of knowledge (simplified representation)

or distributed to others in order to be used afterwards by the recipients[11]. After utilization, comparison and evaluation are made as to whether the knowledge under consideration remains as it is in the knowledge life cycle or whether it should be further developed, whether it should be archived or removed from the cycle because it has become obsolete knowledge. It is also true that the relevance of knowledge decreases if it is not applied regularly.

For the knowledge lifecycle to function smoothly for the benefit of employees, it must be embedded in an efficient knowledge environment with a good knowledge culture of co-operation between the participants. Knowledge sources can be easily identified and accessed. All activities in the life cycle can therefore be carried out without difficulty.

17.2.1 Knowledge Environment and Knowledge Culture

The knowledge environment is the environment in which people generate and acquire, process, pass on and store knowledge in their daily work.

From the outside, the global market, in which competition for increasingly demanding (and globally positioned) customers is taking place, influences the knowledge environment. Today, this market is predominantly a buyer's market, i.e., a customer has several alternative sources of supply for his desired product. The growing needs and demands of customers (especially for product individualization) make it necessary to use IDE in order to achieve the desired performance and quality of products and the associated processes within the specified cost and time frames.

Within IDE, the knowledge environment is influenced by how free, how unstructured, how diverse, and how application-oriented the possibilities are to work with knowledge from different domains (e.g., resulting from the product attributes), to exchange such knowledge among each other and to apply methods, procedures and tools based on it. A good knowledge culture must exist so that these can take place as smoothly as possible. The following environmental conditions are necessary for this:

- There are common values, goals, and procedures of knowledge integration that have been agreed upon by all parties involved (employees and management). The management ensures that this agreement is adhered to by means of confidence-building measures, so that the employees' identification with their tasks and the company remains positive and they are prepared to share their knowledge with others. This also means that both the employees are loyal to their company and the company is just as loyal to its employees.

[11]In contrast to physical objects, knowledge is not diminished by passing on, by sharing and by distributing. The knowledge giver keeps his knowledge, because there is a knowledge participation, but no knowledge transaction, i.e., the knowledge taker gets an adapted "copy" of the knowledge giver.

- There are clear rules for the provision, storage, and use of knowledge that prevent those involved from over-benefiting. These rules of the game also include the possibility and sufficient freedom for unhindered communication between all participants.
- Clear reward and compensation plans help ensure that acquisition, sharing, and application of knowledge are rewarding goals for all stakeholders.
- In order to motivate employees, care should be taken to ensure that the careers of managers and specialists in the company are regarded as equal, so that excellent specialists can also make careers without necessarily having to assume personnel responsibility.
- It is impossible to avoid making mistakes, especially in the case of innovations that involve risks. However, these errors must not be seen as a problem, but as the trigger for improvements. Lifelong learning is thus also anchored in the knowledge culture and the company can develop into a learning company with a living training culture [SpKe-1994].

Figure 17.7 shows the result of a survey on the significance and actual state of the characteristics of a good knowledge culture in the product development of a large medium-sized company.

The bold-printed characteristics of the knowledge culture are also components of the human centricity of IDE and therefore have their appropriate importance (Chap. 4). The other characteristics are primarily elements of organizational and process integration (Chapter 17).

This survey showed that even employees who do not work according to IDE, rate the importance of most of the characteristics of a good knowledge culture as high and important for their work. However, the curve of the actual state of these

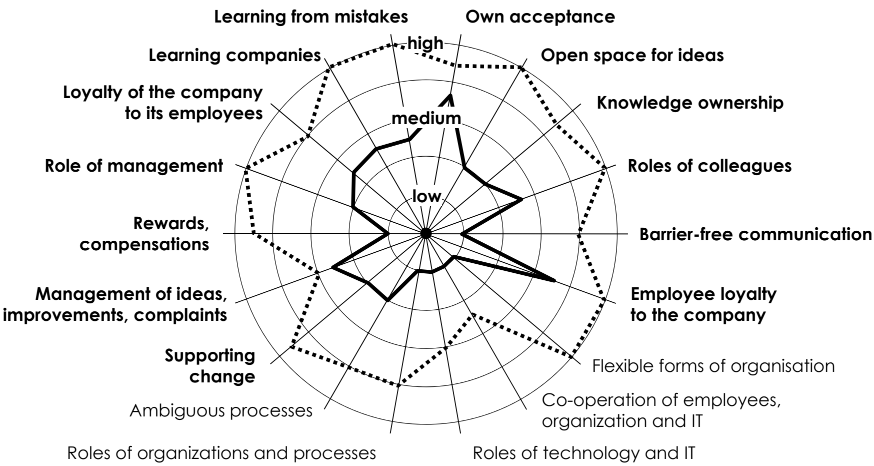

Fig. 17.7 Importance (dotted line) and actual state (solid line) of the characteristics of knowledge culture

properties shows that there are still considerable improvements to be made, which could best be achieved by introducing IDE.

Figure 17.7 also shows that the knowledge culture is significantly shaped by employee co-operation. The processing of tasks in interdisciplinary IDE teams leads to intensive knowledge-based co-operation within the team itself. In many cases, however, the cross-referencing of knowledge between individual teams suffers due to the high workload.

17.2.2 Knowledge Resources

The most important sources of knowledge within IDE are the people with their knowledge and experience, for example, colleagues and employees, customers, internal and external experts, partners, suppliers and competitors, etc., for whom knowledge is predominantly shared with experience and competence (which is, moreover, significantly promoted by learning from mistakes). External knowledge sources provide explicit process knowledge and object knowledge (Sect. 17.1) embedded in the enterprise knowledge environment.

A flexible and permeable organizations as well as functioning communication within the company are prerequisites for the benefit of knowledge sources. From an information technology point of view, an efficient network must be in place.

Figure 17.8 shows various sources of knowledge, evaluated according to importance, reliability, availability, and benefit. First of all, it turns out that all possible sources of knowledge must always be used. However, the best results (besides the own acquisition of the knowledge) are achieved by the knowledge sources "colleague," because the knowledge transfer takes place in the form of a communication between the participants and an immediate feedback for the examination of the imparted knowledge can take place within the scope of the knowledge acquisition.

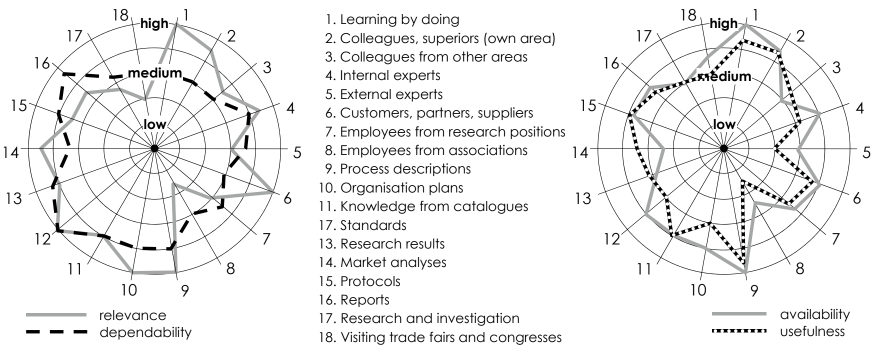

Fig. 17.8 Evaluation of different sources of knowledge

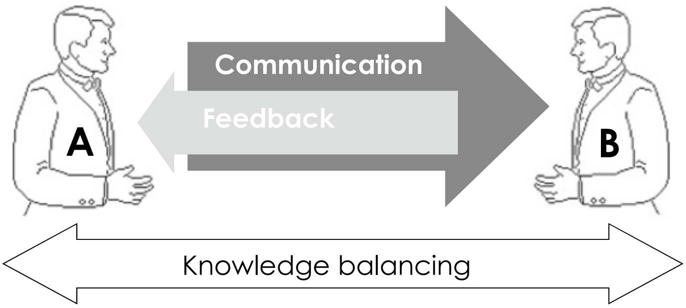

Fig. 17.9 Model of knowledge transfer

17.2.3 Knowledge Acquisition and Communication Distance

As mentioned at the beginning of this chapter, the dynamic environment of IDE requires employees to constantly acquire new knowledge. The acquisition of knowledge (in the form of data, information, rules and meta rules, Fig. 17.1) takes place either through one's own experience, through the transfer of knowledge between people in the form of communication or through the use of other sources of knowledge. Once the knowledge has been absorbed, it should be reflected upon and brought into its own knowledge context so that it can be called up and used for other purposes in the sense of generalization [Gilb-1908].

Figure 17.9 shows the transfer of knowledge between a knowledge donor A and a knowledge recipient B in an exemplary way.

Knowledge donor A possesses such knowledge, experience, and competences that knowledge recipient B would like to acquire for his work or his interests. Therefore, there is a "knowledge gap" between A and B in the concrete case and thus the prerequisite is given that knowledge can "flow" from the donor to the recipient. The donor communicates manageable knowledge units (messages) to the recipient in the form of data, information, and rules. After each transfer, there must be a feedback from the recipient to the donor in order to give the donor the assurance that the knowledge has reached the recipient in accordance with the donor's intention or whether additional messages are necessary[12]. The interplay of communication and feedback iteratively generates new knowledge (and possibly also competence) for the recipient.

However, the following prerequisites must be met for the knowledge donor to be prepared to share its knowledge with the knowledge recipient. The donor

- must be able to trust the recipient to apply the newly acquired knowledge only in the context intended by the donor and, if necessary, to pass it on,

[12] It may be necessary that knowledge donors and knowledge recipients first have to agree on jointly accepted terms and conceptual contents of the knowledge units at the beginning of knowledge transfer [DFFV-2011].

- must not be afraid of the threat posed by the recipient to one's own value and one's own position from the passing on of knowledge,
- expects from the passing on of his own knowledge a (personal) benefit and a certain compensation.

The recipient's acceptance of the transferred knowledge is based on the trust that the donor only passes on knowledge to the recipient that is useful to the recipient in his work. The prerequisite for this trust is that the recipient considers the donor to be sufficiently competent to pass on knowledge and can also establish a sufficiently high level of truth in the knowledge transferred.

If the communication runs smoothly and the feedback has confirmed the correct transmission of a message, there is a comparison of knowledge between the two parties involved. However, this only works if the cultural and semantic basis of the participants is the same. If there is to be a transfer of knowledge between people from different cultural backgrounds, this will be significantly influenced by intercultural aspects [Hofs-2011].

Communication can involve different human senses, depending on the manifestations and tools it uses, Fig. 17.10.

Dialogue and spontaneous interactions ("interjection") are only possible with forms of communication in which the participants have visual contact and which run approximately in real time. Interactive forms of communication increasingly lead to the merge of visual and audible communication forms. Only in direct personal conversation, in which the conversation partners are present in a room, can further senses be used.

	Dialogue	Spontaneous interaction	Real time	seeing	hearing	feeling	smelling	tasting
Dialogue partners present in the same room	X	X	X	X	X	X	X	
Video conferencing and viewphoning	X	X	X	X	X			
Telephone calls	X	X	X		X			
Talks and presentations	(X)	(X)	X	X	X			
Chats, blogs, social networks	X			X				
Emails, SMS, Messenger, Fax	X			X				
Books and documents				X				
Reference works online				X				
Searching in networks				X				

Fig. 17.10 Forms of communication and involved senses. X = possible, (X) = limited possible

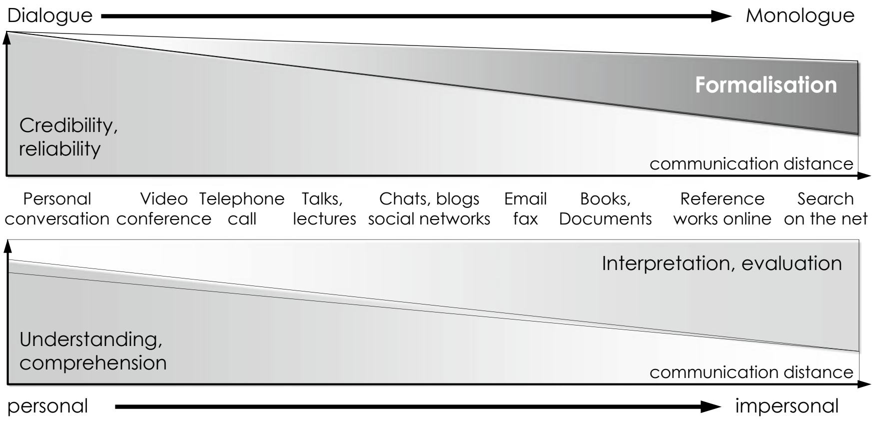

Fig. 17.11 Forms of communication and communication distance

The communication distance plays an important role here. This is lowest in personal entertainment, because in a dialogue between people, the transfer of knowledge and feedback takes place immediately through different senses. However, the fewer senses are involved in communication and the less dialogue and spontaneous interaction become possible, the more the communication distance increases, Fig. 17.11.

With increasing communication distance, the dialogue becomes more and more a monologue, becomes the personal relationship between the communication partners an impersonal consumption of content. Accordingly, the active understanding and the resulting understanding of the message decrease. As a result, a message must increasingly be interpreted and evaluated. Since, however, a lack of understanding and comprehension cannot guarantee that interpretation and evaluation in the sense of the provider of knowledge are correct, credibility, and reliability of the message decrease.

However, by using formalized messages (e.g., formalized minutes of meetings, standards), the share of interpretation and evaluation can be reduced, so that the credibility and reliability of the message can increase.

When transferring knowledge from one IDE project team to another or when an employee leaves the company the collected knowledge must be preserved as unrestrictedly as possible for the enterprise, so that, if possible, the efficiency of the project work, the co-workers and those of the enterprise does not decrease. In order to minimize knowledge losses and to efficiently train new employees, at least an overlap time between predecessor and successor (both for projects and for departing employees) should be provided. During this time, a structured procedure for passing on knowledge to the successor is recommended [HoAl-2008], in which the successor (or the subsequent team) and the project managers participate alongside the predecessor (or predecessor team). If necessary, a moderator and other participants can also be called in, Fig. 17.12.

Content \ Steps	1	2	3	4	5
Areas of knowledge	identify it, characterize				
Results, experiences, consequences, hints				capture, describe	
Explicit knowledge			capture, describe		
Relationships		describe, evaluate			
Networks		describe, evaluate			
knowledge sharing	define	fix	fix	fix	consolidate, prioritize, plan
Results, documentations	List of knowledge areas, knowledge portfolio	Relationship maps, overviews, networks	List of explicit knowledge, knowledge sources	Results, experiences, conclusions, clues	Action lists, Project plans, quality assurance

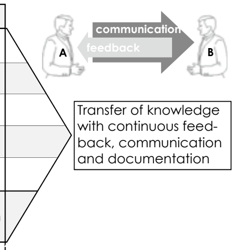

Fig. 17.12 Knowledge transfer to successors (using a figure in [HoAl-2008])

- The first step is to identify and describe the areas of knowledge in question and to define suitable measures for the transfer of knowledge. The results are a list of these fields of knowledge and a portfolio of the knowledge to be passed on.
- The second step consists of describing and evaluating the relationships and networks of the predecessor, defining their forms of knowledge transfer and the actions required to do so. Results are a relationship map (comparable to a knowledge map, Fig. 17.15) and first action lists.
- The required explicit knowledge is collected, recorded, described, and its dissemination determined according to form and activities.
- In the fourth step, the results, experiences, and consequences of the previous work as well as the resulting indications are recorded and their dissemination determined. The result is a compilation of these results, experiences, consequences, and hints, which can be summarized under the keyword *lessons learned*.
- All knowledge transfer measures planned so far will be consolidated, prioritised and set out in action lists, project plans and quality assurance measures for activities in the fifth step before
- in the last step, the actual transfer of knowledge with continuous feedback takes place according to Fig. 17.9. The successful implementation is communicated and documented.

17.3 Knowledge Management

Within IDE, knowledge management takes place under strategic knowledge targets set by the company. It comprises the provision, storage, administration, and maintenance of knowledge in an external memory for realizing the life cycle of knowledge (Fig. 17.6). The activities Knowledge Identification, Knowledge Acquisition, Knowledge Development, Knowledge Distribution, Knowledge Utilization, and Knowledge Archiving are summarized under the keyword Operational Knowledge Management. The Knowledge Assessment and Targeting activities are part of strategic knowledge management [PrRR-1999, Schö-1987]. The interplay of strategic and operative

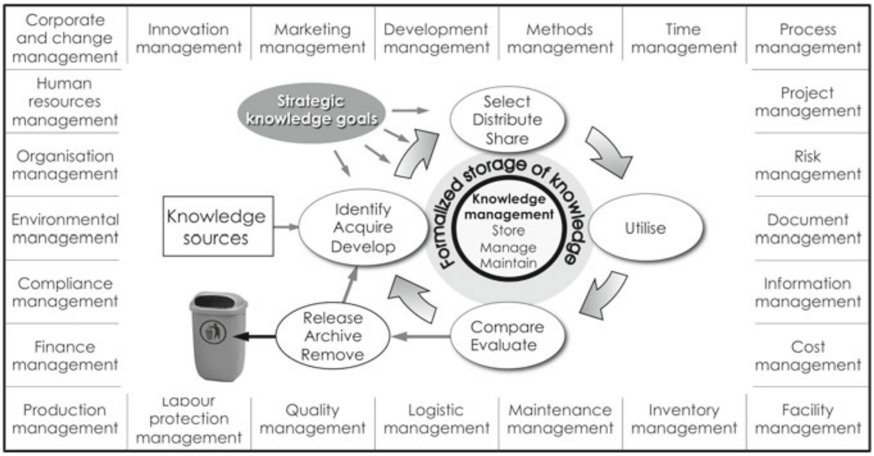

Fig. 17.13 Knowledge management as a basis for all management activities (using parts of an illustration from [Binn-2007])

knowledge management leads to the permanent adaptation and further development of stored knowledge.

Knowledge management within IDE forms both the basis and the driving force for any management activities in the company and is thus the prerequisite for successful entrepreneurial action, Fig. 17.13.

In order to manage the life cycle of knowledge, it must be formalized so that it can be stored, managed, made available, and maintained externally in a uniform knowledge base without redundancy. Formalization takes place by breaking down knowledge into data, information, rules, and meta-rules that can be stored with current hardware and software technologies (lower half in Fig. 17.1). It must also be ensured that consistent terms and term contents are used consistently and stored in a data dictionary (a data directory with metadata for definitions and presentation rules for the terms in question) in order to avoid interpretation errors in the transfer of knowledge [DFFV-2011].

Various knowledge tools are used for the IT implementation, which ensure the necessary supply of knowledge for all systems that support the various activities and processes during IDE. Their (not only economic) success depends on their user-friendliness and availability. Figure 17.14 shows a list and assessment of knowledge tools from the perspective of product development in a company in the automotive industry.

For IDE, the following tools are of interest in addition to the well-known tools of knowledge utilization in product development (for example [VWBZ-2009, Deng-2007, Alex-2011]):

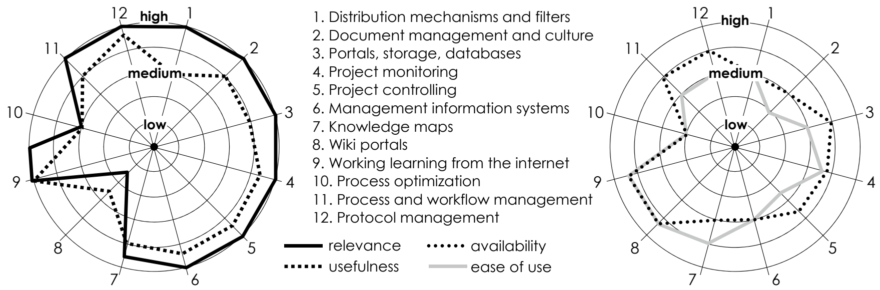

Fig. 17.14 Assessment of knowledge tools

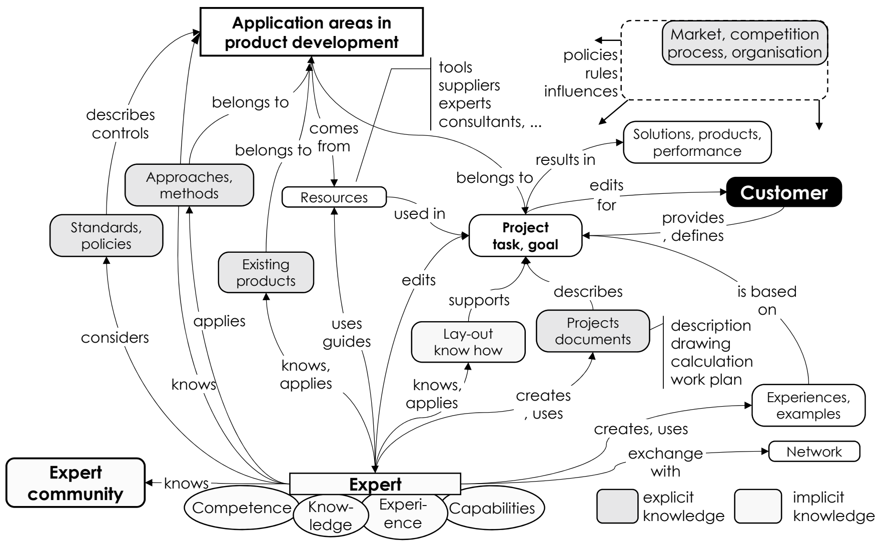

Fig. 17.15 Knowledge map (based on [VDI-5610])

- Knowledge map in the form of a network of acting persons, types of knowledge, sources of knowledge, and activities. Such a map[13] offers the advantage of not only presenting the required sources of knowledge but also of depicting the participants from the various areas of IDE and giving instructions for dealing with problems. In addition to a knowledge map, various topic memories with empirical knowledge and with proven procedures, rules, and working techniques belong, Fig. 17.15.
- PDM system (Sect. 18.3) not only to the document management but also, in analogy to this, to the storage and distribution of knowledge elements in the form of data, information, rules, and meta-rules. The advantage of a PDM system is

[13]Further types of knowledge maps can be found in [Krae-2006].

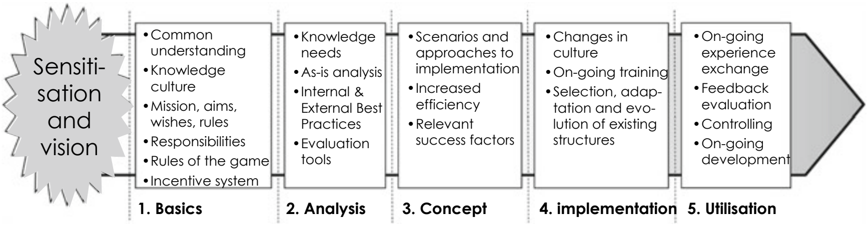

Fig. 17.16 Measures to introduce knowledge management (based on [Olss-1985, AnHe-1987])

the configuration and version management procedures already available there, as well as the consistency of the knowledge elements.

- Archives with templates, company-internal standardized templates or proven sample procedures for[14] meetings, measurement protocols, etc. which are arranged according to various categories and (search) criteria and linked to each other thematically.
- Archives for the documentation and provision of findings and results of activities of the company suggestion scheme.

The introduction of knowledge tools within IDE does not focus on the technology to which an organization has to adapt and in which employees are forced to apply this technology. Instead, the order is reversed, since only a human alone is able to create and use knowledge. Methods and technology are merely aids to knowledge integration. The aim is to create a common understanding of knowledge and a knowledge base for IDE.

The introduction process is based on the IPD models of Olsson (Sect. 1.2.1) and Andreasen and Hein (Sect. 1.2.2) and is carried out in parallel from the perspectives of the human being, the organization and the methods and techniques of knowledge integration (Fig. 17.16). It is divided into the following steps: creating the basics, carrying out analysis, implementing a concept, implementing a solution, and regularly evaluating the results.

1. Basics: First, a common understanding of knowledge integration is developed and the knowledge environment is built, whose most important component (according to the human centricity within IDE) is a good knowledge culture with measures for confidence building and identification, with rules for knowledge exchange as well as incentive systems for knowledge acquisition and provision.
2. Analysis: Identify the knowledge needs of employees within IDE and identify existing and required knowledge sources. The current data of the project organization within IDE are recorded as well as the existing IT systems and knowledge

[14] These include, for example, rules of thumb for fast and efficient results [Otto-2018], reference processes, process libraries, and procedures for process monitoring and optimization.

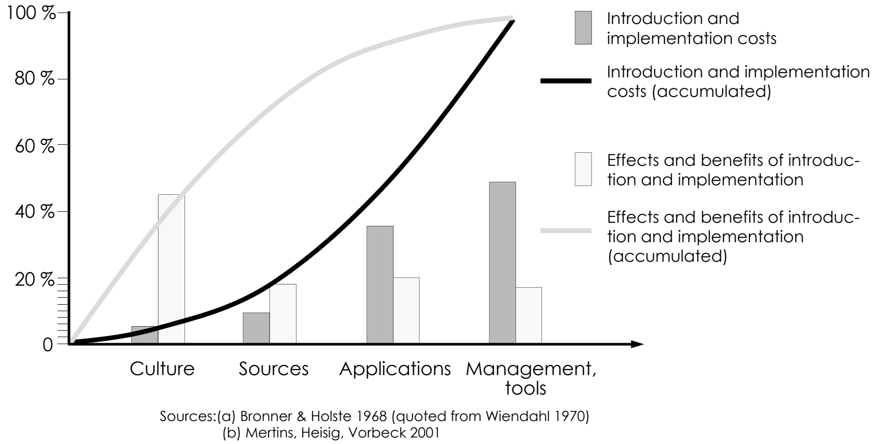

Fig. 17.17 Benefits of knowledge integration (based on [Wien-1970, MeHV-2001, Jura-1951])

management tools. From this, the current information and knowledge flows can be derived.

3. Create concept: Forming scenarios (see also Chap. 20) for knowledge management and possible forms of implementation. Definition and agreement of measures to increase effectiveness and efficiency, together with understanding of relevant success factors and their evaluability.
4. Implement concept: The first step is to adapt the processing of tasks with regard to knowledge integration and the corresponding process models. Existing knowledge sources are integrated, and new ones are made available. Knowledge maps[15] and expert inventories will be established. If not yet carried out, the on-going further training of employees is now institutionalized in the sense of the learning company. Appropriate communication channels are created so that networks of experts can form.
5. Use of the solutions implemented in step 4, combined with an on-going exchange of experience among staff and regular evaluation of the situation.

Figure 17.17 summarizes the influences of knowledge culture, knowledge sources, knowledge management, and knowledge tools on the success of knowledge integration within IDE. Knowledge sources contribute about 18% to the total benefit of knowledge integration, knowledge culture about 45% [MeHV-2001], knowledge applications about 20%, methods, and tools of knowledge processing about 17%.

[15] Also known as "Yellow Pages" (based on corresponding directories of Telekom).

References

[Alex-2011] Alexandrescu, I.: Werkzeuge für die rechnerbasierte konfiguration kundenspezifischer produkte. Dissertation TU Braunschweig (2011)

[AnHe-1987] Andreasen, M.M., Hein, L.: Integrated product development. Springer-Verlag, Heidelberg Berlin (1987)

[Binn-2007] Binner, H.F.: Pragmatisches Wissensmanagement–Systematische Steigerung des Intellektuellen Kapitals", Hanser München (2007)

[Deng-2007] Deng, Q.W.: A Contribution to the Integration of Knowledge Management into Product Development. Buchreihe "Integrierte Produktentwicklung" (herausgegeben von S. Vajna), Magdeburg (2007)

[DFFV-2011] Del Frate, L., Franssen, M., Vermaas, P.E.: Towards a trans-disciplinary concept of failure for integrated product development. Int. J. Prod. Dev. **14**(1–4), S. 72–95 (2011)

[Goet-2006] von Goethe, J.W.: Die Wahlverwandtschaften (Erster Teil, 4. Kapitel). Philipp Reclam Verlag Stuttgart. (2006)

[Gilb-1908] Gilbreth, F.B.: Field System, Myron C. Clark New York, 1908 und Management History Series No. 30

[Hack-2002] Hacker, W. (Herausgeber): Denken in der Produktentwicklung. Hampp Verlag Zürich (2002)

[HoAl-2008] Hofer-Alfeis, J.: Knowledge management solutions for the leaving expert issue. J. Knowl. Manage. **12**(4), S. 44–54 (2008)

[Hofs-2011] Hofstede, G., Hofstede, G.J.: Lokales Denken, globales Handeln: Interkulturelle Zusammenarbeit und globales Management, 5th edn. Beck-Wirtschafts-berater im dtv, München (2011)

[IWSI-1968] N.N.: Pioneers in Improvement and our Modern Standard of Living. IW/SI News, Ausgabe 18, International Work Simplification Institute Cleveland (USA), September 1968, Seiten 37–38 Zitiert aus http://gilbrethnetwork.tripod.com/bio.html (8 Aug 2012)

[Jura-1951] Juran, J.M.: Quality Control Handbook McGraw-Hill New York, (1951)

[Krae-2006] Kraemer, S.: Wissenslandkarten im Wissensmanagement. Mitteilung aus dem Projekt Wissensmanagement der Fachrichtung Informationswissenschaft (FR 5.6) der Universität des Saarlandes. (2006)

[Kurz-1999] Kurzweil, R.: Homo s@piens, Leben im 21. Jahrhundert: Was bleibt vom Menschen? Kiepenheuer and Witsch Köln. (1999)

[LSA-2012] Ministerium für Wissenschaft und Wirtschaft des Landes Sachsen-Anhalt: Forschung und Wissenschaft in Sachsen-Anhalt 2012. Zitiert aus http://www.sachsen-anhalt.de/index.php?id=547 (12.08.2012)

[MeHV-2001] Mertins, K., Heisig, P., Vorbeck, J. (eds.): Knowledge Management. Best Practices in Europe. Springer Verlag Berlin, Heidelberg (2001)

[METO-2008] METOP GmbH Magdeburg: Herausforderungen des globalen Informationsmanagements Mitteldeutsche Mitteilungen des Vereins Deutscher Ingenieure **17**(2), Seite 6 (auf der Basis von [PrRR-1999] und [Schö-1987]). (2008)

[Olss-1985] Olsson, F.: Integrerad Produktutveckling–Arbetsmodel (in Schwedisch). Series 21 Produktutveckling. Sveriges Mekanförbundet, Stockholm, Schweden (1985)

[Otto-2018] Ottosson, S.: Developing and Managing Innovation in a Fast Changing and Complex World—Benefiting from Dynamic Principles. Springer, London (2018)

[PrRR-1999] Probst, G., Raub, S., Romhardt, K.: Wissen managen: Wie Unternehmen ihre wertvollste Ressource optimal nutzen. Gabler Fachverlage (1999)

[Schö-1987] Schön, D.: Educating the reflective Practitioner—toward a new design for teaching and learning in the professions, Jossey-Bass (1987)

[SpKe-1994] Speck, P., Kees, U.: Auf dem Weg zum lernunternehmen—Beispiel werk rohrbach der festo KG. Personalführung **7**, 600–607 (1994)

[Stang-2012] Stangl, W.: Werner Stangl's Arbeitsblätter: Abduktion. Zitiert aus http://arbeitsblaetter.stangl-taller.at/DENKENTWICKLUNG/Abduktion.shtml (8 Aug 2012)

[Vajn-2001] Vajna, S.: Wissensmanagement in der Produktentwicklung. In: 12. Symposium Design for X, S. 1–8. Tagungsband, herausgegeben von H. Meerkamm, Erlangen (2001)

[VDI-5610] N.N.: VDI-Richtlinie 5610: Wissensmanagement im Ingenieurwesen—Grundlagen, Konzepte, Vorgehen. VDI-Handbuch Produktentwicklung und Konstruktion Düsseldorf. (2009)

[Vest-1998] Vester, F.: Denken, Lernen, Vergessen. dtv Wissen München (1998)

[VWBZ-2009] Vajna, S., Weber, Ch., Bley, H., Zeman, K.: CAx für Ingenieure. Springer-Verlag, Heidelberg (2008)

[Wien-1970] Wiendahl, H.-P.: Funktionsbetrachtungen technischer Gebilde—ein Hilfsmittel zur Auftragsabwicklung in der Maschinenbauindustrie. Dissertation. RWTH Aachen (1970)

Chapter 18
Application and Information Integration

Andreas W. Achatzi, Fabian Pilz, and Martin Wiesner

Application integration describes the networked use of modern application systems for continuous computer support within IDE. Application integration ensures that the appropriate IT application system is available for every task and at every point in time. The information integration describes the uniform, complete, consistent and continuous information basis necessary for IDE for the redundancy-free storage of information stocks (among them product models and product data, documents, instructions, etc.) as well as for the extensive avoidance of interfaces between individual information stocks.

As repeatedly stated, IDE leads to a changed way of thinking and working, which is oriented towards a holistic approach and (predominantly critical) consensus building, which presupposes working in partnership with the provider as well as with customers and with partner companies and suppliers. For this purpose, the entire product life cycle is considered, in which both the attributes of the product and the required activities have the same meaning. Product development in IDE is the most important source of innovation in a company and bears the responsibility for successful products. It is thus causally and decisively responsible for the success of the company.

The solution-neutral description of a product in IDE by its performance applying eleven attributes and eleven integrations (Chap. 3) as well as structures and procedures within the emergence of the product (Chaps. 15 and 16) form also the relevant conditions for the digitalization of products, processes, methods and procedures of each kind in the context of industry 4.0.

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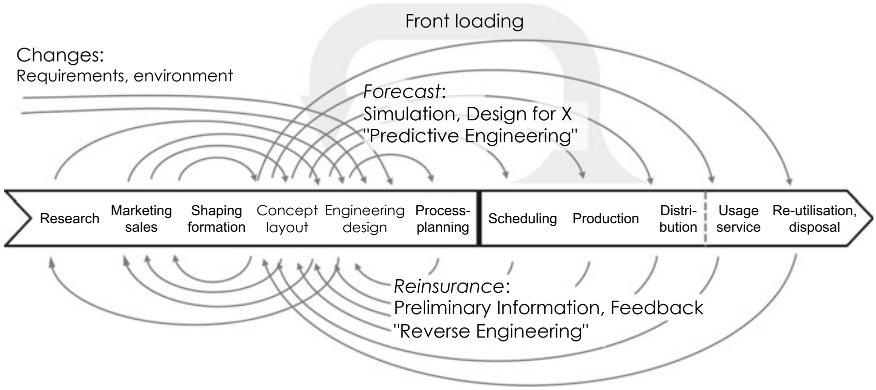

Fig. 18.1 Product life cycle with changes, forecasting, reinsurance and front loading (see also Fig. 1.1)

- For successful digitization, processes, methods and procedures must be described completely in advance, in all branches and with all information flows and required tools[1].
- Industry 4.0 relies on cyber-physical systems, i.e. products with embedded computer performance with the aim of achieving a customer-specific product primarily through the individual configuration of existing components. In these systems (as with mechatronic products), physical components are increasingly replaced by software. In addition, there are sensors and actuators that, in interaction with corresponding algorithms from artificial intelligence[2], are able to enable a certain autonomous behaviour of the product through the ability to decide between alternatives. This makes self-regulating logistical and technological processes possible, enabling, for example, the emerging product to control its production itself. It searches for the required (and standardized) production resources within production in the sequence required for fabrication, including the necessary control software, requests individual parts for manufacturing and assembly, and uses standardized equipment.

With the high demand for integration in IDE, the consideration of external and internal influences is of great importance. Figure 18.1 shows the simplified representation of the product life cycle from Chap. 2, which shows how decisions can be made and influenced by front loading of activities.

[1]In many respects, the process of digitalization in a company corresponds to the introduction or migration of a CAx system, which is discussed in detail in Chap. 13 of [VWZH-2018], for example.

[2]The American-English expression "Intelligence" includes the use of rule-based algorithms, fuzzy logic, neuronal or semantic networks, case-based reasoning and machine learning. This meaning does not correspond to the German term "Intelligenz", which covers wisdom, intellectual giftedness and power [Wahr-1978]. The same is true for other languages; e.g., French [Robe-1973] or Hungarian [Totf-2019].

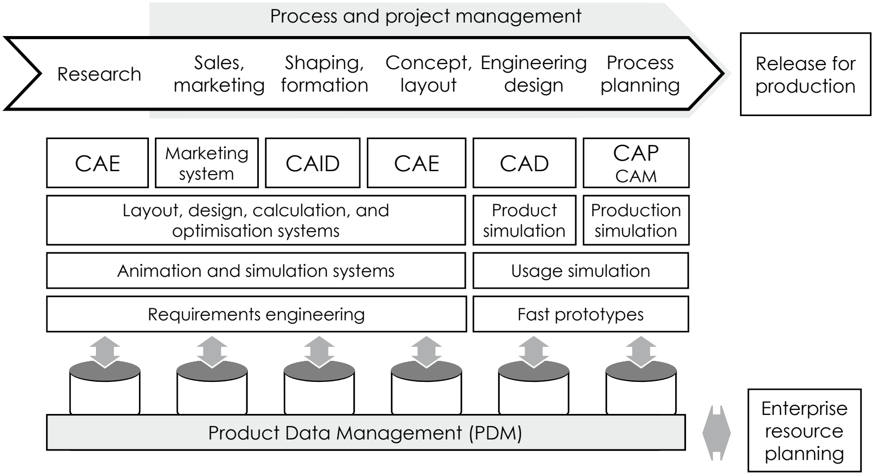

Fig. 18.2 System variety within IDE

- Entities which are of a fundamental nature or which affect all areas of the product life cycle should be determined jointly and continuously by all parties involved. If further fundamental changes occur during project processing, all parties involved must again decide all resulting new specifications promptly.
- The outcomes resulting from the specifications and suitable alternatives are simulated, calculated and evaluated with the aid of preliminary information and feedback from the product life cycle. The prerequisite for this is that information from the areas downstream of the IDE activities is made available to the respective user at the right time, in the right quantity and quality to the right place for use in the most suitable tool. If these activities lead from forecasting and reinsurance to correct and consistent results, activities and decisions can be brought forward to product development.

The resulting decisions and selections are fixed at the latest possible time, but before they are released for production, so that any further changes can be taken into account with little effort.

The realization of the tasks of IDE and the consideration of mutual influences is currently supported by a variety of more or less specialized application systems, since an integrated system that could comprehensively support all activities of IDE does not currently exist (and probably would not make sense),[3] Figure 18.2.

The application systems within IDE can be divided into *generation systems* (systems that generate data or process existing data), *management systems* (which take into account the dynamic approach within IDE when storing, managing and providing data) and *control systems* (to support process and project management).

[3]Such integrated systems were mainly offered in the 1980 s, but were neither technically efficient nor economically successful [Vajn-1992].

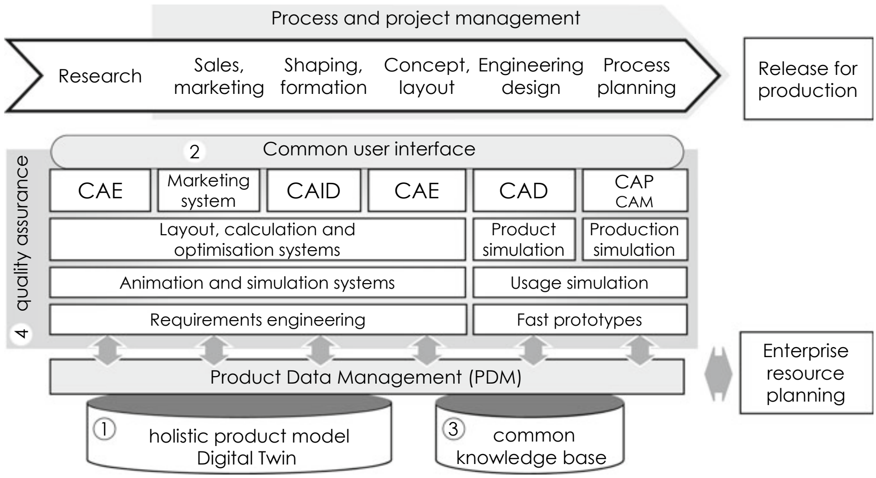

Fig. 18.3 Staged integration of application systems (the individual numbers refer to the text below)

Each application system has its own user interface and usage philosophy, so the learning curve is considerable, especially if an employee has to use multiple systems[4]. The systems usually store data and documents in their own system-specific formats, whereby these formats often contain overlapping data stocks (and thus redundancies) and are usually not compatible with each other. This causes high expenditures for data administration, data alignment among themselves as well as for archiving. It is therefore desirable to accelerate the integration of applications. A first approach is the increasing use of quasi-standardized geometry modellers in various CAx systems. Today, for example, a specific geometry modeller is applied in different CAE, CAD and CAP systems of various performance classes, so that data can be exchanged between these systems with as little loss as possible.

Figure 18.3 shows further steps for the integration in four steps, based on the solution proposal shown in Fig. 18.2.

1. To implement a complete, holistic and comprehensive 3D product model in which all applications would store their data as (partial) models and could thus integrate them. This product model is called *Digital Twin*. The digital twin accompanies the product throughout its entire product life. It digitally maps the current state of the product (how it was developed, how it was delivered and installed, how it was updated, etc.), its history and the associated structures, processes, calculations, simulations (of behaviour and strength), etc., at all times. On the one hand, information and documents can be (partially) automatically derived from the digital twin at any time; on the other hand, possible product changes can be calculated and simulated in advance on the digital image of the original [VWZH-2018]. With the digital twin, information and data between the individual application

[4]In the course of the further development of systems, the user interfaces do change–often for no apparent reason and not always to the advantage of the user.

systems no longer need to be converted and information stocks from other CAx systems (for example, from customers, partners, suppliers) could be more easily integrated.

2. To set up a common user interface for all application systems so that the handling of the systems can be fundamentally consolidated and input errors avoided.
3. A common knowledge archive could be created for all groups and areas involved in IDE (see also Chap. 17).
4. To implement an accompanying and permanent quality assurance of all activities of the application systems based on the current requirements and boundary conditions (e.g. product models based on features in cooperation with a Design Spell Checker [VWZH-2018]) to prevent errors during processing.

Information stocks are physically created and stored at different company locations, in different areas and on different systems. In this environment, it is difficult to maintain a complete overview and control over these stocks. This leads, for example, to the time-consuming task of finding out which version of the data of a component can be used, which document contains this version and where to find it. If inaccurate information is passed on to subsequent departments, it results in erroneous results that must either be corrected or, in the worst case, must be rejected. The transfer of information stocks from IDE to production is particularly (time-) critical, especially at the time of production release. Without an integrating solution in data management, such problems can no longer be solved satisfactorily.

Further difficulties are caused by the fact that documents are stored in different change states without always being aligned with the actual reference documents (and in many cases, it is no longer clear which of the documents was the original reference document). In addition, users (e.g. in an IDE team) store different versions of a document that is actually identical and everyone believes that they are the rightful owner of the document and therefore have the only applicable version. Some also make their own copies ("black data stock") for their protection, to which other users or systems have no access.

In IDE, documents are needed both as input data and as output data, which requires multiple conversion of the documents created or changed in the process from input data to output data and vice versa, Fig. 18.4.

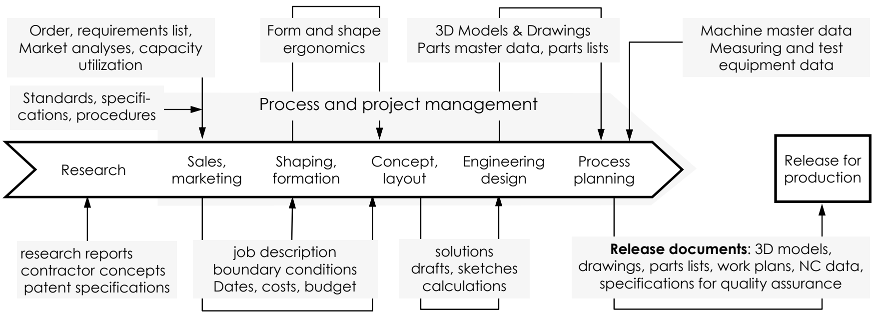

Fig. 18.4 Document flow in IDE (only the top processing level is shown)

Figure 18.4 shows only those product documents at the top level that are processed in several IDE areas. If the transfer of a document also requires a change of application system, interfaces are used that are now powerful, clearly defined and also quite stable, and usually do not destroy any data during the transfer, so that the data exchange is clear, simple and controllable. However, most documents (about 80%) are created, edited, used and stored locally in the respective areas.

At the time of release for production (vertical line between "process planning" and "scheduling" in Fig. 18.1), all documents describing the product must be complete and consistent. The following different but equivalent documents are essential:

- The computer-internal 3D product model and the technical drawings derived from it determine the target geometry of the product with its current dimensions (geometric realization).
- The bill of materials (BOM) describes the structure of the product from different perspectives. This structure can be derived from the internal "assembly" structure of the 3D model of the product and from the corresponding data in the PDM system, resulting in modular BOMs that can be transformed into any BOM form (structural implementation).
- Work, assembly and test plans contain instructions and procedures for the manufacture, assembly and quality assurance of the product (material realization).
- Dispositive data assigns the product to a current order.

This chapter deals with different CAx systems (as generation systems), the computer-aided cooperation of spatially and temporally separated teams (for their structure and organization, see Chap. 15), PDM systems (as administration systems), the organization and structure of application systems, and archiving, because all these applications have significant influences on application and information integration.

18.1 Application of CAx Systems

The use of CAx systems[5] which supports the product developer in IDE to make the relevant decisions about a product at the best suitable time after various product alternatives have been designed, calculated and simulated as realistically as possible. CAx systems stand for a comprehensive computer support of the processes within IDE by systems specialized on certain task groups. This includes above all the CAD systems with which the computer-internal model of the product (product model) is designed. Critical factors for a successful IDE are both quality and completeness of the modelling, because most of the other systems used for computer support within IDE depend on the use of products modelled in CAD systems. However, the detailed

[5]The collective term CAx covers computer-aided systems in product development, including Computer-aided Design (CAD), CA Industrial Design (CAID), CA Engineering (CAE), CA Planning (CAP), CA Manufacturing (CAM) and CA Quality assurance (CAQ) systems. Further information can be found in [VWZH-2018].

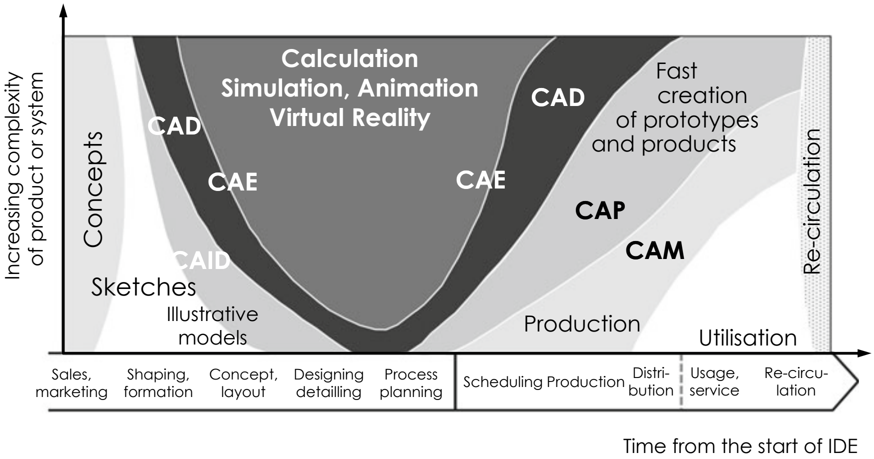

Fig. 18.5 Use of CAx applications within IDE (after [Otto-2003])

product documentation (increasingly in the digital twin) also provides for cases of product liability.

But especially in IDE, you cannot do without the traditional way of modelling with manual tools. Figure 18.5 gives a representative overview of the possibilities of using CAx systems and the accompanying solutions, depending on the complexity of the task and the elapsed (processing) time. The (still dominant) role of manual techniques such as sketching and model building is also included.

The abbreviations used in Fig. 18.5 have the following contents (for the long forms of the abbreviations see Footnote 5):

- Concepts: Design of the product to be produced as well as the planning and design of the development and manufacturing processes required for this. This should be carried out in a team predominantly with classical methods and aids (brainstorming, gallery method, morphological box, metaplan, etc.).
- Sketches: Preparation of preliminary drafts using hand sketches, as it is currently neither sensible nor economical to work with a CAx system[6] in the very early concept phases. By creating sketches and drawings, a wide range of concepts can be visualized within a very short time.
- Visual models: Visualization of the product design through physical models, especially in critical questions of design, ergonomics and the design of a product. By using an initial CAID or CAD model, physical models can also be produced by additive manufacturing (Sect. 9.2).

For work with concepts, sketches and illustrative models as well as suitable aids, see also Sect. 18.1.2.

[6]This is because CAx systems can only store all elements with exact data in the 3D product model. Continuous value ranges or fields with multiple discrete values for dimensions cannot be processed with the description methods used in the 3D model.

- CAID: Systems for the computer-aided forming of products in the sense of creating the product shape (Chap. 6 and Sect. 18.1.1)
- CAD: Computer-aided design and modelling of products as well as the creation of the corresponding documentation. The main result is the–3D product model from which all other documents (e.g. parts lists, drawings, work plans) can be derived.
- CAE: Collective term for all programmes and systems for the calculation and simulation of load cases, flow behaviour, etc., and the resulting product behaviour. These include FEM systems for structural–mechanical simulation and evaluation (FEM = Finite Element Modelling), CFD systems for fluid dynamics simulations (CFD = Computational Fluid Dynamics) and MBS systems for the simulation of motion and dynamic behaviour (MBS = Multi-Body System).
- CAP: Computer-aided planning of manufacturing processes. The manufacturing process is planned independently of a special order, deadlines and allocation plans of the machine tools in order to determine the work steps necessary for the production of a component as well as its time and machine requirements.
- CAM: Computer-aided manufacturing. This begins with the computer-aided creation of NC data and includes computer support for all control processes within production.
- Fast production of prototypes and (in the case of one-off productions or small series) of products: For this purpose, a 3D product model is divided into thin virtual layers (layer thickness about 0.05–0.1 mm) and built up layer by layer using different additive manufacturing processes (see Sect. 9.2). For prototypes, various plastics, resins and paper are used as starting materials for prototypes. For products created by additive manufacturing, metal powder and binders of various types are used.
- Return of products into the cycle: This may involve the dismantling of a product, the treatment and reuse of products or their components, the recycling of materials or disposal.

Detailed information on the introduction, application and cost-effectiveness of CAx systems and their peripherals can be found in [VWZH-2018].

18.1.1 CAID Systems

Within IDE, the attribute *Product Gestalt* is one of the six equivalent attributes that fully describe a product (Chap. 3). Product Gestalt (Chap. 6) gives products appearance, identity and creative order, differentiates them from other products and makes the product understandable. CAID systems support the design process, i.e. the early modelling of the product shape. The industrial designer's manual design process is based on representations with pencil, marker and model making. These are complemented by a digital 3D model in the CAID system. With this system, the user can be creatively active and work conceptually without having to technically design components. He can concentrate fully on the creation of the surfaces and the presentation of the product.

The difference to CAD systems can be found in the direct, easy and fast editability of the overall shape, in particular through direct transformability and the provision of tools that enable the creation of Class A surfaces with transitions that change with the curvature. In addition to the actual form design, CAID systems offer functions for rendering products (Sect. 18.1.1.2), which are useful for assessing the form effect. The result is a spatial model that, in the form of a high-quality, photorealistic visualization, contains the industrial designer's design intent in all dimensions of the product design (form, colour, material and surface).

An idea can be interactively converted into an object using existing design tools in the CAID system. Usually, existing data is used, such as digitized hand sketches, scanned 3D objects (such as hard foam or clay models), sketches created on the CAID system (consisting of NURBS curves[7], drawing elements, etc.) or existing 3D CAD product models.

18.1.1.1 Modelling Methods Within CAID Systems

Depending on the CAID system, there are different approaches for creating geometries. These differ in the modelling methodology and in the mathematical description of the surfaces.

- Direct modelling: The creation of models without the explicit use of parameters or references between model elements. This modelling method is particularly suitable for creating shapes that correspond to the designer's concept drawings. 2D sketches are positioned on working planes in the CAID system and scaled correctly. Iteratively, the shape is adapted by direct modelling so that it corresponds to the positioned sketches. Further information on direct modelling in Sect. 18.1.2.1.
- Modelling based on polygons: It is based on a network of a finite number of points used to form polygons.
- Modelling with NURBS surfaces: An exact mathematically describable modelling, which is usually based on previously created NURBS curves.
- Modelling with T-splines: A T-spline is a NURBS, but the row of points forming a T-spline does not have to cross the entire NURBS surface. This modelling type is placed between NURBS and polygon modelling. It enables an efficient modelling of a closed NURBS surface lattice with fewer control points.
- Modelling based on subdivision surfaces: These surfaces are created from coarse polygon meshes by continuous interpolation and approximation of intermediate points in the polygon mesh that lead to a higher number of polygons and

[7] Abbreviation for Non-Uniform Rational B-Spline. NURBS forms a very general and powerful mathematical basis for the description of freeform curves and surfaces, but also of analytical geometries such as conic sections. With NURBS even very complex free-form geometries with a relatively small number of curve and surface segments can be modelled [VWZH-2018].

thus to smoothed surfaces. This method combines properties regarding efficient modelling of polygon surfaces as well as detail accuracy and consistency of NURBS surface types.

The appropriate modelling method should be chosen depending on the requirements with regard to level of detail and surface quality as well as available time resources. Polygon models are generally only suitable if the product should be created purely digitally and an exact mathematical description of the curvature at each point is not or not yet relevant. Modelling with NURBS surfaces is the method of choice for all Class A surfaces. Subdivision surfaces and T-splines enable efficient modelling with an acceptable surface quality for most applications.

18.1.1.2 Rendering CAID Models

In the present context, rendering means the creation of realistic images or animations, usually computer-aided[8] and based on 3D models. For this purpose, a structure (texture) is applied to the surfaces of a (computer internal) volume model and (if required) is coloured. Light and shadow are positioned to represent possible atmospheres of the intended use. The solid model is represented in different perspectives in order to be able to represent it realistically. Rendering data does not become part of the volume model [VWZH-2018]. If this model has to be set up in the CAID system first, then the assignment of colours, surface condition and environment definition, the photo-realistic preparation of the object and if necessary also an animation of the product handling take place. In this way, not only initial requirements are implemented, but also the design of form and appearance of the product are visualized and the functionality is illustrated. This allows concepts to be coordinated and adapted with the customer during early phases of the product development process.

18.1.1.3 Interfaces of CAID Systems

CAID models can be stored in different formats. If this is done with NURBS or standardized exchange formats such as STEP or IGES, the geometry can be read directly into a CAD system. If saved in[9] STL format, physical models can be generated using generative or additive manufacturing methods (Added Manufacturing, Sect. 9.2, which also includes rapid prototyping). Figure 18.6 shows a selection of interfaces to and from a CAID system.

[8] 2D renderings can also be created as analogue or digital drawings.

[9] The STL format is a triangulated (and thus simplified) surface model of a volume. For generative manufacturing (Added Manufacturing, Sect. 9.2), this surface model is divided into slices of defined thickness.

Fig. 18.6 Interfaces to and from a CAID system. Possible image formats: .jpg, .bmp, design format: .obj, geometry formats: IGES, STEP, NURBS, added-manufacturing format: .stl, playback formats: Quicktime, .zcp (Picture source: Hewlett-Packard)

18.1.2 CAD Systems

Current CAD systems have powerful spatial geometry modellers that can access direct modelling modules as well as parametric, feature, 2D, optimization and knowledge modules. The modules mentioned may well be interwoven. The most important components for IDE are presented below.

If a 3D modeller offers parametrics and features in addition to direct geometry processing, its basic structure follows the example of a common 3D-CAD modeller, Fig. 18.7.

- Access to all functions of the modeller (user functions) is via the user interface.
- In direct modelling (interactive working), concrete geometry elements are directly created, modified and deleted by the user. These elements with their discrete data

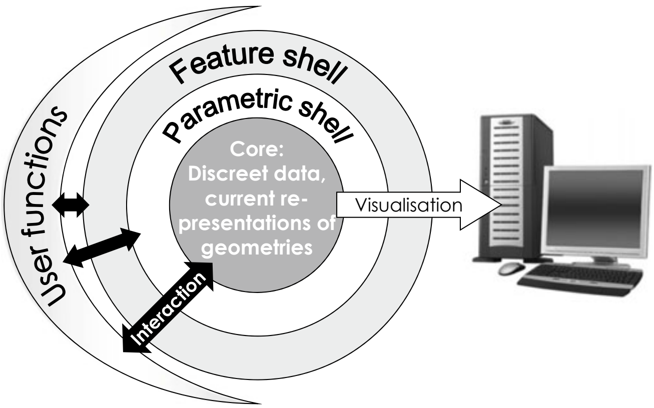

Fig. 18.7 General structure of a 3D CAD modeller

in their current state form the innermost part of the modeller. This innermost part also contains the data for displaying the current model on visual display units.

- The parametric shell contains the references to the parameters of the respective geometry element in the innermost part. Parameterized elements are no longer controlled interactively, but via parametrics. For this purpose, the parametric model is constructed with extensive consistency checks. An interactive change remains possible as long as the consistency of the parametric model is not compromized.
- The feature shell accesses the parametric shell and adds non-geometric or semantic information (such as intended use, creation rules, etc.) to the elements.

18.1.2.1 Direct Modelling

Direct modelling is the creation of models without the explicit use of parameters or references between model elements. Direct modelling provides local and interactive access to individual geometry elements in the 3D model. A facet body enveloping the component can be scaled and deformed, or grabbing and moving nodes can edit the course of a curve. The freeform surfaces based on these are recalculated accordingly when editing the facet body. Thus, a fast and direct modelling of freeform surfaces is possible. The working technique of direct modelling is intuitively applicable and very flexible. The geometry is edited directly by creating individual elements or groups from it and by dimensioning, modifying, moving, rotating, mirroring, distorting, reducing or enlarging them directly in 3D space.

Direct modelling is most commonly used in the conceptual design phase of the 3D model of a component. Usually, this design phase takes place in an activity of the holistic IDE procedure model as a support activity during the development and design of the component (Fig. 18.4). It is precisely here that concept changes must be able to be quickly modelled and presented. With already existing models it is possible to take up existing concepts and to change them fast with the help of direct modelling, since one works directly on the concrete geometry.

18.1.2.2 Sketch-Based Modelling

The most common type of modelling currently in use is sketch-based modelling, which complements the elementary generation of volume primitives (block, cylinder, sphere, etc.). Before the composition of a 3D volume according to this method can be started, its defining 2D contours must be created. These are usually designed as two-dimensional structures (sketches) in a working plane that can be positioned at will. The sketch technique works like direct modelling, with the difference that here the characteristic sizes of a geometry element and the relationships between geometry elements are not defined as fixed sizes, but as conditions between the sketch elements. In contrast to direct modelling (where neither the history nor the parametrics of the model are taken into account), sketch-based modelling is based on a chronology.[10] Individual geometric elements are build on each other in a certain order of creation according to parent–child relationships; i.e., they are associatively connected to each other. Based on the sketches, the 3D geometry is formed by individual predefined shape elements that are the result of extrusion, rotation and translation operations.

18.1.2.3 Feature-Based Modelling and Advanced Features

In general, CAD language usage, features are typically complex geometric elements to which a number of non-geometric properties can be added (for example, manufacturing information for holes).

However, a more comprehensive feature definition, incorporated in the VDI Guideline 2218 [VDI-2218], better addresses the needs of an integrated approach. Here a feature is an information technology element that can model areas of special (technical) interest of a product. A feature contains not only geometry, but also requirements and functions. This type of feature enables the modelling of very simple and space-saving structures as partial models whose structure and administration are based on the configuration management of a PDM system (Sect. 18.3).

With many CAD systems, the product developer is not restricted to the use of pre-set features, but has the option of defining and using application-specific features ("user-defined feature", UDF). With UDFs, multiple programme intrinsic features are aggregated as needed and stored in libraries, giving every developer in the organization access to the UDFs. The use of UDFs can lead to more efficient work, especially in repetitive product development and modelling processes.

For example, a rim manufacturer has several rim models in its range, all of which have a specific hole circle. A UDF can therefore be created for the hole circle. This UDF can contain the shape of the hole and the pattern of the holes as default features. Values such as hole circle diameter, number of holes and hole diameter are defined via parameters. To create a hole circle, the developer only has to select the UDF, determine the parameter values and select a placement reference; everything else is done by the UDF.

18.1.2.4 Parametric Modelling and Parametrics

Parametric modelling is characterized by the fact that any geometric object is described on the basis of parameters instead of directly influencing its position and shape as in direct modelling. This means that the model does not have to be adapted directly via its geometry, but via individual parameters, which can change the model

[10] A chronology saves the historical and logical order of creation (resulting from parent–child relationships) as well as the current structure of an object in the 3D model [VWZH-2018].

fundamentally at any time. *Parametrics* refers to the linking of these individual parameters with each other.

Based on sketch-based modelling and individual form elements and features, relationships and restrictions are defined between these and the parameters describing them (for example, "triple length" or "parallel to", etc.). For the actual parameterization process, considerable experience is required in order to minimize the subsequent modification effort.

Functions for parameterizing the model are particularly advantageous when creating series. Initially, they enable the development of geometric variants and part families with relatively little effort. Non-geometric quantities (e.g. forces, moments, material, etc.) can also be linked to a parameterized element. Instead of fixed relationships, rules can also be defined between the parameters, which can be handled by the editability of the parameter relationships in external tables.

The added value of parametrics lies in the fact that the consistency of a design can be ensured to a large extent by built-in checking mechanisms. Subsequently, changes to the design can also be carried out very easily and consistently. The external use of parameters as an interface to variant design (example design table) or with regard to external optimizations can also be advantageous.

18.1.2.5 Modelling Systematics

Especially with extensive and highly parameterized CAD models, which are created by interdisciplinary teams, it is advisable to have a (rules-based) working technique created by experienced users. This is particularly important if the product is highly complex and many users have to work on identical CAD data. It is possible to save a considerable amount of time if CAD models have a uniform structure and the individual geometric elements are named in a standardized way so that different users can quickly find their way around the model structure. Specifically, appropriate templatesare created for the respective application, users are trained in the specific working technique, and compliance with conventions is checked using analysis tools. Templates are to be understood as basic skeletons in which all necessary steps or conventions of the working technique are structured. If the user follows the individual steps, these are easy to understand for each further user and the processing can be continued with little training effort.

When simulating with a CAE system, the aim is to predict product properties in order to reduce the use of complex tests and cost-intensive prototypes. This makes it easier to evaluate and compare different alternatives. This leads not only to the timely recognition of necessary changes, but also to a reduction of development time and costs. The most common applications for CAE systems are finite element analysis (FEM), multi-body simulation (MBS) and computational fluid dynamics (CFD).

If a CAD model is available and it forms the initial model for the simulation, this model must first be prepared accordingly in the so-called preprocessor. In the first step, the complexity of the geometry of the model is reduced to such an extent that meaningful results can be expected within a reasonable computing time. A typical example of simplifying a model is removing chamfers from shafts and holes. In the case of FEM simulation, the model is then modelled again using finite elements that dispose of defined properties, whereby this is usually done automatically today using network generators, which are components of the 3D modeller. Quality and computational effort depend essentially on the type (linear or quadratic or volume or shell elements) and on the size of the selected finite elements.

By assigning material models and introducing loads and boundary conditions into the FEM model, the preprocessing is completed and the calculation can be carried out using appropriate equation solvers. The selection of the solver depends, among others, on the type of load case (static or dynamic) and on the type of finite elements used (linear or quadratic). Both presentation and evaluation of the results are created in the postprocessor that supports the obligatory plausibility check.

If the CAD model does not yet meet the requirements sufficiently, it must be adapted on the basis of the results and then be calculated again. This process continues until the CAD model meets the requirements sufficiently well. In order to shorten the development time, the aim is to keep the number of necessary iterations as low as possible, although they cannot be avoided completely. However, if these iterations lead to too much effort, the implementation of an automated optimization must be considered.

18.1.3 Optimization

The interaction of CAD and CAE systems is the prerequisite for the optimization of a product (if used frequently, optimization can also be automated). In principle, optimizations can be made in all IDE phases; in general, they are essential during the development of a product if the best (and not only the next best) solution is to be found for each required property of the product.

In addition to powerful simulation and animation processes (up to the complete digitization and virtualization of product creation and assembly), optimization processes are also integrated into CAx systems. Since today's 3D modellers are geometry-driven, the methods are predominantly applied to the relevant parameters of the geometry model. Occasionally, it is also possible to optimize the topology of the geometry. For this purpose, the "large" providers of CAx systems offer corresponding modules, which, however, are usually based on approaches that allow the optimization of only a single criterion (linear optimization).

For IDE, optimization methods based on biological evolution[11] have proven to be particularly efficient, as they are able to optimize several criteria simultaneously (multi-criteria optimization) [Clem-2006]. The *Autogenetic Design Theory* (ADT; Sect. 1.7) applies this optimization method. ADT describes the creation of a new product (new design) or the modification of an existing product (adaptation design) as

[11]Evolution means development through continuous adaptation and optimization to constantly changing external and internal influences [VBCJ-2005].

the ongoing optimization of an initial solution under initial, boundary and constraint conditions. The goal of the optimization itself can have a dynamic character, since the respective requirements, initial and boundary conditions as well as constraints can be variable.

Suitable algorithms, such as genetic algorithms and evolutionary strategies, can be used for the mathematical simulation of evolution and its three operators *Selection* (choice based on current abilities and environmental conditions), *Recombination* (generation of offspring's) and mutation (spontaneous modification of a gene) [VBCJ-2005]. In the case of multi-criteria optimization, one speaks of so-called MOEAs (Multi-objective Evolutionary Algorithms), which are particularly capable of finding Pareto-optimal solutions (see also Fig. 1.33). These are solutions that can only be improved in one criterion by worsening another criterion. From this group of solutions, the product developer can select the most suitable solution for him.

On the basis of Fig. 1.32, Fig. 18.8 shows the structure of a parameter optimization system (already presented in Fig. 1.36) that has proven itself in practice for IDE applications, which also shows the interaction of the modelling and simulating systems with the actual optimization module.

In order to be able to perform such an evolutionary parameter optimization, the target function must first be defined with the optimization goals (e.g. minimum weight at permissible stresses) and a parametric 3D model must be created in which the parameters serve as design variables. All CAD systems that allow parameterization can be used for this purpose, especially if, in addition to dimension parameters, design, material and topology parameters can also be defined, so that not only the dimensions but also both design and material of an object can be varied. However,

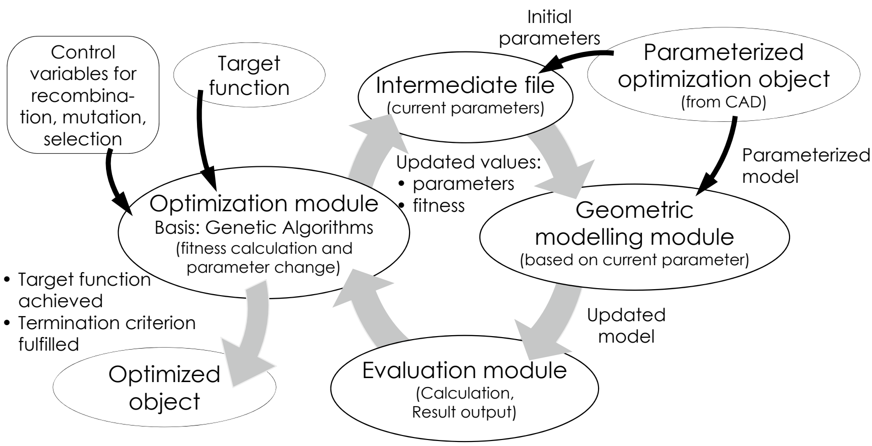

Fig. 18.8 Evolutionary optimization with modules for geometry modelling, evaluation and optimization. Grey arrows: ongoing optimization process (according to [VaKB-2011])

experience shows that a "normal" (i.e. design- or production-oriented) parameterization cannot always be used, but that the 3D model must be parameterized differently or anew, depending on the optimization goals.[12]

- The start generation is generated in the geometric modelling module. The start generation consists of several versions (individuals) of the model to be optimized, which were generated by parameters with different values in each case.
- In the evaluation module (usually a CAE system), the current performance of the individuals is calculated. For structural–mechanical tasks, an FEM system is used; for fluidic problems, a CFD system is used; and for motion simulations, a multi-body system (MBS) is used. For this purpose, the current 3D model data generated in the previous module is imported into the CAE system, the geometry is networked with a finite number of elements (discretization), and the calculation is then performed.
- In the optimization module, the calculation results from the evaluation module are evaluated and converted into corresponding current values of the fitness function, which is compared with the target function. Based on this evaluation, it is determined which individuals are selected, mutated or recombined with which probability. The affected parameters are changed and passed in an intermediate file to the geometric modelling module to create the updated model.

This (automatic) procedure is repeated until the results correspond to the desired specifications (i.e. the current fitness function corresponds to the target function) or an abort criterion is reached. Abort criteria can be, for example, that the changes in fitness values between two or more generations fall below a certain threshold value or that the maximum number of optimization runs has been reached.

The main benefit of evolutionary optimization is that, in contrast to conventional optimization methods, completely new solution concepts can emerge that product developers usually did not think of [VaKB-2011]. This can essentially be traced back to the fact that evolutionary processes, due to their stochastic characteristics, can capture all possible solutions in a given solution space; i.e., they are so to speak "unbiased", while the product developer, justified by time pressure and specifications, usually does not work out the best solution, but only the "next best" one. For example, the optimization of a car catalytic converter required a calculation time of 3 h per individual. However, only 500 out of a possible 530 million individuals had to be calculated to arrive at a significantly improved solution. A conventional optimization of the catalyst carried out in parallel required several man-years, whereby the result achieved was significantly lower than the optimized one [SCJP-2004].

[12] For example, in the case of flow optimization problems, all contours flowed against and through must be parameterized, since their geometries, topologies, dimensions, material and surface properties, etc., can influence the flow problem.

18.1.4 CAP Systems

The last area of product development, process planning, and the first area of production, scheduling, combine product development and production. In between lies the release for production. Process planning involves checking the producibility of the individual product concepts (see also Chap. 9) and the preparation of the necessary production steps, Fig. 18.9. At the time of release for production, all technical, logistical and administrative documents describing the product and its performance must be available so that it can be manufactured completely and without errors[13].

After the performance of the product and its behaviour have been described via the product attributes in the phases and areas prior to process planning (key question: What is to be done?), the technologically meaningful and possible work processes are defined in process planning, the processing machines assigned and the data prepared that are necessary for controlling the processing machines and achieving a certain processing quality (key question: How and how can the specifications be implemented in production?).

For known production processes (and this applies to most orders), the basic data for process planning is known. Operations and sequences of operations shall be simulated until any inconsistencies in the procedures are resolved. Only then are the data for controlling the processing machines generated and simulated. In the case of ablative production, these are usually tool travels (NC travels), in the case of additive production, the choice of material and technology (Sect. 9.2). The same is done

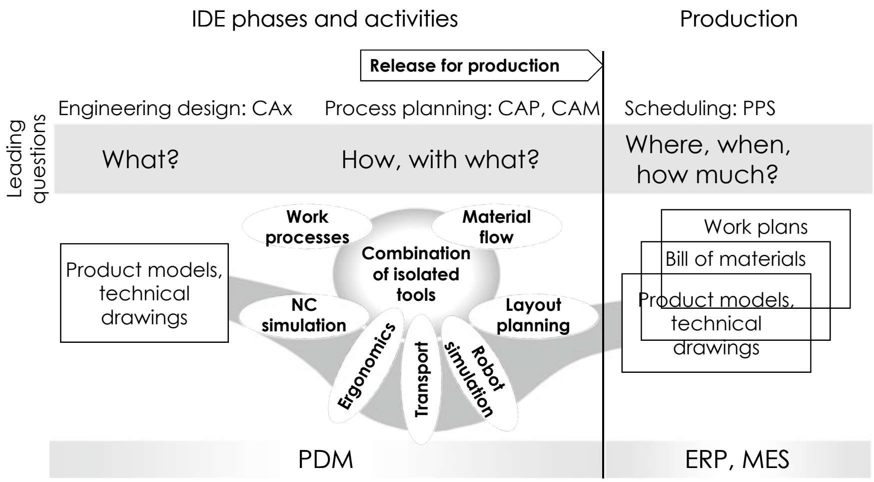

Fig. 18.9 Process planning and production control. PDM: Product Data Management. ERP: Enterprise Resource Planning. MES: Manufacturing Execution System (according to [VWZH-2018])

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[13]This statement applies to every product, regardless of whether it is a real product, a virtual product, a software, a service (in the broadest sense) or (almost any) combination thereof (c.f. also Chap. 2)

with the planning of the material flow to the processing machines, with the robot simulation for handling devices and with the transport simulation for conveyors. The results are documented in layout plans for production, in parts lists and routings.

CAP systems make use of extensive databases for process planning. These include catalogues with geometric properties of processing machines (e.g. working space, existing fixtures, clamping options for machine tools), performance of the existing processing machines and the resulting chip removal volume per time (ablative production) or order speed (additive production) and finally technological information such as type and application of the tools used in ablative production, surcharges for the machining of certain materials, feed rates, cutting speed, use of cooling media and consideration of the service life of the individual tools. In today's CAD systems, some of this data is already assigned to the features in the 3D model of the product, so that a check for manufacturability can already be carried out during modelling. CAM systems determine the work steps on the basis of the results of CAP systems and derive further control information for processing machines and equipment.

As soon as the release for production has taken place, the production of the product (its "materialization") can be started (central question: Where can something be done when and how many pieces must be produced?). The corresponding documents are transferred from the PDM system to the ERP system for production planning and control. The implementation and control of production activities is carried out using a production control system (see also Fig. 18.2).

The scheduling system uses the production control system to infiltrate and execute the defined work sequence and the specification of certain processing machines from the work schedules as well as the scheduling data of the current order (order quantity and lot sizes, time and cost frame) between other orders and on the basis of current quantity data (capacities, deadlines) into the current production.

18.2 Cooperation of Spatially and Temporally Separated Teams

Increasing product complexity in IDE projects usually leads to increasing project complexity, whereby IDE teams usually have an interdisciplinary character and can also work spatially separated (see also Sect. 15.6). This requires a high degree of communication, cooperation and coordination, often over long geographical distances [HFPK-2008]. In order to work on the tasks resulting from these, methods and tools are needed, which are summarized under the term e-collaboration (Electronical Collaboration). This term refers to the Internet-based and networked collaboration of a number of people. The goal of e-collaboration is to optimize collaborative processes with the help of web-based information and communication solutions. Ideally, people can work together on a problem as if they were standing next to each other.

With the use of e-collaboration, project teams can ensure efficient communication in all phases of product development within IDE. These tools can help to find suitable team members during the initialization of a project and to compose a suitable the project team: Using social bookmarks, social networks and employee profiles, experts can be found in specific areas that allow the project participants to be put together according to their tasks.

E-collaboration tools can support project teams in finding ideas during the concept phase. For example, the targeted use of *electronic meeting systems* (EMS) in methods for generating ideas (e.g. brainstorming) can have a positive effect on the result. By making it possible to submit suggestions anonymously and to evaluate or criticize them anonymously via chat entries, for example, inhibitions among participants can be reduced and diversity and originality of ideas can be increased. In addition, this anonymity ensures that the position or acceptance of the idea provider in the group has no influence on the evaluation of the submitted idea, but that the content is in the foreground. The EMS takes on the role of the recorder. All contributions of the participants are stored and serve as group memory in the further course of the project.

Even during the detailing phase of a project, it is possible to optimize processes by using Enterprise 2.0[14] tools. For example, it is not uncommon for different partners in a project (for example, customers and suppliers) to use different CAD systems. The common work becomes inefficient by the conversion of CAD data or the use of standard formats, since thereby substantial information and time losses can evolve, even if today's converting systems are very efficient. For example, CAD viewers, which can display a large number of common CAD formats, already have considerable added value, since project meetings can be supported by visualizing the product at an early stage of detailing.

Web 2.0 makes the Internet-based approach of e-collaboration possible. The user is no longer just a consumer; he becomes a designer himself and generates his own content. This includes the use of social software, such as wikis, blogs, instant messaging and social networks. Collaborative editing of shared content also takes place in Web 2.0. These services have already established themselves in private communication. The use in enterprises is not yet so far, but shows a large potential for the improvement of communication in and between enterprises.

In addition to communication, e-collaboration also focuses on the distribution of knowledge and access to this knowledge in a company [HFPK-2008]. E-collaboration thus includes the following areas [KoRi-2009]:

- Create and edit documents together,
- Contact management and expert search,
- Dissemination of knowledge,
- knowledge retention and
- Coordination and information transparency.

[14]Enterprise 2.0 refers to systems that can be used to coordinate project coordination, support knowledge management and other communication tasks [Gabl-2019].

18.2.1 E-collaboration Tools

The tools of e-collaboration are divided into three generations according to the chronological order of their introduction. The tools of the first two generations have established themselves and are used successfully in companies and project teams [HFPK-2008]:

- The first generation (since 2006) includes e-mail, telephone and calendar. These tools have been in use for quite some time. Although these tools are the foundation of e-collaboration, they were not yet classified under this term at the time of their introduction.
- The second generation includes instant messaging (chat), presence awareness, document management systems (DMS) to secure and share data, project management tools to coordinate projects, desktop sharing to present content to other users on their own screens as well as whiteboards and repositories that enable users to collaborate on documents using text, annotation, highlighting and other editing tools.
- In addition to the tools, the third generation offers new approaches to working and thinking with regard to the dissemination and use of knowledge and its potential within a company. These tools have been in private use for a long time and are called social software. These include blogs and wikis as diaries or knowledge databases and social bookmarks, which enable the collection, provisioning with keywords and publishing of own bookmarks. Social networks serve to build up a network among employees with their own profiles analogous to certain occupational groups. In addition, there are RSS readers that automatically inform you about important changes and tags that display freely assignable keywords for any content objects such as images, word documents and blog posts.

The third generation differs from the first two primarily in the social aspect of knowledge processing and knowledge preservation. Each team member can provide her or his own knowledge and make it available to other team members.

E-collaboration can also be helpful for CAx applications. For example, some CAx systems provide options for online collaboration. This enables multiple users to simultaneously view the same CAD model and, for example, make comments, share the design environment and communicate with each other.

18.2.2 Integration of E-collaboration

The successful use of e-collaboration depends strongly on the approach of integration in a company. E-collaboration should not replace the direct communication between the employees (the personal conversation), but offer an opportunity to work together effectively and efficiently.

Certain challenges must be overcome in order to integrate e-collaboration. Common challenges are [HoKB-2011]:

- Benefits are not recognizable: Employees must be able to clearly recognize the benefits of the tool in order to accept it. Often the benefit is not clear or working with the tool is perceived as an additional burden.
- Too much transparency, which can result in sensitive data falling into the wrong hands. Encryption of the data can help.
- Private use for private exchange (for example, in chats or social networks) impairs business use. Clear rules and possible sanctions are helpful here.
- Lack of affinity with technology: Older employees in particular run the risk of shying away from modern technology and its use.
- No change in corporate culture and management: In addition to the employees, the management must also change and set an example for the use of e-collaboration.
- Technical complexity of the solutions that (still) prevent companies from implementing e-collaboration.

The integration leads to significant changes in the corporate culture and in the individual way of working. It is necessary to open up communication and organization at all levels both within the company (management and employees) and in the project team [HFPK-2008]. A manager must be able to delegate leadership and responsibility to employees and thus enable the free sharing of knowledge and self-organization. For example, wikis and blogs can only assert themselves if the content is not restricted by a central administration. However, the community can correct incorrect entries. Furthermore, the free distribution of tasks according to the expertise within a team is also possible.

Of course, the affected employees (regardless of whether individual employees or members of a project team) must be involved in the decision-making process for the introduction of e-collaboration, both in the basic question for or against an introduction ("Whether?") as well as in the method of introduction ("How?"). Experience has shown that the acceptance of a new tool increases if the employees according to their experience and requirements can select it.

18.3 PDM Applications

A PDM system (PDM = Product Data Management) supports all activities related to creating, changing, versioning and archiving all product structures within IDE (including those that do not lead to a finished product), whereby the elements of the product structure are provided by CAx systems. The PDM system manages the information stocks (mainly consisting of documents and data) required or created for this purpose and treats them as relevant resources that are required by many other areas in the company. The essential benefit of a PDM system is that the required information is made available to the right user at the right time, in the right quantity and quality, comprehensively and without contradiction.

The PDM system is the basis and backbone for the controlled flow of documents and data to and from IDE during the entire product life cycle; i.e., it implements the document flow (see Fig. 18.4) and leads to better cooperation between the systems, which are still predominantly isolated today[15], as shown in Fig. 18.2.

PDM systems work according to the client–server principle with graphically oriented user interfaces. They are usually characterized by a modular structure of the system components. The basis for a PDM system is formed by commercially available, predominantly relational, but also partly object-oriented database management systems, which form the so-called data safe.[16] You have an internal data model that consists of objects, relations and methods. In this data model, the users are grouped together by different role descriptions. Processes and workflows can then be assigned to these groups. The data model is set up once during the system introduction and then successively extended by new components (users, systems, documents).

In addition, there are tools for system adaptation, for restarting and for data reconstruction after a system breakdown ("recovery") as well as interfaces for data exchange with other systems. A general PDM system architecture is shown in Fig. 18.10.

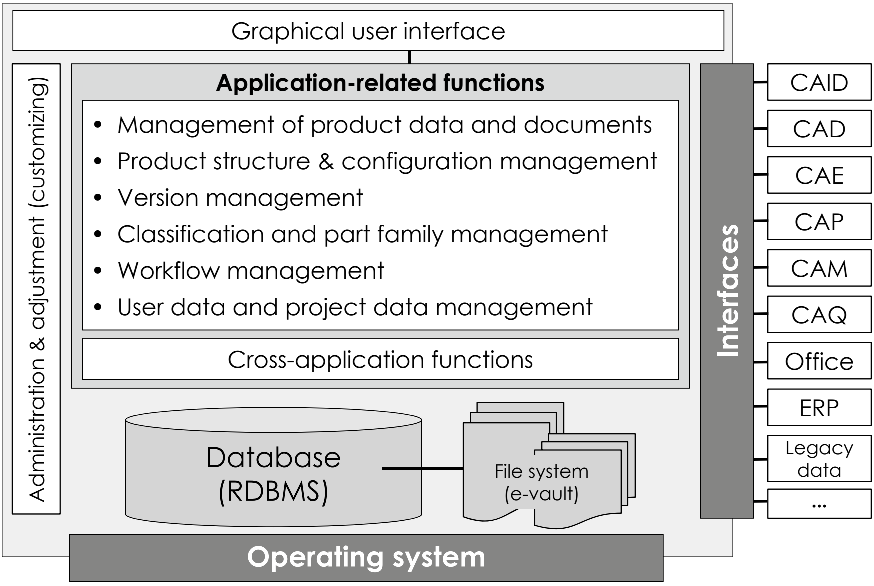

Fig. 18.10 PDM system architecture (RDBMS: Relational Database Management System [VDI-2219, VWZH-2018])

[15]If product lifecycle management (PLM) is to be introduced in the company to consolidate isolated applications, then the successful use of PDM applications is the first prerequisite and the indispensable central application for this.

[16]Also known as *Vault*, *Information Warehouse* or *Repository*.

PDM systems usually have the following application-related function groups, whereby the modules can vary from system to system:

- Product data and document management implement the general administration of product data and the associated documents such as CAx models, drawings, parts lists, work plans including the various file types and the coupling to the respective generation systems. This includes version or status management, the management of files and of folders (for groups of related documents) and the management of metadata for objects, such as classification data.
- Product structure and configuration management ensure the connection of product and related data and documents (the PDM objects) in their respective versions over the entire life cycle of the product and thus support project work within IDE. Both are based on the individual phases of the life cycle, on information about the respective status of a PDM object (in process, released, to be changed, etc.). This includes the creation and editing of product structures, the generation of bills of materials or parts where-used lists, as well as the management of changes in product structures over time in the form of configurations (a configuration is a specific grouping of objects) and versions (further developments of this configuration) and the management of product variants (different variants of this configuration, for example, versions of the same configuration for the German and French markets). This includes the history of a PDM object, which documents and manages all status changes. For this purpose, the product structure is outlined orthogonally to the document structure, Fig. 18.11. The product hierarchy goes from top to bottom, the document hierarchy from left to right.

Figure 18.11 shows three typical times for an individually configured product: "as designed", "as built" and the state at the final installation of the product after a

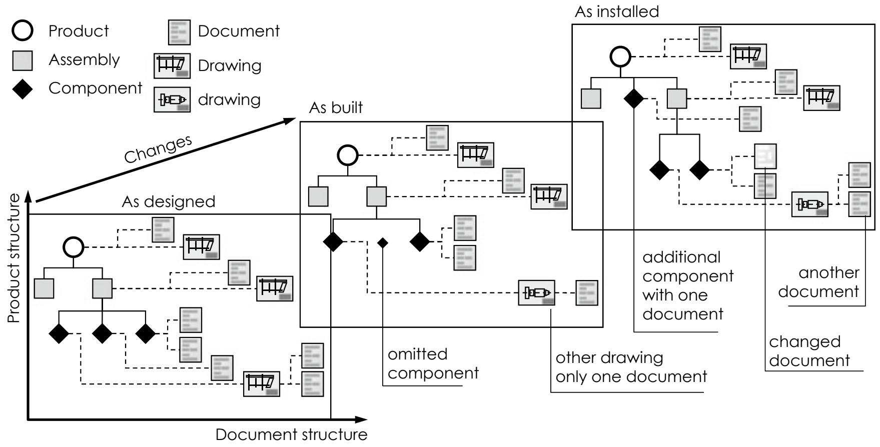

Fig. 18.11 Configuration management (left: design, centre: construction, right: installation of the product)

test phase in the company "as installed". The changes in the state of construction mostly result from adjustments to the design made in the meantime. A new version of the product is created. In the installed state, the changes result from findings from the test phase or the initial deployment phase, which in turn leads to a new version of the product. In the further product life, further states can apply, e.g. "as maintained" or "as rebuilt".

Within a PDM system, there are different function groups that map different applications:

- Classification and part family management: Classification of components, e.g. via lists of characteristics (SML) [DIN-4000] and provision of efficient mechanisms for searching and retrieving component or product information.
- User management: Mapping of the organizational structure or the administration of roles, access rights and functions of users or user groups.
- Workflow management: Mapping and control of firmly linked work processes (e.g. release and change processes) as well as the provision of status information on the work progress.
- Project management: Formation of process sections (e.g. development phases), definition of milestones, necessary services and delivery dates.

In addition to these function groups, there are other modules that are either integrated in the PDM system or can be covered by third-party providers:

- Automatic data backup with specialized hardware, today mostly with running double storage ("mirroring") of the data, for example with a RAID system (Sect. 18.4.2).
- Establishment, operation and maintenance of a digital archive in which documents and data of products that are no longer currently being processed but are still active are stored (more details in Sect. 18.5).
- Presentation of documents and data on systems other than those with which they were generated ("Viewing"), combined with the possibility of marking areas of interest in the presentations ("Markup" and "Redlining") and adding annotations (not changing the document) ("Annotation"), see also Sect. 18.2.1).

If a new IDE project is started, a separate area is created in the PDM system for it. Then usually the existing roles for users as well as structures and specifications for products and processes from corresponding templates must be adapted to the requirements of the IDE project and the required interfaces must be activated or set up. The basic equipment (existing product data and documents) must be provided in the project area. In this project, it is now possible to plan the project by means of project management and workflow management. In addition, employees responsible for processing the individual tasks can be assigned and provided with the required submission documents (e.g. parts lists, drawings or revisions). The PDM system enables all project participants to participate in the project and its data within the scope of their assigned roles and to access the development data even without the corresponding specialized programmes (for example, a CAD system is not required for reading and commenting CAD models).

If a new PDM system is introduced, adjustment, configuration and administration tools are used to set up the PDM environment and to customize the data model, the class structures for documents and data, and the menu structures and forms of the user interface. Interfaces to common CAx systems, ERP systems and office automation systems (e.g. Microsoft Office) are usually part of the PDM system and only need to be adapted to the existing systems.

Further tasks are the transfer of existing data ("old data"), because a PDM system is usually introduced into an existing IT landscape. In the case of digital legacy data, a fundamental distinction must be made as to whether all content is to be inserted or only a reference to it is to be transferred, while the actual content remains on the legacy systems. Documents on non-digital media, such as microfilm or paper, can be scanned in and stored digitally in raster format or can only be used as a reference. In this case, a set of metadata is created that describes the content of the document and additionally defines the location of the file (see also Sect. 18.5 and Fig. 18.18.).

Today, cloud-based PDM systems, which are more scalable than conventional PDM systems, offer an alternative to the PDM systems used locally in the company. External cloud providers provide the necessary resources flexibly as a service. In this way, IT capacities are permanently reduced for the own company and only requested as required. While a "stationary" PDM system requires the creation of an organizational structure within the software and the subsequent assignment of named users, a cloud-based PDM system is typically licenced per user. Furthermore, the maintenance tasks for the maintenance of the PDM system are outsourced to the provider of the PDM system. In addition, the company is able to work independently of its local ties, which increases flexibility and cooperation. A disadvantage of cloud-based PDM systems is the fact that the company's own (possibly critical and sensitive) information stocks are placed in the hands of external providers. However, these are usually subject to strict confidentiality agreements, which guarantee the security of the data, but this still presents companies with new barriers. In addition, the functions and interfaces can only be adapted slightly for individual sites. It should also be borne in mind that an independent solution is often financially more cost-effective, especially when a PDM system is used for several years.

18.4 Structure and Organization of Application Systems

Efficient application and information integration is essentially determined by the interaction of the generator systems and the management systems. For IDE, a structure that has proven itself many times in practice is suitable (based on [VDI-2219]), Fig. 18.12.

- The PDM system (Sect. 18.3) plays a key role in the interaction with the other application systems within IDE by managing product-related data and documents. This is where the product structure is built up and further developed. The system also serves as an integrator between the product development systems and the

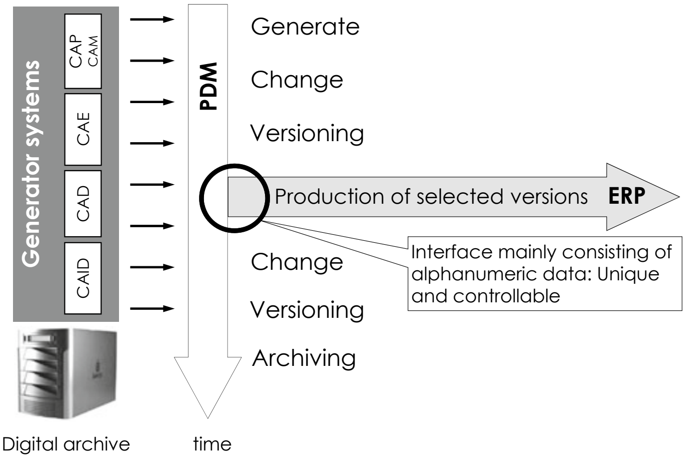

Fig. 18.12 Logical structure for application integration (according to [VDI-2219])

production systems, which are mainly managed by ERP systems. This results in integration at user, process, function and data level.

- CAx systems (Sect. 18.1) generate the computer-internal model and the documents for a product and thus the elements of the product structure. Figuratively speaking, models and documents are "hung" into the corresponding structure ("tree") in the PDM system.
- Products that are no longer active are transferred from the PDM system database to the digital archive, from where they can be quickly and completely retrieved and processed again at any time (see also Sect. 18.5).
- When a concrete order is submitted, the ERP system[17] supports the production ("materialization") of a selected version of the product structure by carrying out the necessary scheduling and capacity planning during order processing and entering the orders in production. It can also be used for product planning and order processing. The latter means that an order is first created in the ERP system and from there the creation of a new product structure in the PDM system is triggered. Once the order has been developed, the PDM system transfers the relevant documents and data back to the ERP system when it is released for production.

If the interface between the PDM system and the ERP system is as suggested in Fig. 18.12 then only alphanumeric data (essentially dispositive data, 3D models, technical drawings, parts lists, work, assembly and test plans, etc.) must be transferred.

PDM and ERP systems have commonalities. Both manage the information stocks arising in the respective areas, make them available to the respective user in the right quality and quantity at the right time and support the necessary processes. Mutually

[17]ERP = Enterprise Resource Planning, an extended and company-wide PPS system that supports production and assembly as well as applications from order processing, logistics and shipping.

required information stocks (e.g. order data, parts lists and work schedules) are provided via the interface mentioned above. The data model on which these activities are based must be carefully and meaningfully divided between the two systems, whereby in each individual case it must be decided which system is to have data sovereignty. In the case of redundant data storage (which cannot always be avoided for reasons of data security or access time), corresponding synchronizations of the two systems must be scheduled.

From these analogies, however, it cannot be concluded that the two systems are interchangeable; i.e., a PDM system could be used for production or an ERP system within IDE. Rather, there are differences in the

- Objects to be treated: Within IDE, a single, initially imaginary, later digital or virtual product is processed (= quantity 1). In production, the actual (order) quantity of the physical product is created (quantity = N).
- Processes to be supported: Within IDE these are very complex, require high flexibility, are not always reproducible and do not run extremely time-critically. Processes in production and administration, on the other hand, are less complex, less flexible, but very time-critical and always reproducible in order to achieve a uniform quality level (see also Fig. 10.2).
- The amount of data that is generated: Relatively small quantities within IDE, much larger quantities in production and administration.
- Areas of effect of data and documents: Most data and documents remain in the area in which they were created. Only a few technical and scheduling data and documents from IDE are needed in production.

These differences lead to the interaction of the participating systems with a clear distribution of tasks shown in Fig. 18.12.

For the system structure within IDE, the client–server network, which is particularly suitable for decentralized applications, has proven itself, Fig. 18.13.

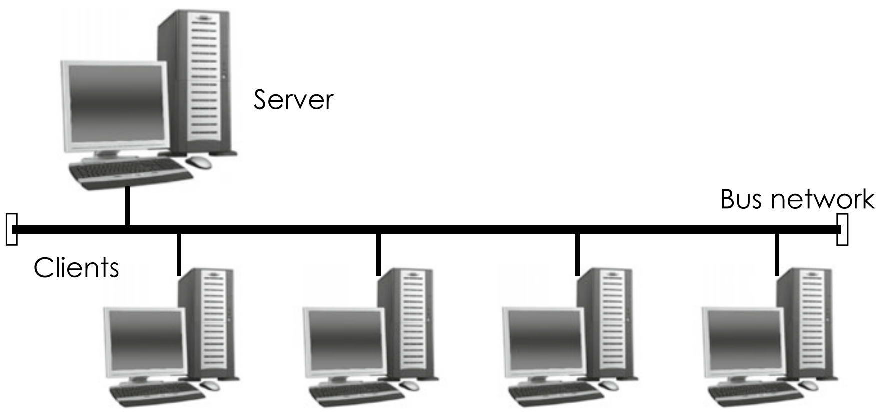

Fig. 18.13 Principal structure of a client–server network

In its purest form, a high-performance computer with high storage capacity acts as a server in the network, providing all central services, such as the central storage and transmission of programmes and data, the control of all peripheral devices and the connection of the local network to the company-wide network. The local applications run on the clients. Their access to programmes, data and devices takes place exclusively via the server.

Both the server and the application programmes can also be implemented as a cloud-based service. This means that computing power, storage resources as well as required maintenance and IT expenditure are all outsourced to third parties in the form of a “product-as-a-service” system. This eliminates the need for an internal server and the individual clients access an external data source.

While the advantages of sharing peripherals are mainly economic, the local centralization of programme and data management also has functional advantages:

- Central programme storage and maintenance results in the same programme status for all users. The dreaded proliferation of special versions from the point of view of system support cannot even arise in the first place. The programme maintenance is much easier, because for example you only have to install new versions of a programme at one place (on the server) and can distribute them from there in a controlled way.
- Central data storage is a prerequisite for the sensible use of shared databases. In addition, rational data backup can only be carried out with central data storage (especially for archiving).
- A client–server network also has the advantage that it is self-similar; i.e., a server can easily be the client of a higher-level client–server network at the same time. Similarly, a client can be the server of a child client–server network at the same time. Since the hardware requirements for servers and clients always remain the same, this self-similarity also reduces the otherwise expensive variety of hardware to the necessary minimum.

With the increasing use of different application systems, the question must be clarified whether it makes sense to use different systems for the same applications.

- Advantages of a uniform system for an application are lower running costs due to the lower support effort as well as simpler maintenance and care. Fewer employees are required than know-how carriers. The drawback is that the lowest common denominator of a unified system cannot always satisfy the performance needs of an area (there is a risk of oversized systems not being fully exploited).
- Reasons for the system diversity are mostly uncoordinated procedures in procurement or the demand of an important customer for a certain system, which demand their own system from the supplier in order to ensure a smooth data exchange, especially for order developments.

The aim should always be to standardize the systems as far as possible, whereby very special application areas should also use their own solutions.

18.4.1 Systems Management

For a stable operation of a client–server network[18], in addition to the administration and organization of all servers with the clients assigned to them, the administration of the rights of all users working on the clients, the installation and use of software, the backup of data, the control of peripheral devices as well as the connection to other networks are required. All these activities are summarized as System Management.

In a client–server network, the application modules are divided into those for the basic software (from which as many licences are required as there are clients) and additional software, from which fewer licences are purchased (the exact number must be determined during operation, see below). A site licence is useful if the application systems are not distributed across several sites and if many workstations with uniform software equipment are available or are to be set up in the foreseeable future.

In addition to regular and case-by-case data backups (see next section), system management has the following tasks and objectives:

- Maintain system availability at 95–98% through short response times, stable system parameters and performing maintenance and backup work outside regular working hours.
- Regular updating and, if necessary, adaptation of the software modules.
- Statistical evaluation of the frequency of use of software licences, which (except for a basic software package installed on each client) should not be bound to specific systems or networks, but should be freely usable in the network (so-called floating licences). If software licences are rarely required, their number should be reduced. The number of licences experiencing bottlenecks should be increased.
- Statistical evaluation of occupancy and frequency of use of all peripheral devices in order to configure and position such devices according to requirements.
- Preference for software modules that offer a high degree of user and maintenance friendliness.
- Ensure the quality of training materials (consistent, use of in-house examples, encourage self-learning) and documentation (available online with examples, same amount of information also available on other media).

18.4.2 Safeguarding Information Stocks

The protection of information stocks (documents and data) must be carried out and monitored on a regular basis, as information stocks ultimately represent a significant

[18] As a first measure for the stability of the network, all servers and the most important clients should be connected to an uninterruptible power supply (UPS). A UPS can bridge the power grid failure for a certain time and compensate for voltage fluctuations. UPS modules are available for all common computer sizes and always represent a worthwhile investment.

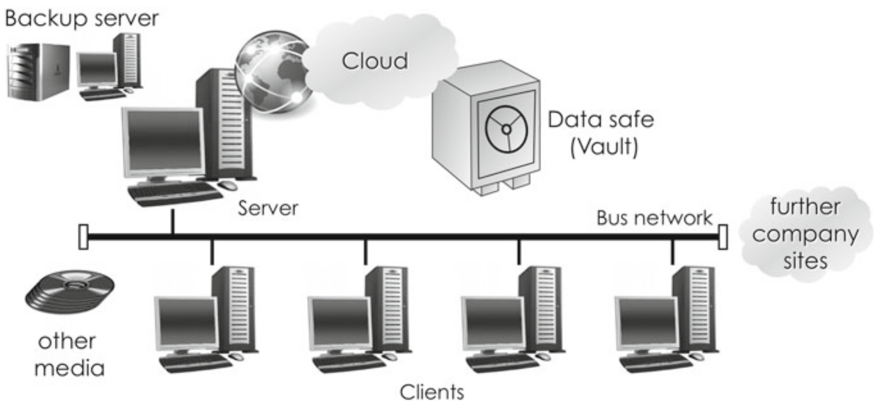

Fig. 18.14 System structure for securing information stocks in the company

(albeit intangible) part of operating assets. It must also be ensured that lost information can be recovered safely and quickly (recovery). Information stocks must therefore be backed up several times redundantly and on different storage media (not only on the mainly used ones) in order to largely prevent losses of information stocks.

The process of backing up information on computer internal or external storage media is always a critical moment, because if an error occurs in the computer systems during the backup, this can lead to information loss (which can usually hardly be repaired). In order to avoid this, a system structure with appropriate procedures is required that can minimize this risk, Fig. 18.14.

Figure 18.14 shows the client–server network from Fig. 18.13. For ongoing backup, specially protected areas on the server as well as a backup server with a redundant storage system (such as a RAID)[19] and areas on the cloud are available. Completed orders and critical documents and data are additionally saved in the data safe (vault). Physically multiple redundant backups can be performed on systems at other company sites or on other media, for example.

18.5 Archiving

The task of archiving is to secure information stocks, to maintain them constantly and to guarantee fast and precise access to searched information. The aim of an archiving system is to fulfil these requirements and to provide the user with a comfortable and cost-effective tool. For this purpose, a uniform and consistent information pool must

[19]In a **r**edundant **a**rray of **i**ndependent **d**isks (RAID) system, several storage media (usually magnetic hard discs) are combined into a virtual memory as a logical unit. The redundancy results in higher data security, large amounts of information can be managed more easily and defective storage media can be changed during operation.

be built up from which each user can extract the information relevant to him in order to store it again there after processing in a modified form. The need for archiving results from

- the necessity to secure company know-how in the form of work results, procedures, processes as well as information and knowledge collections independent of persons and current orders and work areas outside the structures and systems that are used for the processing of everyday business.
- the documentation obligation (Directive 85/374/EEC, Article 11 [EEC-1985]), which is about being able to provide evidence of discharge in possible product liability cases. To this end, it must be possible to trace the stage of development and the associated modification processes at least 10 years after the product has been placed on the market. However, the usual archiving period in the automotive industry for safety-relevant components is up to 20 years, in the machine tool industry up to 25 years.

An archive is defined as the totality of all the information stocks on corresponding media that are required for a transaction and created there. Characteristic of a digital archive is the entirety of the programmes and information stocks available on corresponding media in an IT system. Figure 18.15 shows selected requirements for an archiving system.

On the basis of the management of and the guiding rules for the flow of documents shown in Fig. 18.4, a general basic configuration has been emerged for the digital archive, Fig. 18.16.

The user works interactively with the PDM database in which the current backup takes place. This assures that not only the 3D models of a component, but as well all accompanying information stocks are stored at their appropriate places within the PDM structure. The current processing status is saved regularly or if required

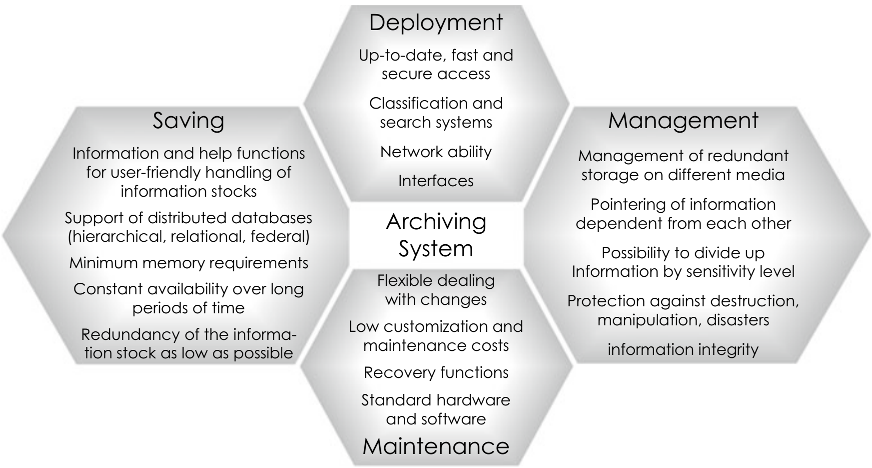

Fig. 18.15 Requirements for an archiving system

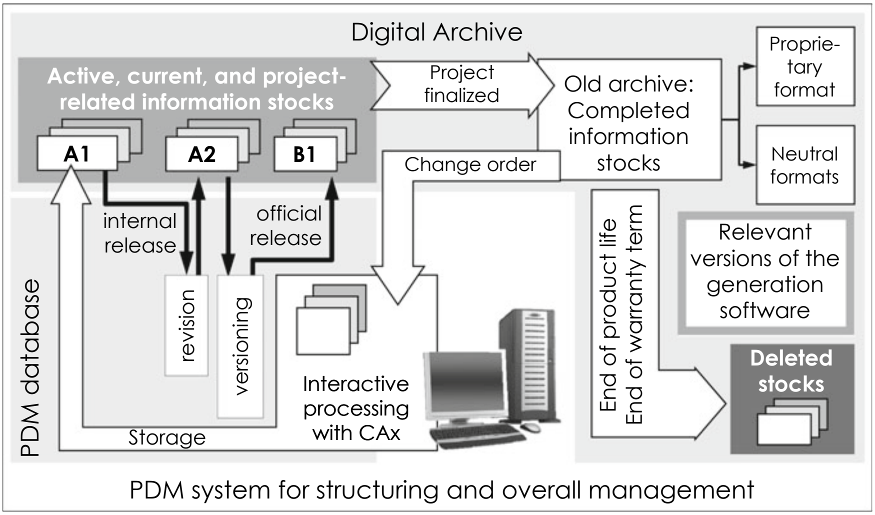

Fig. 18.16 Basic configuration of a digital archive with different memories (A1: current status of processing, A2: area with information stocks to be released, B1: released information stocks)

in memory area A1 of the digital archive. As soon as the user has finished his work and released it internally, the work results are transferred from area A1 to the release area A2 using a transaction.[20] In area A2, the results are then available for further activities for release and control of e.g. conformity with standards. The data is assigned a version number that reflects the current processing status. After the official release, the information is transferred to area B1 (so-called Check In) and is now available to authorized users. If change requests occur or problems arise, the data is transferred again by transaction to the interactive area A1 (Check Out), where the post-processing takes place.

This process can also take place in the course of a revision, in which the current status of the existing information stock is adapted, and in the case of a new versioning. Again, the information stock is transferred from area B1 to the interactive area A1 (Check Out), where it is only available to the current user until the end of processing. Once processing is complete, the information stocks are transferred back via the area A2 to area B1 (Check In). Both during revision and versioning, the old versions of the information stocks are archived and are still available to the user for retrieval.

At the appropriate time (for example, when an order is completed or a product is no longer produced), the corresponding information stocks are placed in the old archive. From there, however, they can be reactivated at any time during a change request. The data can be stored in system-specific (proprietary) format or in a neutral

[20]In a transaction, the content is copied from one storage area to another and the source data is then deleted in the source area. This operation is consistent because it does not create copied (and therefore redundant) information stocks.

format (e.g. STEP for CAx product models, TIFF for drawings, ASCII for text documents).

- A proprietary format has the advantage of fast access without conversion of information stocks as long as the software version of the generation system with which the stocks were created is not too far back, as the readability of the information stocks with the subsequent versions may decrease due to (possible) changes in the data structure. The upward compatibility[21] makes it relatively easy to read information once it has been stored. However, if the time interval between the current version and the version in which the information stocks to be changed were created is too large, the stocks must be converted across all intermediate versions with corresponding effort before they can be used again in the current system.
- A neutral or standardized format, for example the STEP format for CAx product models, has the advantage that the information stored in it has a long service life (independent of the respective software version) and can also be easily processed by other systems. This minimizes interface problems when transferring from one system to another.

Only when the information stocks are to be definitively deleted (for example, because the product life has ended or because warranty claims have lapsed), they are placed in the "Deleted stocks" archive area, where they remain for a while (for security reasons) before they are finally removed from the archive.

Different storage media can be used to store information stocks, where the most important issue is the possible lifespan of the information stocks on a particular storage medium. In this context, "lifetime" does not mean the physical lifetime of the storage medium, but the period of time during which the stocks on this storage medium can still be read unambiguously and error-free. Figure 18.17 shows a selection of storage media as well as their capacity, access time, possible service life and intended use.

As shown in Fig. 18.16, archives are usually structured and managed by a PDM system (Sect. 18.3). This helps to address and classify content to make it easier to find it again.

A proven concept for the interaction of different archives, as these might have been developed over the years, is shown in Fig. 18.18. The PDM system enables a complete overview of all archives in a company and thus a consistent administration and provision of the information contained therein. It does not matter on which different storage media the information stocks are stored. While information stocks can be searched by using the tools available in the PDM system, non-digital data or such information stocks that are not stored in the system used can be found using metadata that either classify the contents of the non-digital data and documents or dispose of access possibilities to the other systems.

[21] Upward compatibility is the compatibility from the current to the next three to four higher software versions. In CAx systems, upward compatibility is a part of the system so that a user can access data created once at any time (even data created with an older version).

Type	*Capacity*	*Access time*	*Lifespan of information stocks*	*Usable for*
Internal magnetic hard disk	4,000 GB	< 3,5 ms	5...10 years	Programs, current information stocks, libraries (standard and purchased parts, variant and calculation programs, symbol catalogs), transport and backup of information stocks
External magnetic hard disk	4,000 GB	< 3,5 ms	bis 10 years	
Semiconductor hard disk (Solid-State-Drive)	1,000 GB	< 0,2 ms	5…10 years	
CD-ROM (read-only memory CD)	900 MB	< 50 ms	up to 100 years	
CD-R (only once writable CD)	900 MB	< 50 ms	up to 70 years	
CD-RW re-writable CD)	800 MB	< 50 ms	up to 50 years	
DVD (ROM, R, RW, etc.)	4.7 GB per side and layer	< 50 ms	up to 30 years	Programs, application data, data transport, data backup, multimedia data, also in an archive
Blu-Ray disk	25 GB per side and layer	< 25 ms	50…80 years	
Crystaline storage (Flash EPROMs, storage chips and -arrays, USB sticks)	up to 2,000 GB	< 1 ms	10…30 years	Parametric elements, variants, (standard and purchased parts, functional complexes (features), CAx software, operating systems, current work files, programs, transport and backup of information stocks
ZIP Drive	250 MB	< 200 ms	up to 10 years	Transport and saving of information stocks
Magnetic tape (DAT)	220 TB	variable	10…20 years	Saving of information stocks
Micro film	unlimited (only limitation: Blackening degree)	some minutes	some 10 to 100 years	Completed, released orders, protection against uncontrolled changes, drawing replacement (due to space reasons), redundant backup
Drawing	unlimited (only limitation: Blackening degree)	variable	100 years and longer	General archiving approaches, transfer to customers and suppliers (observe the data protection rules!)

Fig. 18.17 Storage media for archiving (status 08/2019)

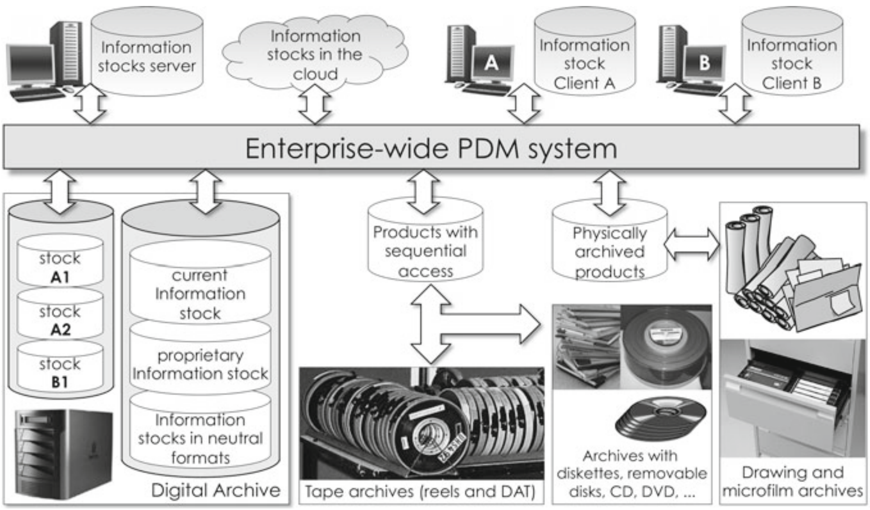

Fig. 18.18 PDM system for managing different archives

All storage media with archive content should be stored redundantly in secure locations outside the company. At the same time, a mirrored digital archive in a cloud makes sense (see also Fig. 18.14). Especially when archiving critical and safety-relevant information stocks, it is still not advisable to rely only on digital media only, which are in addition always dependent on an energy supply. Therefore, information should not only be stored in system-specific or standardized formats, but also in image formats and on media that do not require energy (e.g. paper, microfilm, etc.).

References

[Clem-2006] Clement, S.: Erweiterung und verifikation der autogenetischen konstruktionstheorie mit einer evolutionsbasierten und systematisch-opportunistischen Vorgehensweise. Dissertation Otto-von-Guericke-Universität Magdeburg (2006)

[DIN-4000] DIN 4000-1.: Class list of characteristic lists—Part 1: Terms and principles. Beuth Berlin (2012)

[EEC-1985] European Community.: Directive on the approximation of the laws, regulations and administrative provisions of the member states concerning liability for defective products. July 25th, (1985)

[Gabl-2019] Gabler Wirtschaftslexikon zum Thema Enterprise 2.0, Zugriff am 29. 10. 2019 https://wirtschaftslexikon.gabler.de/definition/enterprise-20-53577/version-276655

[HoKB-2011] Howaldt, J., Kopp, R., Beerheide, E. (Hrsg).: Innovationsmanagement 2.0—Handlungsorientierte einführung und praxisbasierte impulse, p. 1. Auflage, Gabler Verlag, Springer Fachmedien, Wiesbaden (2011)

[HPFK-2008] Hornstein, M., Fischler, A., Pertek, M., Koller, M.: E-Collaboration – Mehrwerte durch moderne Kommunikationsmittel schaffen, Whitepaper, namics ag (2008)

[KoRi-2009] Koch, M., Richter, A.: Enterprise 2.0—Planung, einführung und erfolgreicher einsatz von social software in unternehmen, 2., aktualisierte und erweiterte Auflage, Oldenbourg Wissenschaftsverlag, München (2009)

[Otto-2003] Ottosson, S.: Verification of product development methods. Conference paper Technical University of Budapest (2003)

[Robe-1973] Robert, P.: Le Petit Robert, Dictionnaire alphabétique and analogique de la langue française. Société due nouveau littré, Paris (1973)

[SCJP-2004] Sartiono, R., Clement, S., Jordan, A., Kellner, P., Vajna, S.: Prototypeinsatz evolutionärer algorithmen in der aggregateentwicklung bei volkswagen. Motortechnische. Zeitschrift. **66**(3), S. 220–226 (2004)

[Totf-2019] Tótfalusi, I.: Magyar etimológiai nagyszótár (Hungarian etymological dictionary). http://www.szokincshalo.hu/szotar/?qbetu=i&qsearch=&qdetail=4726. Accessed 11 Mar 2019

[VaKB-2011] Vajna, S., Kittel, K., Bercsey, T.: The autogenetic design theory—product development as an analogy to biological evolution. In: Birkhofer, H. (ed.) The future of design methodology. Springer, London (2011)

[Vajn-1992] Vajna, S.: 35 Jahre CAD/CAM. CAD-CAM Report **11**(12), S. 40–47 (1992), und CAD-CAM Report **12**(1), S. 42–54 (1993)

[VBCJ-2005] Vajna, S., Bercsey, T., Clement, St., Jordan, A., Mack, P.: The Autogenetic Design Theory: An evolutionary view of the design process. J. Eng. Design. 16(4), 423–440 (2005)

[VDI-2218] VDI-Richtlinie 2218: Informationsverarbeitung in der Produktentwicklung—Feature-Technologie. Beuth Berlin (2003)

[VDI-2219] VDI-Richtlinie 2219: Einführungsstrategien und Wirtschaftlichkeit von EDM/PDM-Systemen VDI-Gesellschaft Entwicklung Konstruktion Vertrieb Düsseldorf (2016)

[VWZH-2018] Vajna, S., Weber, Ch., Zeman, K., Hehenberger, P., Gerhard, Dr., Wartzack, S.: CAx für Ingenieure, eine praxisbezogene Einführung (dritte und vollständig neu bearbeitete Auflage). Springer Berlin Heidelberg (2018)

[Wahr-1978] Wahrig, G.: Deutsches Wörterbuch (German Dictionary). Bertelsmann Lexikon Verlag, Gütersloh (1978)

Chapter 19
Requirements Engineering in the Context of IDE

Beate Bender

The task of requirements engineering is to identify all requirements relevant for product development. This involves deriving them from the goals and framework conditions, to break them down into units that can be handled by individual developers and to make their interactions transparent. The results are a finite number of objectively verifiable criteria (requirements) collected in the requirements base, the fulfilment of which in total satisfies customer demands. The process from customer demand to triggering a product life cycle is characterised by complex and dynamic goals and framework conditions (see Fig. 2.4). Depending on the trigger (cf. Sect. 2.2.2), there are unavoidable reasons not only at the beginning of a product development project but also along the entire product life cycle for changes to the objectives and framework conditions for the development of the product. These must be tracked and documented in the context of requirements management.

In terms of industrial psychology, the development of products represents "complex problem solving" [HaSa-1998]. The development of innovative solutions involves an alternating iterative concretisation of problem definition and solution approach, the so-called "Co-evolution of Problem and Solution" (see also Sect. 15.9 and [MaPB-1996, DoCr-2001]). This characteristic process of engineering design causes a high degree of lack of transparency for the developers, both with regard to the solution to be developed and the solution path to be pursued. A highly dynamic development process is characterised by changing framework conditions during the processing of the problem ([Bend-2004, Rück-1997, RüGS-1997]). Changes can be caused, e.g., by changing customer requirements or new standards applicable due to newly developed technical solutions. In addition, complex development projects are carried out in interdisciplinary collaboration within cooperation

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networks. Development often takes place across departments or even companies [Fran-2011, EhMe-2017].

Parallel processing also makes it possible to shorten the development time. The development project is broken down into sub-projects and work packages in order to divide the workload between different specialist domains according to an overall project plan (concurrent engineering, Sect. 15.1). The partial results must be recombined to form the overall solution according to their logical and temporal dependencies. Especially for complex systems, this process involves a risk of error with regard to the consistency of the objectives and thus also of the individual partial solutions as integrated for the implemented solution of the overall development problem. Thus, the continuous alignment between problem, goal and solution concept plays a central role in product development. This requires an operationalisation of all objectives in the requirements forming the basis of the development team's work. The division of labour in the interdisciplinary, distributed cooperation network requires the documentation of all currently valid requirements accessible to all participants. Interfaces to other data sources (e.g. ERP, PDM or CAx systems, Chap. 18) and business processes must be designed without contradictions, and double data storage must be avoided. The property assurance (as reflected in the validation and verification of requirements), which also take place parallel to the development process, must show as early as possible to what extent the requirements implemented in the technical solution hold the potential for solving the development problem.

19.1 Transformation from Development Goals to Requirements

According to EHRLENSPIEL, goals are target ideas of a client or customer that may be blurred (comparable to the target profile of attributes, Sect. 3.2). As example, they cite "The dishwasher should be quieter than all the competitors' machines". For the implementation of the development project, this goal must be reformulated into verifiable requirements. In the example given, this could read "The noise of the dishwasher must not exceed 70 dBA at a distance of 2 m in the standard room" [Ehrl-2009]. The reformulation into requirements contains two essential aspects. On the one hand, the non-specific goal is concretised by the technical expertise of the development team (70 dBA). On the other hand, the formulation ensures that it can be clearly determined on the basis of objectively measurable criteria whether and to what extent the requirement is fulfilled by the product developed.

Due to the complexity of the overall system and the interactions of (partial) objectives, changes in requirements---and thus the attainability of goals---lead to change costs and efforts in all areas of the company. These changes become disproportionate especially in late project phases. This is illustrated in the "Rule of Ten"---dilemma of product development [EhMe-2017], Fig. 19.1.

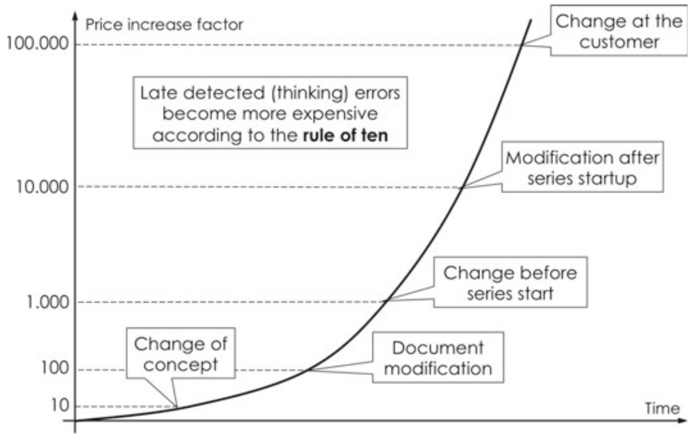

Fig. 19.1 Rule of ten for the propagation of changes [EhMe-2017]

As the design of the product and the associated activities in other company functions progresses, an increasing number of people and other company functions are affected by the contents of the development, who have to check and, if necessary, adjust or even redesign their work share when requirements relevant to their scope of work change. Examples of such activities affected by changes may be

- Development of technical concepts and interfaces to other sub-functions of the product,
- Triggering of orders in purchasing,
- Planning and preparation of production,
- Implementation of customer meetings and handing over of information material by the sales department,
- Development of resource planning in controlling.

With increasing progress of the work performed at the time of the requirement change, the effort needed to incorporate the resulting changes to the product design, calculations or accompanying documents increases. In addition, subsequent changes to existing drawings, calculations or other data and documents as work progresses increase the probability of causing errors, Fig. 19.2.

The initial transformation of frequently vague goals into a verifiable initial requirements base free of contradictions takes place in the first phase of the product development process. Clarification of the task is therefore of central importance in product development, as this is where the key characteristics of the product to be developed are determined. During the following project phases and throughout the entire product development process, the initial requirements base must be further elaborated and specified. The systematic tracking of goals connected with related derived requirements, their interactions as well as the way the implementation as a contribution to the overall system serve as a control instrument and measure for the success of the development project. The target system is further developed during

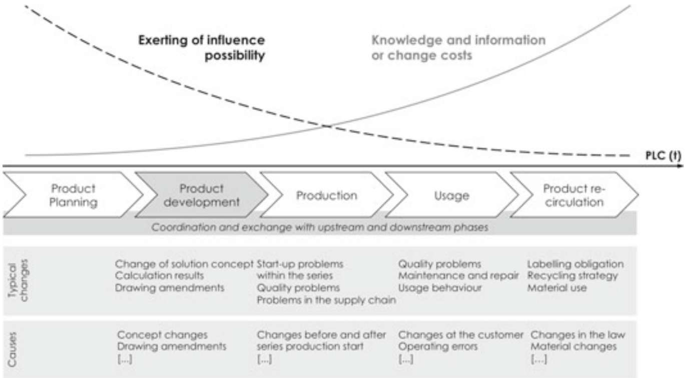

Fig. 19.2 Phases within the life cycle of a product [BeGe-2020] [PLC: Product life cycle (The terms "Manufacturing" and "Re-circulation/re-utilisation" used in the original image in the representation of the product life cycle were replaced by the IDE terms "Production" and "Product re-circulation".)]

product development on the basis of new findings and changing conditions, customer requirements or other objectives. The process of change to objectives or (provisionally assumed) framework conditions requires a vote of all parties involved. In doing so, the interactions of changes due to the often dynamic and (partly) still non-transparent interactions between these objectives must be taken into account, Fig. 19.3.

For example, the postponement of the scheduling chain due to an additional prototype to be manufactured for a desired trade fair date, the change in the cost framework due to a changed competitive situation, the availability of experts due to bottlenecks in other projects or even the change in a bolt diameter (material characteristic value, packaging size, …) due to new standardisation specifications, can have far-reaching consequences for the feasibility of a selected solution principle and thus the achievement of defined development goals. Accordingly, the interactions of objectives and related requirements are not limited to the technical system and its sub-systems, but extend over the entire target system, including cost and time constraints. These dimensions of the target system are described in more detail in the VDI Guideline 2221 [VDI-2221/2019].

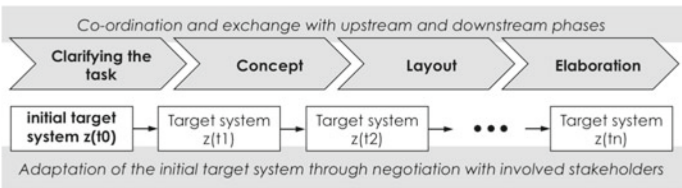

Fig. 19.3 Derivation of the initial target system and further development [BeGe-2020]

19.2 Developing the Initial Requirements Base

In the first work phase of a development project, a stable requirements base is created in order to represent a complete, clear and consistent target system according to the current level of information. This must take place involving all relevant stakeholders. Depending on the trigger of the development project (cf. Sect. 2.2.2), the mandate contained in the development contract must be taken into account. The mandate describes the nature and scope of the development team's interpretation options and freedom of decision that may be used in solving the problem, defined sub-goals or partial solutions, Fig. 19.4.

The initial requirements base is developed continuously throughout the entire project. It serves all participants in all development phases as a benchmark for assessing the success of the project. Throughout the entire development process, the requirements represent the working basis for the actors involved. In all phases of a development project, requirements serve as a measure of the extent to which the development goals are achieved or show the potential to be achieved with a certain probability, based on current knowledge. Development objectives not represented in the requirements base will not be systematically pursued across all project phases and down to all levels of specification. Moreover, contradictions to existing goals or new goals identified during development cannot be always identified in time. Also higher-level priorities such as the implementation of modularisation concepts or maintenance and servicing requirements can only be controlled for the overall technical system by implementing dedicated requirements into the specific development order.

In summary, dealing with requirements in a development project comprises two major tasks. On the one hand, the team must make sure all technical and non-technical development goals without exception are represented in the requirements basis and assigned to at least one person responsible to follow up on their implementation in the product to be developed. On the other hand, the identification and clarification of contradictions between the interdependent requirements for the chosen solution is

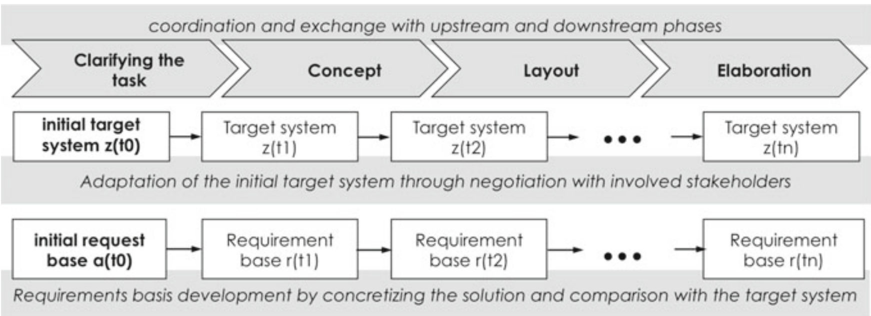

Fig. 19.4 Derivation of the initial requirements basis and further development in the course of the project [BeGe-2020]

central to developing a successful product. This applies both on sub-system level, as relevant to single responsible engineers, as well as on overall system level, requiring an overall view only possible as joint team performance. All these activities result in a concretisation and revision of the initial target system.

19.2.1 Requirements Sheet and System Specification

The so-called requirement and specification process means translating customer requirements into the technical specification of a product jointly between customer and contractor. This formalised procedure is originated in plant engineering. It has proven to be helpful in practice also in other markets and industries, so that it is used now in many other areas. The requirements formulated by the client are defined in the so-called requirements sheet[1], which is made available to the contractor (the executing company, the provider). The contractor then qualifies the requirements sheet into a system specification suitable as development contract for the development team.

The client for product development can be an external customer from both the capital goods and the consumer goods industry as well as an internal customer from within the company. Examples of internal customers are marketing, sales or product management, who define product ideas on the basis of a corporate strategy following market and competition analysis.

The requirements sheet reflects the customer's view and answer the question of "what" to develop and "for what" to use the product to be developed. In the system specification, the contracting company---or the organisational unit within the company entrusted with development---describes the manner in which the requirements of the requirements sheet are to be implemented in their system specification. For this purpose, the requirements of the client are detailed and concretised into realisation requirements. This must take place in coordination with the client, since his requirements are interpreted, supplemented and completed from the contractor's point of view. The question to be answered by the system specification is "how" to develop the product and "with what" means are the requirements to be implemented [VDI-2519].

The aim of the requirement and specification process is to agree on a scope of supply and integrated services complementing the customer requirements with the experience and expertise of the contractor, considering the scope of the technically feasible and economically reasonable implementation. The customer describes an ideally solution-neutral target state that he wishes to achieve when using the product. A consistent, complete and feasible technical definition of the product is left to the expert, i.e., the contractor, Fig. 19.5.

[1] In IDE, the requirements sheet corresponds to the qualitative target profile of the attributes. It should be noted that target profiles for capital goods are usually complete, whereas those for consumer goods are not necessarily complete or cannot be (see also Sect. 3.4.1).

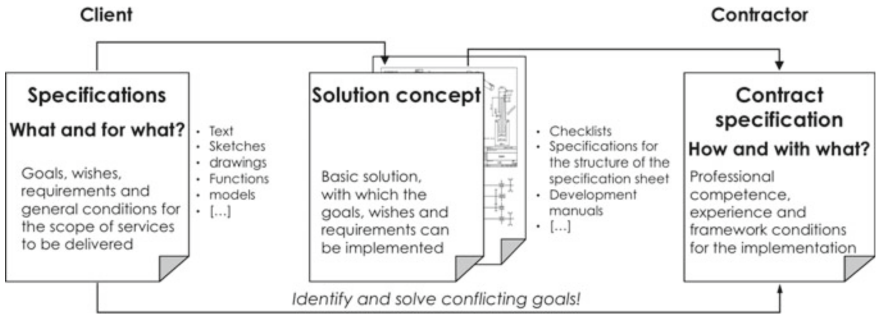

Fig. 19.5 Requirements and specification process [BeGe-2020]

In the requirements specification, the customer describes target states and characteristics of the product, but also framework conditions that are important to him, and prioritises these, e.g., in comparison with other product-specific targets, delivery time or delivery costs (for methods for structuring requirements, see Sect. 19.3). However, this description of the objectives by the customer is usually not complete and sufficient to develop a product that is permanently functional, approved, safe, maintainable and serviceable, producible or recyclable, as the customer lacks the technical expertise to define related requirements (e.g., applicable standards and guidelines). Another group of requirements does not exist at all from the customer point of view, these refer to, e.g., the re-usability of the solution for other customers, the adherence to company-specific production facilities, standardisation or modularisation rules. Further requirements result from the contractor's goal of being able to be profitable. This does not only trigger cost targets but is due to interactions also relevant to resource and schedule requirements, which again can interact with specific characteristics of the product to be developed.

The system specification is to be understood as the contractor specific proposal for the implementation of the customer requirements specified in the requirements sheet. The specifications of another contractor answering to the same requirements (e.g. in the course of a tender) can be completely different due to company-specific different framework conditions, such as production possibilities, existing technical expertise or a different business model.

For the preparation of the system specification, the contractor must check the customer requirements formulated in the requirements sheet with regard to feasibility, completeness and consistency. This applies in particular to the following criteria:

- **Technical feasibility**: requirements that are generally, or for the contractor, not feasible.
- **Consideration of standards, guidelines and property rights of third parties (patents)**: Such requirements are often not known to the customer. In addition, there is often no negotiating potential with regard to changing the specification due to the legally binding nature of patent rights. What can be negotiated, however, is

the cost allocation between customer and contractor in case of unexpected patent cost charges.

- **Compliance with own internal company norms or standardisation strategies**: The customer may not know these requirements, but may be willing or forced to adapt his requirements to them during the negotiation process. Depending on benefits for the customer, such as taking advantage of proven solutions or standardised spare parts the potential a negotiation potential might exist here.
- **Requirements with low customer benefit in relation to the implementation effort**: These are requirements where the customer is usually not aware of the effort that would be required to implement a low-priority requirement. For example, a customer might have unknowingly chosen a colour from the RAL spectrum for the enclosure of a plant, which causes high costs due to high conversion efforts or necessary pre-treatments, without the colour being an important decision criterion for him. Thus, a different colour could be chosen for the product without affecting important customer interests causing cost reductions and/or reduced effort for both the customer and the contractor.

At the end of the requirements and specifications process, a revised development contract is drawn up which is bindingly defined by both parties and is in line with the adapted target system (Fig. 19.5). Implementation and interpretation of the specifications are specific to the contractor. This means that the specifications are always to be understood in connection with the chosen technical implementation of the contractor as well as his general conditions. A customer can therefore obtain many different system specifications from potential contractors for a single set of requirements specifications. This is common practice in tendering procedures, for example.

19.2.2 Requirement Types

Requirements can be differentiated depending on the associated specification objectives. In principle, requirements can be divided into functional and non-functional requirements. This distinction originates from software development. Functional requirements describe how the product should behave. Non-functional requirements are often cross-functional and describe more precisely in what way and under which conditions the functions are to be fulfilled. Applied to the development of products that contain physically implemented components, functional requirements address higher levels of abstraction of the solution concept than requirements addressing the physical form. The axiomatic design of Suh [Suh-2001] also exclusively distinguishes between functional requirements and non-functional requirements, whereby additional dependencies on external conditions or between system parameters are taken into account. This implements the idea that the development of products is a mere transformation process from the functional space into the physical world, whereby functional requirements are translated into design parameters [TNAV-2018].

Functional requirements play an important role in the design of products with integrated software functionalities that interact with the physical form and/or its environment.

Other types of requirements can be distinguished based on [Baum-2016] using the following criteria:

- **Subject of the requirement**: Distinction between product-specific and product-neutral requirements. Product-neutral requirements must be fulfilled by each product, such as general requirements with regard to assembly, production or approval. Product-specific requirements only apply to the product to be developed.
- **Binding nature of the requirement**: Differentiation between mandatory requirements and wishes, whereby the wishes can additionally be prioritised, i.e., weighted, in different levels (e.g., 1, 2, 3). This enables the comparative evaluation of different solution alternatives with regard to the defined evaluation profile.
- **Criticality of the requirement**: Differentiation of active and passive requirements, depending on the number of interactions with other requirements [EbLi-2010]. Active requirements, which have many interactions with other requirements for a given solution, lead to extensive further changes in the case of a change in requirements due to the propagation effect, which can strongly influence the selected solution concept. In a solution concept, partial solutions in which active requirements are implemented should either be the partial solution related to the requirement must be configurable flexibly to avoid potential changes propagating to other parts of the design.
- **Influence on customer satisfaction**: Differentiation between basic, performance and delighter requirements (see also Fig. 19.11). Unfulfilled basic requirements are exclusion criteria for the purchase or use of the product. Delighter requirements represent a high incentive to buy or use and enable the differentiation of competitive products. Performance requirements increase linear with customer satisfaction.
- **Stakeholder of the requirement**: Differentiation between internal and external stakeholder of the requirements. The assignment of requirements to stakeholders is the prerequisite for their interpretation, prioritisation and, if necessary, adaptation or modification within the negotiation process when compromising between competing objectives during product development.
- **Tolerance range of the requirement**: Differentiation of point requirements, limit requirements and area requirements [Lind-2016]. Point requirements leave no room for manoeuvre; they must be fulfilled precise to their specification point. Limit requirements allow a one-sided deviation from a given requirement parameter, and they are specified to an upper or lower limit (maximum or minimum). Range requirements specify a permitted range of requirement parameters in both directions. Investigating the tolerance range of requirements allows for the definition of a margin for interpretation, prioritisation and adaptation or modification of requirements when compromising on design objectives.

- **Solution fixation of the requirement**: Differentiation of requirements that are solution-neutral, for example, a description of the problem to be avoided or a function to be implemented, or solution-specific, this would be the detailed description of a feature or measure. This is reflected in some approaches to methodological development, in which a distinction is made between properties or functions to be developed in comparison with physically implemented features or design parameters [Suh-2001, Webe-2005].
- **Measurability of the requirement**: Differentiation between qualitative and quantitative requirement characteristics. Qualitatively formulated requirements must always be converted into quantitatively formulated requirements for further use in the development process[2]. If there is no other way of quantification of qualitative requirements such as "the vehicle must look good", customer questionnaires or similar means must be used to allow for statistical evaluation. The measurability of s requirement is a prerequisite for the tracking and evaluation of its implementation and thus indispensable for the assurance of the product's properties.

The requirement types each represent different views of the totality of the requirements derived from the development goals. These differentiation views overlap, some of which are relevant for specific design phases or stakeholders of the development project. Exploring these views can help the team in the development process with various tasks. Examples are to identify room for interpretation, to find definition gaps or to establish evaluation profiles when comparing alternative solutions.

As already shown in the context of axiomatic design [Suh-2001], the consideration of the external conditions under which these requirements are valid is of central importance for the interpretation and implementation of requirements. For example, a statement about the load-carrying capacity or service life of a train is always linked to certain operating conditions and load cases. Or the promise to achieve certain cabin temperatures in a train can only be valid against the background of external climatic conditions, the number of passengers in the passenger compartment and the opening time of the doors due to the routing. In general, the determination or prediction of each product property by means of suitable models, methods and tools is always carried out under the assumption of certain external conditions [VWZH-2018]. Therefore, these boundary conditions must be documented or, if necessary, determined and specified together with the objectives to be achieved and the requirements derived from them.

19.3 Tasks in Dealing with Requirements

In requirements development, the goal is to identify and structure requirements for the product to be developed as comprehensively as possible [Grand-2011]. The starting

[2] Within IDE, the target profile of the attributes contains the qualitative specifications of the customer, while the actual profile of the attributes of the provider is the quantitative response to the target profile (see also Fig. 3.4).

point is the first development phase, the clarification of the development task, when a possibly still vague customer need has to be concretised and its feasibility and implementation effort must be reflected in possible product concepts. In addition, both general and solution-specific conditions must be clarified with the participation of all parties involved. The expertise of the development team is of great importance for this. The requirements must be specified so clearly that their successful implementation at a defined point in time can be established beyond doubt. Due to the further development of the solution and refined knowledge and framework conditions, the requirements development must be pursued throughout the entire project.

A central task when working with requirements is to concretise and track the individual requirements in the course of the project with regard to their implementation (verification and test planning). At this point, it is important to distinguish between verification and validation.

- The task of verification is to track the implementation of each individual requirement and to demonstrate its fulfilment. It must be possible at any time to answer the question as to whether the current product model is suitable for satisfying the requirements known at that time.
- Validation, on the other hand, addresses the question of the extent to which the developed product meets the objectives pursued and, in particular, the customer's requirements. The question of the initial objectives of product development is clarified in product planning, i.e., before the development project is started.

In the course of the elimination of conflicting goals or the progress of knowledge in the course of the development project, new insights are obtained interacting with the initial target system, which then has then to be further developed and adapted in accordance with a procedure agreed with all participants (Fig. 19.6). This may also mean that the question of the validation of development objectives may have to be asked again.

Working with the existing requirements base, also called requirements management, focuses on the data acquisition and maintenance of the requirements base during the entire course of the development project [Pohl-2007]. The aim is to make a documented valid status of the requirements clearly identifiable at all times in

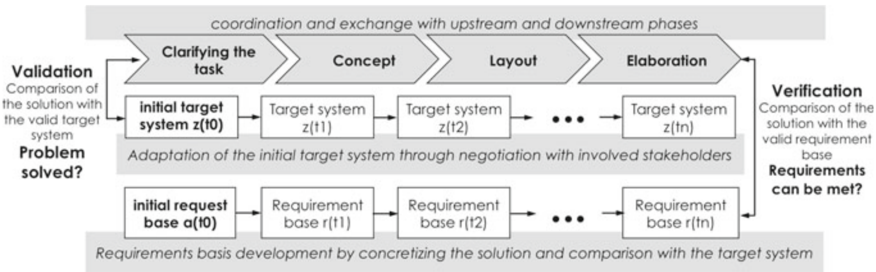

Fig. 19.6 RE—RM—validation and verification within the product development process [BeGe-2020]

the project and to identify and track changes throughout the entire project duration (details can be found in [BeGe-2020]).

Activities in dealing with requirements are generally the responsibility and support of different organisational units within the company. In *requirements development,* the focus is on the professional---usually technical---processing of the development order. These activities are determined by knowledge of existing (predecessor) products, relevant standards and norms, rough ideas about possible concept variants, but also rough initial design estimates. In *requirements management, the* focus is more on specialist knowledge of process flows, data management and IT support through software tools when working with requirements. The *assurance of properties*, i.e., the tracking of the implementation of the requirements, requires a further specific competence profile of the employees and is often represented by domains assigned to testing. Depending on the maturity level of the developed solution, concepts for virtual or physical testing must be found. In the design review, the quality and progress of the developed solution is assessed and compared to the requirements basis.

Regardless of the understanding of the term and its functional assignment in a company, the following basic activities can be distinguished when dealing with requirements [Lind-2016]:

- Elicitate requirements,
- Specify requirements,
- Structure requirements,
- Analyse requirements,
- Document requirements,
- Change requirements,
- Version requirements,
- Trace back requirements and
- Check and communicate requirements.

The focus of the activities in the development of requirements focused here is on the identification and specification of individual requirements as well as the structuring and analysis of the entirety of the requirements [Grand-2011]. Requirements elicitation refer to the completeness of the requirements with regard to the attainability and feasibility of the development goals. Requirements specification means the comprehensible and unambiguous formulation of the requirement, which in addition unquestionably allows an objective assessment of its degree of fulfilment. Requirements structuring addresses the functional assignment of requirements to corporate functions and thus to responsible actors. In addition to completing the requirement base, requirements analysis enables the consistency check of the target system and the resolution of target conflicts.

All activities in dealing with requirements are accompanied by the continuous checking of assumptions made about the problem and solution as well as the validity of the assumed framework conditions. Due to the large number of people involved, the technical and organisational perspectives and the increasing complexity of products to be developed, this places high demands on the design of the requirements management process and the communication between all persons involved. The range of the activities mentioned and the resulting required competence profiles show that cross-functional close cooperation between all organisational units is necessary for the development and work with requirements in order to achieve the development goals. According to EIGNER, requirements development refers to a cooperative, iterative, incremental process for determining, analysing, understanding and defining requirements [EiRZ-2014].

Changes to the requirements base may only be made in agreement with the client or other affected parties, since they can have far-reaching effects not only on the (technical) problem solution, but also on cost and schedule. For example, a minor change from engineering design point of view in the technical specification of a holder for a hose clamp could affect the bundling of purchased parts to achieve large batch sizes, influence the assembly process, change the delivery logistics or even affect the interface to an external engineering consultancy. So this minor technical change has the potential to affect the time schedule, the cost schedule or the scope of delivery and services contractually agreed with the cooperation partner.

19.3.1 Elicitation of Requirements

Based on the development objectives and the development mandate as well as the framework conditions known at that point in time, the initial quality, deadline and cost requirements are determined as clearly and comprehensively as possible. In order to develop an initial requirements base, available sources and documents should always be checked in the initial approach with regard to the representation of relevant requirements. In addition to the development contract or the specifications (see Sect. 19.2.2), this can also include further contractual documents such as performance and delivery plans or minutes of meetings from customer or supplier meetings. From the information available, the first requirements can be derived, which must then be completed iteratively to the initial requirement base with the help of systematic approaches.

Often there is already a comparable predecessor product in the company on whose requirements can be built (adaptation development, change development, product generation development [PaBe-1977, Vajn-1982, AlBW-2015]). In this case, it is important not only to add new requirements, but also to find and question irrelevant requirements for the current development project. The unchecked transfer of "old requirements" into new projects leads to high costs and efforts and can practically not be corrected later due to the complex interaction of requirements and solutions. Therefore, the initial requirements determination is of central importance for every type of development process.

All stakeholders of the product must be taken into account as sources for requirements. In this context, stakeholders are understood to be all stakeholder groups that may have requirements for the product over the entire product life cycle (see Sect. 4.3). Beyond the customer perspective, requirements can stem for example from suppliers, development partners or approval bodies outside the company.

However, the most important source for identifying requirements is the customer. If the product does not meet his essential requirements, does not meet them sufficiently, or does not meet the cost or deadline, the development order cannot be processed successfully. It must be remembered that the customer does not necessarily have to be the user of the product. Nevertheless, the fulfilment of the user's requirements is usually in the high interest of the customer, who translates them into his own requirements and passes them on to the client.

When determining customer requirements, it is important to detect implicit requirements as well. These include, of course, requirements that are expected and therefore not explicitly mentioned or not consciously communicated to the customer or user (cf. Kano model, Fig. 19.11 and Fig. 2.4). Methods for determining implicit requirements, which are often only recognised as not or poorly fulfilled after market entry, are, e.g., benchmarking, complaint systems, use tests, interviews with "lead users" or "focus groups", "lost customer" surveys and win/loss reports [Ahre-2000].

Despite their great importance, no successful product can be developed solely on the basis of customer and user requirements. There are many other requirements and framework conditions that have to be taken into account, which customers and users are not aware of or which do not affect them. Nor is there any direct interest from the customer's point of view in the contractor's compliance with internal plant standards, but for the manufacturer, it is essential for cost reduction and error prevention. Accordingly, the methodical elicitation of requirements beyond customer and user requirements is indispensable (c.f. Sect. 2.2.2).

When searching for relevant requirements for the product to be developed, it is helpful to take different perspectives:

- Product: Which requirements can result from the fulfilment of the specifications regarding performance and performance behaviour of the product? Examples are the transmission of required drive power, compliance with a certain service life or the specification of a data interface.
- Product life cycle (Chap. 2): What requirements can result from the consideration of life cycle phases outside product development, such as manufacturing, assembly, product use, maintenance or recycling? Here, reference is also made to the design guidelines (Chap. 6).
- General rules of design methodology: Do the basic rules of design or the design principles [BeGe-2020] give rise to specific requirements for the problem at hand?
- Stakeholders (Sect. 4.3): Which requirements can arise from the interests of relevant parties involved and affected?
- Competition: Which requirements can be derived from the analysis of competitive products?
- Framework conditions: Which requirements of a technical, organisational or ethical nature can arise from the environment (conditions of use, laws, approval requirements, socio-political concerns, etc., but also objectives for inclusive or sustainable product design)?

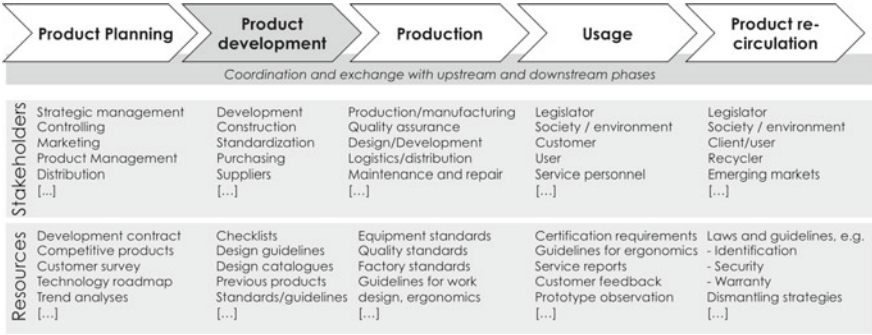

Fig. 19.7 Perspectives for the identification of requirements [BeGe-2020]

These perspectives are not free of overlaps, but should support the mental structuring of the task in the sense of a checklist and can be supplemented product-, company- or individual-specific, Fig. 19.7.

A frequently used checklist is the list of criteria to support the identification of essential and design-determining product requirements (Fig. 19.8). Going through the listed points helps to identify relevant requirements for the development project through associations.

In the following, methods that have proven helpful in practice are presented, which can support the analysis and completion of the requirements base.

19.3.1.1 Questionnaire

The questionnaire is a method for explicitly questioning a large number of stakeholders in order to record and compare their conscious knowledge. The questions contained therein can be closed (questions with different predefined answer options) or open, allowing for individual answers [PoRu-2015]. For the design of a questionnaire, dedicated criteria have to be considered [Pors-2013]. Once a questionnaire has been developed according to these criteria, the requirements of the interviewed stakeholders can be determined quickly. Questionnaires can also be used as a basis or guideline for (standardised) interviews, i.e., in oral form.

19.3.1.2 Benchmarking

Benchmarking refers to the systematic comparison of one's own products or processes with those of other companies. The goal is to orientate towards the most successful competitive solutions in accordance with a "best practice" in order to improve one's own solution [MeKo-2009]. Characteristics and properties of the best

Concept

Material
- Input, raw and finished products:
  - chemical properties
  - physical properties
- Auxiliary materials
- Prescribed materials (food law etc.)
- Material flow and transport

Energy
- Performance
- Loss
- Efficiency
- State variables:
  - Pressure
  - Temperature
- Warming
- Cooling
- Connection energy
- Storage
- Start of work
- Energy Conversion

Signal
- Input and output signals
- Display type
- Control gear
- Monitoring devices
- Signal form

Geometry
- Dimensions / tolerances
- Diameter
- Installation space
- Quantity
- Arrangement
- Connection
- Extension

Mechanics
- Weight
- Load
- Forces:
  - static
  - dynamic
- Friction
- Thermal stress
- Stability
- Strength:
  - Deformation
  - Stiffness
- Kinematics:
  - Movement type and direction
  - Acceleration
  - Speed
- Kinetics:
  - Suspension properties
  - Responses

Electrics / Electronics
- Nominal voltage
- Nominal currents
- Grid fluctuations
- Fuse / safeguarding
- Shielding
- Filtering
- EMC
- Connection
- Wiring
- Isolation
- Air/creep distances
- Connector
- Module order
- Function groups
- SMD components
- Availability of components
- Accessibility
- Exchange

Software
- Integration
- Interfaces
- Updates
- Hardware
- Testability
- Emergency operation

Safety
- Direct safety engineering
- Indirect safety engineering
- Indicative safety engineering
- Operational safety
- Occupational safety
- Environmental Safety
- Risk potential
- Borderline risk
- Risk assessment

Ergonomics
- Human-machine relationship
- Display and controls:
  - Operation
  - Type of operation
  - Clarity
  - Lighting
- Anthropometric dimensions
- Operating forces
- Tactile coding
- Haptics

industrial Design
- Meaning
- Aesthetic functions
- Indicator functions
- Symbol functions
- Product recognition value
- Colour scheme
- Sinus Milieu

Product life cycle phases

Purchasing
- Make-or-buy strategy
- A suppliers
- Local content
- Catalogue assemblies
- Operative / strategic purchasing
- Data exchange

Manufacturing
- Restriction by production site
- largest producible dimension
- preferred manufacturing process
- Manufacturing equipment
- possible quality and tolerances

Control
- Measuring and testing possibility
- Specific regulations (e.g. TÜV, DIN, ISO)

Assembly
- Special mounting instructions
- Assembly
- Installation
- Construction site assembly
- Foundation work
- Tools
- Auxiliary materials
- Safety data sheets

Maintenance
- Maintenance-free or number and time required for maintenance
- Inspection
- Exchange and repair
- Cleaning
- Lubrication
- Place of action

Recycling
- Re-use
- Disposal
- Final disposal
- Removal
- Pollutants and hazardous substances
- Recycling-critical materials
- Accessibility
- Solvability

Transport
- Lifting gear limitations
- Path profile
- Transport routes according to size and weight
- Shipping methods and conditions
- Delivery time

Usage
- Low noise
- Wear rate
- Application and sales area
- Operation environment (e.g. sulphurous atmosphere, tropical...)
- Humidity
- Service

Organisation

Planning
- max. permissible manufacturing costs
- Tool costs
- Investment
- Amortization
- End of development
- Delivery date
- Network for intermediate steps
- Penalties
- Company know-how

Sustainability
- Eco-balance
- Energy efficiency
- System costs

Market
- Competitor
- Customer Segments
- Customer behaviour and needs
- marketable standard
- Sales figures

Fig. 19.8 Checklist for determining requirements [BeGe-2020] competitive products provide requirements for the own development project. With this method, however, there is a risk that hardly any innovation will be promoted by focusing on existing solutions only.

19.3.1.3 Scenario Technique

The development of complex products always takes place iteratively, since in the co-evolution of problem and solution, both can only be further developed together. New insights gained by concretising a partial solution can raise new problems, or conversely, new framework conditions found by concretising can render already established technical solutions obsolete. Furthermore, the development and manufacture of complex products can take a long time, often several years. This means that the requirements for the use of the product to be developed must anticipate customer needs and framework conditions at a much later point in time.

For these reasons, a systematic examination of possible environmental scenarios, technical possibilities, user needs or even legal regulations is essential. A suitable method for this is the scenario technique, which is presented in Chap. 20.

19.3.1.4 Prototype Observation

Requirements can also be determined by observation and analysis of reference products or prototypes. A prototype is understood to be any type of product concept model that can be used to demonstrate the functionality and/or design of the product to be developed. Physical models of the solution concept or existing products, in which a partial solution to be developed, have already been implemented, as well as virtual models of the solution concept, but also integrated model concepts such as hardware or software-in-the-loop are conceivable. In particular, if the customer or other stakeholders lack the professional expertise to formulate their requirements clearly and (not only) technically, prototyping allows for them to describe requirements more precisely and in more detail directly referring to the prototype. In addition, deviations between requirements and implementation (e.g., “over-engineering”) can be avoided through early direct customer involvement. Prototypes have the advantage that they can be tested and thus be experienced by the customer. This allows for additional analysis of how certain groups of people (e.g., older people) interact with the product and what problems might arise.

The use of prototypes allows for testing of product-related services, even before the actual product is finished. Thus, prototyping as a method can be used beyond the requirements determination also for the validation of the solution [Naga-2013]. With the help of augmented reality (also called mixed reality), it is possible to make virtual prototypes that can be experienced with several senses.

19.3.2 Specifying Requirements

Many of the customer's explicit requirements are vague and rather formulated as goals. This means that they must be translated into precise, technical requirements for development. This is the prerequisite to check whether the developed product meets the requirements. For example, the phrase "the vehicle must be technically up to date" would be a formulation whose implementation would be difficult to verify. Neither is it specified to which technical features this requirement refers (e.g., energy consumption, safety, connectivity), nor which concrete values must be achieved under which framework conditions. Conversely, it can happen that the customer already specifies detailed requirements with very specific target values and thus (unknowingly) limits the number of feasible solutions. If a margin of manoeuvre in achieving target values is permissible, the requirement must be specified accordingly, for example by specifying a value range or limit value instead of a fixed-point value (see for example [Lind-2016]).

In general, quality criteria must be adhered to when specifying requirements in order to enable targeted development and reduce costly iterations. The following quality criteria are mentioned in the literature [PoRu-2015]:

- Unambiguous: Without room for interpretation, with marking (e.g., identification number),
- Valid and current: Released, e.g., by review or approved change request,
- Correct: Accurate in content,
- Prioritised: Weighted, at least according to "desired" or "must",
- Realisable: Technically and economically feasible (according to the information available at the time of consideration),
- Traceable: To the party involved, to the solution, in terms of evidence,
- Agreed: Released by all parties involved,
- Verifiable: Testable characteristics by specifying measurable values (e.g., width of 3 m)
- Comprehensible: Clear formulation,
- Complete: Contains all relevant additional information (general conditions).

The adherence to quality criteria is particularly difficult in the early phase, when ambitious goals of stakeholders involved are confronted with a low degree of concretisation of the problem solution and thus encounter a high knowledge and information deficit of the development team. This leads to fundamental contradictions in the specification of requirements, which Eiletz [Eile-1999] formulates as pairs of conflicts:

- Operational versus solution-neutral: The creative freedom to find solutions is severely restricted by too much insistence on unambiguous, detailed requirements.
- Complete, unambiguous versus in time: The definition of a complete target system is accompanied by a high loss of time or is not yet completely possible in early development phases because the necessary knowledge is only gained in the course of development. Assumptions made too early in order to avoid uncertainties in the

development of the problem solution can lead to changes (iterations) that become necessary later (cf. also Sect. 3.2).
- Conflict-free feasible versus ambitious: Conflict-free goals contradict the effort to achieve innovative solutions through ambitious goals. Too high goals, which are impossible to reach, on the other hand, can have a demotivating or even paralysing effect on the developers involved.

Requirements must be specified by measurable quantity values in order to provide a clear and verifiable description. Initially, qualitatively formulated goals such as "The car must look sporty" must be broken down into verifiable characteristics as far as possible. A verifiable characteristic could be the inclination of the A-pillar or the shape of the headlamps on a passenger car. If no such properties can be found to sufficiently quantify the requirement on the basis of measurable properties, customer surveys can be used to assess the implementation of qualitatively formulated requirements. Here, too, it must be determined within the framework of the requirements specification which product properties must be requested from which customers to what extent and how they must be assessed in order to check whether the requirements are fulfilled. If a specification of the requirement by measurable target values is not possible, it must be removed from the target system or reformulated.

When formulating requirements, a description in natural language often leads to different interpretations by different people. Words such as "light" or "rather" cannot be interpreted unambiguously. A large selection of terms to be avoided is given in a guideline of the VDA, the German Association of the Automotive Industry (VDA) [VDA-2006]. It is also recommended to create a glossary of the terms used to avoid terms being interpreted differently [Naga-2013]. In the VDA guideline, it is proposed to formalise the description of requirements. The method uses fixed sentence elements, the order of which can be used flexibly to maintain correct grammar:

- *Subject*: The executing element, such as the system, the sub-system or the user, is described as the subject.
- *Request word*: Request word is an optional sentence element and describes the meaning of a request.
- *Object*: Objects are passive elements that are involved in an action.
- *Action*: The action is described by a verb.
- *Condition*: Condition is an optional sentence element and describes, among other things, temporal aspects, states of the system or the outside world.

Example: The noise of the dishwasher (subject) must not (request word) exceed 70 dBA at a distance of 2 m (action) in the standard room (object).

19.3.3 Structuring Requirements

The requirements base for a product to be developed represents a complex system of interacting individual requirements. They are under the responsibility of different disciplines, often concern different phases of the product life cycle, and their implementation is prioritised differently. Many requirements only arise from the chosen (technical) solution and therefore change dynamically with new findings through the concretisation of the solution, when the framework conditions change or when neighbouring requirements are changed. The target system of a complex product therefore very quickly becomes complex. The systematic implementation and tracking of all requirements in the requirements base therefore calls for a uniform structuring of the requirements. This allows for duplications to be found as well as missing information, but also fosters the identification of contradictions between objectives. For this purpose, the individual requests must be distributed according to technical responsibility to persons who are then responsible for their further processing. Also, tracking the implementation of all requirements is only possible if there is a responsible person in the development team for each requirement.

The number of requirements to be considered for the development of a product can range from a few to several tens of thousands of individual requirements, depending on the complexity of the product to be developed and the framework conditions to be taken into account. In addition, requirements affect decisions or concepts from different specialist disciplines and are therefore usually processed in parallel in different organisational units of a company. It must also be ensured that each request has exactly one responsible processor. Requirements without a responsible person are not systematically followed up during processing or may be neglected completely. In the case of requirements that have several responsible persons, there is a risk of unsolvable conflicts or, in the sense of problem solving, bad compromises between the different technical views of the agents in the case of conflicting objectives.

The structure according to which requirements are distributed to areas of responsibility must allow a clear assignment. For this purpose, it must be possible to assign requirements not only to the physical product itself with its sub-systems, but also to product functions to be fulfilled, process steps to be carried out or general conditions to be considered. For a complex development project, this leads to an extensive outline structure that is similar to a project structure plan. In practice, many companies orientate the structure of their requirements base on existing classification or structuring criteria as represented in sector-typical standards or guidelines and adapted these for their specific purposes. The advantage is the proven consistency of the structure in terms of content and usually agreed and tested with the parties involved, at least at a general level. In addition, the use of standardised structuring criteria enables standardisation usage throughout the company, which is known and familiar to all parties involved. Figure 19.9 shows the so-called requirements breakdown structure for projects in railway technology, which is derived from DIN EN 15380-5 (2014)

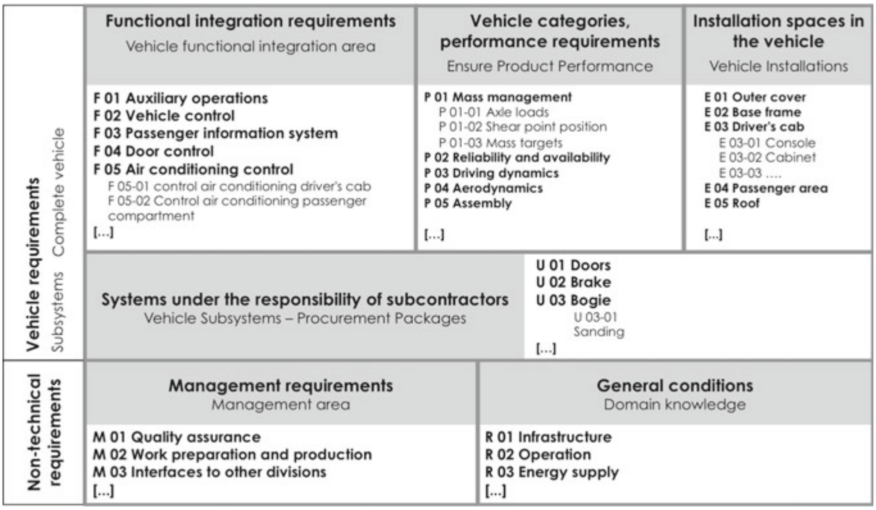

Fig. 19.9 Requirement structuring derived from EN 15380 using the example of railway technology [BeGe-2020]

"railway vehicle identification system"[3] [DIN-15380] that has been adapted for a specific company.

In railway engineering, requirements for a train can be assigned, for example, to the traction system (e.g., overhead line voltage 15 kV), the mechanical support structure (e.g., energy consumption in the event of a crash 650 kJ) or the braking system (e.g., braking deceleration at least 1 m/s^2). On the other hand, there are requirements for which this assignment is not possible without overlap. For the example given in Fig. 19.9, this would be the requirement for a maximum permissible service mass of the train of 120t. This cannot be attributed exclusively to the traction system, the mechanical support structure or the braking system.

All functions work together to transform this requirement into a technical solution to achieve the target value. For the development of the traction and braking system, the service mass is an input variable to be taken into account for the design. The mechanical support structure of the train must be capable of absorbing all the subsystems of the train and the energy to be absorbed in the event of a crash. At the same time, all (partial) systems contribute to the service mass of the train. Nevertheless, there must be one single person responsible for tracking the implementation of and compliance with the requirement and coordinating between the individual processors. In the example, this would mean that the responsibility for maintaining the service mass of the train would be allocated to the so-called mass manager as the main

[3]This document defines the system structure for rail vehicles and their essential characteristics. It also applies to special vehicles such as construction machinery and snow ploughs. The systems frequently used in conjunction with general rail vehicles are included in this document, while the special systems characteristic of their work processes are not covered. They should be added for these individual projects.

responsible person. The tracking of the requirements for the mass of sub-systems such as brake or traction system is delegated to the technically responsible members of the development team. Although they are thus responsible for the mass of their sub-system, the mass manager is responsible for ensuring that the sum of all sub-systems corresponds to the total mass. Also, the mass manager must track cross-system requirements such as the mass distribution in the train and the calculation of the centre of gravity.

A further objective when structuring requirements is to identify their dependencies and hierarchy among each other and make them transparent. This is an important prerequisite for the analysis and traceability of requirements. Traceability of requirements is essential when working with requirements in order to be able to determine where the requirement is originated and which other requirements would be affected if it were changed or conflicted with other requirements. Types of dependencies between requirements can be described using network or graph theory, Fig. 19.10. It should be noted that the dependencies between the requirements might only apply to their concrete implementation in a particular solution concept. For example, the requirement to take VDI 2230 into account for the dimensioning of bolted connections contradicts the requirement to use exclusively non-detachable

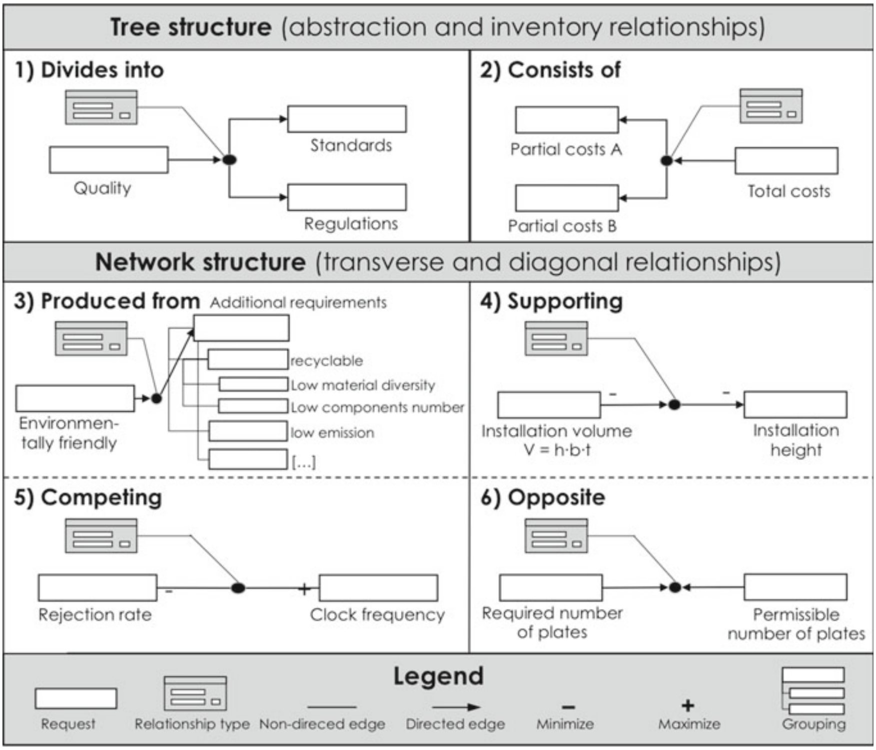

Fig. 19.10 Hierarchy of requirements [Geba-2001]

component connections only, if the selected solution concept requires the use of bolts as connecting elements at all (for example, for assembly reasons). Also, the requirement for a minimum required service life of defined components can only be checked on the basis of concrete design solutions with known load distributions and can turn out to be contradictory or in line with other requirements for different selected solutions in the course of the development process.

The result of structuring the requirements is a requirements base organised according to defined criteria. These criteria can be the technical assignment of the requirements to persons or company divisions. If the requirements are available in a database, this allows the requirements to be filtered according to specific criteria. These may be views of different parties involved, relevance to certain sub-systems or the number of requirements met/not met at a given time, examples are "sub-system view: brake only", "procurement view only" or "unsatisfied requirements only". The structuring of requirements is closely related to the analysis, because the assignment of requirements to a structure often has to be accompanied by an analysis of the contents.

19.3.4 Analysing Requirements

The requirements base represents the working basis of the development team. It also serves as the most important measure of project success, since in the requirements base it is documented if and how each and every requirement is fulfilled. Therefore, the requirement base must be complete, consistent and unambiguous with regard to the requirement parameters to be achieved. The goals of requirements analysis are to complete the requirements base and to identify and resolve conflicts of objectives by prioritising requirements. The result of the analysis is a consistent requirements basis free of contradictions according to the current state of knowledge about the solution and the applicable framework conditions.

A prerequisite for the analysis is the structuring of the requirements and the assignment to responsible persons (Sect. 19.3.3). In a first step, the respective responsible disciplines clarify the content of their initial requirements and check compliance with the quality criteria for the respective requirement specification (see Sect. 19.3.2). In parallel, the processors must complete their part of the requirement base on the basis of technical knowledge and experience derived from predecessor products or with the aid of checklists (see Sect. 19.3.1). Furthermore, it must be checked whether cross-system requirements and interfaces between the sub-systems are sufficiently defined. The responsibility for this lies with the project management or the corresponding cross-sectional functions, for example in engineering.

The identification of conflicting goals is unavoidable when analysing requirements and at the same time represents a central success factor in solving complex problems. On the one hand, competing development goals and framework conditions cause contradictions between requirements for a chosen solution, i.e., improving the fulfilment of one requirement worsens the fulfilment of another requirement or makes its fulfilment completely impossible. On the other hand, non-competing, i.e., jointly realisable requirements regularly lead to conflicts of objectives, too. Due to limited financial, time and technological resources, not all requirements of a development project can be implemented in the best possible way. Finding a compromise or the selection of alternative solutions requires prioritising the requirements among each other.

Therefore, the decision as to which of the competing requirements can, should or must be fulfilled to what extent must be made regularly during the development process. The prioritisation of requirements enables the weighing of different selection criteria and thus represents an important prerequisite for the resolution of conflicting goals. This process affects the target system. If it becomes apparent during the analysis that objectives in the target system cannot be simultaneously (optimally) achieved, for example, due to physical interactions of the selected solutions, the way forward must be clarified in an iteration step with the stakeholders involved. Due to the co-evolution of problem and solution, such conflicting goals are not only identified in the early phase of clarifying the task, but can occur throughout the entire development process. The clarification is therefore often bundled in the context of regular design reviews with the client (and possibly other affected parties).

Criteria for the analysis and prioritisation of requirements can be

- Binding nature of the requirement: Is the fulfilment of the requirement a demand or a wish, also referred to as a mandatory or optional requirement.
- Degree of fulfilment of the requirement (only applies to area requirements), differentiation of point, limit and area requirements [Lind-2016].
- Contribution that the fulfilment of the requirement makes to customer satisfaction: Kano model [Kano-1984], House of quality (within the framework of quality function deployment, QFD, for example [Hehe-2011]).
- Interactions with other requirements: If the fulfilment of a requirement for a chosen solution has positive or negative effects on the accomplish ability or the degree of fulfilment of other requirements, these interact with each other for a given solution. With increasing strength of the interaction, the effects on the overall system increase when the considered requirement does change. This characteristic is therefore called “criticality” (see Sect. 19.2.2 “Types of requirements”). The criticality of requirements can be used to prioritise requirements as well as to design the solution, e.g., to distinguish between basic and adaptive building blocks in modular systems.

19.3.4.1 Kano Model

The model created by Kano structures and categorises requirements in terms of their impact on customer satisfaction [Kano-1984]. Basic requirements are often not explicitly mentioned because they are taken for granted. If they are not fulfilled, this leads to a high level of customer dissatisfaction. Performance requirements, on the other hand, are usually mentioned explicitly and serve as relevant benchmarks for comparison with other competitive products. Their degree of fulfilment has a roughly

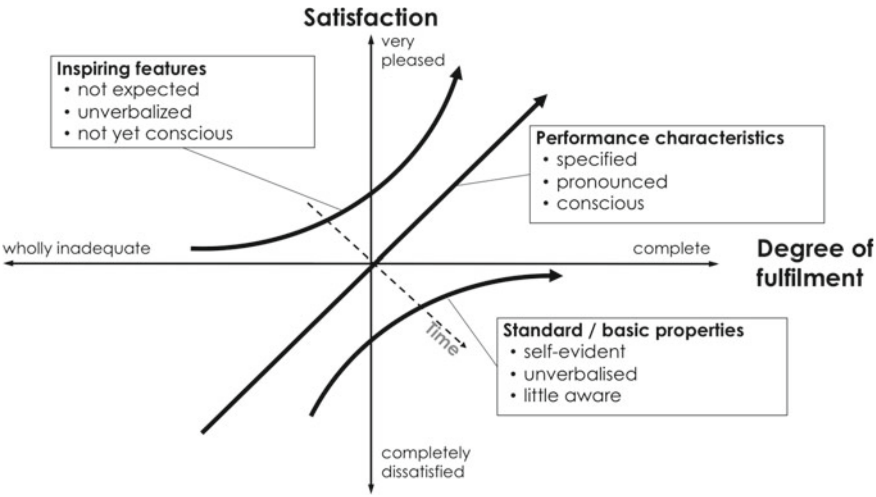

Fig. 19.11 Kano model [Kano-1984]

proportional effect on customer satisfaction. Enthusiasm requirements again include implicit requirements that are not expected by the customer and which, if fulfilled, will increase their satisfaction disproportionately. Therefore, enthusiasm requirements usually lead to differentiation from the competition. However, the influence of time must be taken into account, i.e., requirements that initially excite the customer become performance and finally basic requirements as progress is made, Fig. 19.11.

19.3.4.2 Conjoint Analysis

The conjoint analysis is a method that uses customer evaluation to determine which features and characteristic values of a product are particularly important for customer satisfaction [BaBr-2009]. To do this, the characteristics with differentiated values that are to be queried you first be selected. These are then combined in such a way that a number of product concepts are created in which at least one of the chosen characteristics varies. In total, each characteristic value must occur at least once in any product concept. The task of each customer surveyed is now to rank these product concepts according to their personal preference. The characteristics and their manifestations are thus not examined in isolation, but evaluated in the context of the effects on the customer preference for an overall product concept. Nevertheless, statistical methods can be used to draw conclusions about the significance of individual characteristics and expressions.

References

[Ahre-2000] Ahrens G.: Das Erfassen und Handhaben von Produktanforderungen. Dissertation TU Berlin (2000)

[AlBW-2015] Albers, A., Bursac, N., Wintergerst, E.: Produktgenerationsentwicklung – Bedeutung und Herausforderungen aus einer entwicklungsmethodischen Perspektive. In Stuttgarter Symposium für Produktentwicklung (2015)

[BaBr-2009] Baier, D., Brusch, M. (eds.): Conjointanalyse: Methoden-Anwendungen-Praxisbeispiele. Springer, Berlin (2009)

[Baum-2016] Baumgart, I.: Requirements Engineering. In: Lindemann, U. (Hrsg): Handbuch Produktentwicklung. Hanser München, S. 425–453 (2016)

[BeGe-2020] Bender, B., Gericke, K.: (Herausgeber): Pahl/Beitz Konstruktionslehre, 9th edn. Springer, Berlin (2020)

[Bend-2004] Bender, B.: Erfolgreiche individuelle Vorgehensstrategien in frühen Phasen der Produktent-wicklung. Zugl.: Berlin, Techn. Univ., Diss., 2004. Berlin, Düsseldorf: Techn. Univ; VDI-Verl. (Fortschritt-Berichte VDI Reihe 1, Konstruktionstechnik/Maschinenelemente, 377). Online verfügbar unter. https://edocs.tib.eu/files/e01dd01/476564778.pdf

[DIN-15380] DIN EN 15380-5 Bahnanwendungen – Kennzeichnungssystematik für Schienenfahrzeuge – Teil 5: Systemstruktur (2014)

[DoCr-2001] Dorst, K., Cross, N.: Creativity in the design process: co-evolution of problem-solution. Des. Stud. (5), 425–437 (2001)

[EbLi-2010] Eben, K.G.M., Lindemann, U.: Structural analysis of requirements. Interpretation of structural criterions. In: 12th International Dependency and Structure Modelling Conference DSM '10, S. 249–261 (2010)

[Ehrl-2009] Ehrlenspiel, K.: Integrierte Produktentwicklung: Denkabläufe, Methodeneinsat. Carl Hanser, Zusammenarbeit (2009)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung. 6. Auflage. Hanser München (2017)

[EiRZ-2014] Eigner, M., Roubanov, D., Zafirov, R. (eds.): Modellbasierte virtuelle Produktentwicklung. Springer Vieweg, Berlin (2014)

[Eile-1999] Eiletz, R.: Zielkonfliktmanagement bei der Entwicklung komplexer Produkte - am Beispiel PKW-Entwicklung. Zugl.: München, Techn. Univ., Diss., 1999. Als Ms. gedr. Aachen: Shaker (Reihe Konstruktionstechnik München, 32) (1999)

[Fran-2011] Franke, H.-J. (Hg.): Anforderungsmanagement für kundenindividuelle Produkte. Methodische Lösungsansätze, praxisorientierte Tools, industrielle Anwendungen; Ergebnisse der BMBF-Projekte DIALOG und KOMSOLV. Aachen: Shaker Verl. (Berichte aus dem Maschinenbau) (2011)

[Geba-2001] Gebauer, M.: Kooperative Produktentwicklung auf Basis verteilter Anforderungen, Dissertation Universität Karlsruhe, Shaker Verlag Aachen (2001)

[Grand-2011] Grande, M.: 100 Minuten für Anforderungsmanagement. Kompaktes Wissen nicht nur für Projektleiter und Entwickler; [mit Online-Service]. 1. Aufl. Wiesbaden: Vieweg + Teubner (OnlinePlus) (2011)

[HaSa-1998] Hacker, W., Sachse, P.: Allgemeine Arbeitspsychologie. Huber Bern (1998)

[Hehe-2011] Hehenberger, P.: Computerunterstützte Fertigung – Eine kompakte Einführung. Springer, Heidelberg (2011)

[Kano-1984] Kano, N.: Attractive qualitiy and must-be qualitiy. Hinshitsu (Qual. J. Jpn. Soc. Qual. Control) **14**, 39–48 (1984)

[Lind-2016] Lindemann, U. (Hg.): Handbuch Produktentwicklung. Hanser München (2016)

[MaPB-1996] Maher, M.L, Poon, J., Boulanger, S.: Formalising design exploration as co-evolution. A combined gene approach. In: Advance in Formal Design Methods for CAD (1996)

[MeKo-2009] Mertins, K., Kohl, H.: Benchmarking: Leitfaden für den Vergleich mit den Besten. Symposion Publishing Düsseldorf (2009)

[Naga-2013] Nagarajah, A.: Methodisches Klären und Präzisieren der Aufgabenstellung. In: Jörg Feldhusen (Hg.): Pahl/Beitz Konstruktionslehre. Methoden und Anwendung erfolgreicher Produktentwicklung. Unter Mitarbeit von Gerhard Pahl und Wolfgang Beitz. 8., vollst. überarb. Aufl. Berlin: Springer Vieweg, S. 291–401 (2013)

[PaBe-1977] Pahl, G., Beitz, W.: Konstruktionslehre. Springer, Heidelberg (1977)

[Pohl-2007] Pohl, K.: Requirements Engineering—Grundlagen, Prinzipien. Dpunkt Verlag, Techniken (2007)

[PoRu-2015] Pohl, K., Rupp, C.: Basiswissen requirements engineering. Aus- und Weiterbildung nach IREB-Standard zum Certified Professional for Requirements Engineering Foundation Level. 4. Aufl. dpunkt.verlag Heidelberg (2011)

[Pors-2013] Porst, R.: Fragebogen: Ein Arbeitsbuch. Springer, Berlin (2013)

[RüGS-1997] Rückert, C., Gaedeke, O., Schroda, F.: Wirksamkeit und Erlernbarkeit der Konstruktionsmethodik. Konstruktion **49**(1997), 23–26 (1997)

[Rück-1997] Rückert, C.: Untersuchungen zur Konstruktionsmethodik – Ausbildung und Anwendung. Fortschritt-Berichte VDI, Reihe 1, Nr. 293, Düsseldorf. VDI Verlag (1997)

[Suh-2001] Suh, N.P.: Axiomatic Design. Oxford University Press, Oxford (2001)

[Vajn-1982] Vajna, S.: Rechnerunterstützte Anpassungskonstruktion. Dissertation Universität Karlsruhe 1982. Fortschrittsberichte VDI-Z Nr. 16, VDI-Verlag Düsseldorf (1982)

[VDI-2221/2019] VDI-Richtlinie 2221 Blatt 1: Entwicklung technischer Produkte und Systeme – Modell der Produktentwicklung. VDI, Düsseldorf (2019)

[TNAV-2018] Toepfer, F., Naumann, Th., Anderer, J., Vajna, S.: Integrating the knowledge about functional interdependencies into a parameter-based information flow (Vortrag 222). In: Marjanovic, D., Storga, M., (eds.) Proceedings of DESIGN 2018, Zagreb (2018)

[VDA-2006] VDA 2006, 2003: Geometische Produktspezifikation. Oberflächenbeschaffenheit - Regeln und Verfahren zur Beurteilung der Oberflächenbeschaffenheit. VDA-Verlag (2006)

[VDI-2519] VDI 2519: Vorgehensweise bei der Erstellung von Lasten-/Pflichtenheften. Beuth-Verlag, Berlin (2001)

[VWZH-2018] Vajna, S., Weber, Ch., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S.: CAx für Ingenieure, eine praxisbezogene Einführung (dritte neu bearbeitete Auflage). Springer, Berlin (2018)

[Webe-2005] Weber, C.: CPM/PDD—an extended theoretical approach to modelling products and product development processes. In: Bley, H., Jansen, H., Krause, F.-L., Shpitalni, M. (Hrsg.) 2nd German-Israeli Symposium on Advances in Methods and Systems for Development of Products and Processes, Berlin 2005. Proceedings of the 2nd German-Israeli Symposium, S. 159–179. Fraunhofer-IRB-Verlag, Stuttgart (2005)

Chapter 20
Scenario Technique

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The business opportunity for innovative products lies at the interface of market needs, technological capabilities and the offerings of competitors. The most successful products are those that are not met by the competitors but can be met with technologically mature and viable solutions. Identifying this area of conflict is therefore essential for the success of product development. In order to recognize the right time for a market launch, future developments of markets, technologies and customer needs must be anticipated. Therefore, future scenarios must be created and analyzed. The Scenario-Technique has established itself as a tool for this. Further, it can be used as a tool for anticipating future requirements in product development [Rand-2015, GrPS-2017].

The strategic planning refers back to the original military strategy and implicitly defines scenarios [Reib-1992]:

> The strategy is the use of combat for the purpose of war; it must therefore set a goal for the whole act of war which corresponds to its purpose, i.e. it draws up the plan of war, and to this goal it attaches the series of actions which are to lead to it, i.e. it makes the drafts into the individual campaigns and arranges the individual battles in these. Since all these things can usually only be determined according to conditions which do not apply to all of them, but a lot of other, more detailed determinations cannot be given beforehand, it follows of itself that the strategy must also go into the field in order to arrange the individual on the spot and to make the modifications for the whole which become inaudibly necessary. So it cannot withdraw her hand from the work at any moment. [Clau-1832]

In addition to planning, other aspects of successful strategies can be identified from the military concept of strategy: The on-going review and adjustment of once made assumptions and strategies in response to the changing business environment. In the early 1970s, the military concept of scenarios developed into the first approaches of scenario technology in the context of planning and corporate management. The future scenarios of the Club of Rome ('The Limits to Growth', see [Mead-1974]) are

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the first qualitative future scenarios in this context. In the strategic planning of the mineral oil company Shell, scenarios were incorporated into the strategic planning under Pierre Wack right from the start. Shell was thus able to successfully master the oil price crises of the 1970s [Wack-1985].

20.1 Introduction

The basic assumptions of the Scenario Technique are based on two basic ways of thinking: Systems thinking and multiple futures [GaFS-1996].

1. Systems thinking is based on the basic assumption that influence factors cannot be considered individually when looking at a company but influence each other mutually. A company's complex system is for example characterized by both, the diversity of its activities and by the dynamics of the environment.
2. An exact prediction of the future is difficult, if not impossible, which is why different futures, the multiple futures, are considered. The creativity of foresight is stimulated by the conscious thinking of the unthinkable through as many extreme but conceivable possibilities as possible.

The basic idea of the Scenario Technique can be symbolized by the scenario cone (compare Fig. 20.1) from Reibnitz. While the personal situation and the current state of the influencing environmental factors are largely known, the uncertainty and complexity of a forecast of the future grow exponentially with advancing time

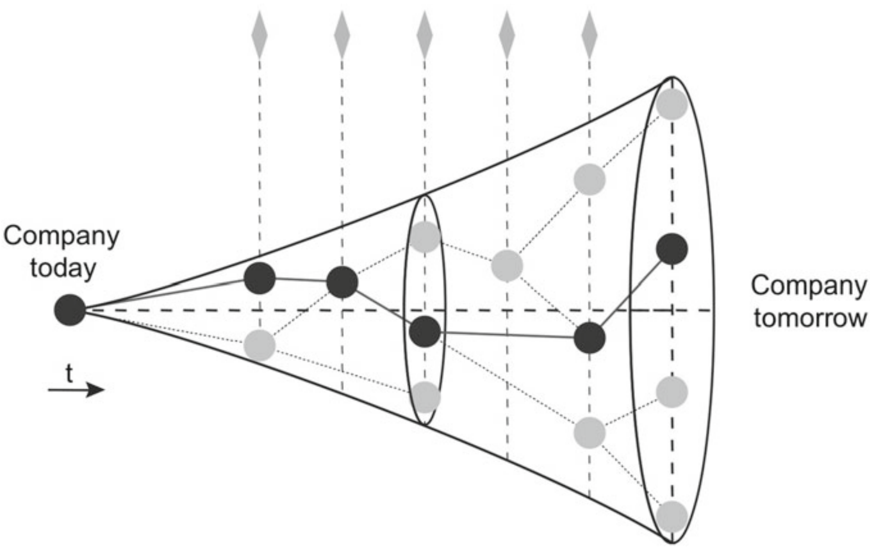

Fig. 20.1 Scenario cone based on [Reib-1992]

horizon. Following the thinking of the multiple futures, different states are conceivable for every factor. The cross-section through the cone at a given point in time represents the quantity of all conceivable states at that time. Such a state is to be understood as a scenario [Reib-1992].

Through disruptive events and decisions, linear development of the actual state is unrealistic. The horizons of three to 20 years [BWBC-2005] thus explicitly extend beyond the frame of strategic goals. For the preparation of scenarios, MIETZNER and REGER specifies the following five criteria, whereby no more than five scenarios are to be selected in total [MiRe-2005]:

- Plausibility: Can the scenario occur?
- Difference: Are the scenarios structurally different?
- Consistency[1]: Is the single scenario contradiction-free?
- Benefits for decision-making: Does the scenario contribute insights for decision-making?
- Challenge: Does the scenario question the company's established view of the future?

Presented below are various approaches to the development of scenarios.

20.2 Scenario Technique Approaches

There is no uniform approach to forecasting using the Scenario Technique. However, the methods can be divided into different schools, which differ from each other both in the way in which the scenario is created and in the type of scenario output.

In this section Intuitive Logics, Cross-Impact, Consistency-Based Approaches and other approaches are presented. The schools follow similar process models. The process model defined by GÖTZE specifies the steps of scenario building without specifying exact methods [Götz-1993] and will, therefore, be used as a framework for the presented methods in the further course, Fig. 20.2.

In particular, the schools presented differ fundamentally in the development of scenarios. Scenario development by intuitive logic methods is purely qualitative and by cross-impact methods purely quantitative. With the consistency-based approaches, the scenarios are generated both quantitatively and qualitatively [AmDJ-2013].

[1] A definition of consistency can be found in Sect. 20.2.3.

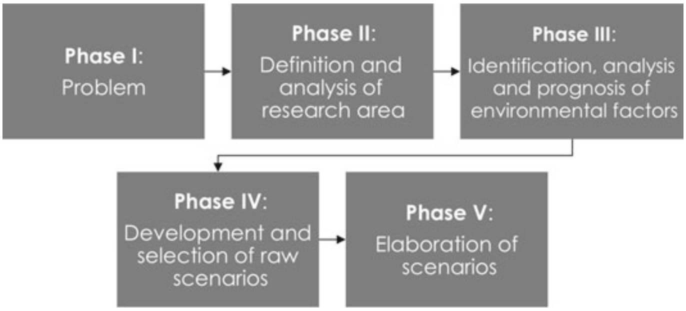

Fig. 20.2 Scenario development phases [Götz-1993]

20.2.1 Intuitive Logics

The intuitive approaches are historically the first approaches for scenario planning. The Intuitive Logics method was developed by Herman KAHN and the RAND Corporation in the 1960s. It was widely used especially in military planning in the USA during the Cold War and into the 1960s [BWBC-2005]. This method became widely known through successful application by the Shell Corporation and is therefore sometimes referred to as the Shell approach [Wack-1985].

The development of scenarios by Intuitive Logics is done on a purely qualitative basis without using mathematical algorithms. The emergence goes back to two basic needs in scenario development by experts: The need to arrive at a resilient and consistent opinion in groups of experts and to create future environments that allow different strategic alternatives and their consequences [BWBC-2005].

This consideration led to the Intuitive Logics School and the Delphi Method for consolidating and bringing together expert opinions. An expert team is put together, questioned and, if necessary, iteratively confronted with the results of the previous round and questioned again (see Fig. 20.3) [Stei-1997].

As a result of the method, the user receives flexible and consistent scenarios in qualitative prose-form, which results in a coherent picture of the future approved by experts. However, the application of the method requires a high level of knowledge, commitment, credibility and communication skills from the team members. The team members come from their own organization, which requires a high level of knowledge about the use of the method within the organization. At the same time, this carries the risk of a limited and prejudiced view of possible future developments. External help can be used in the form of a moderator. However, only generic methods such as brainstorming or stakeholder analysis are needed as tools.

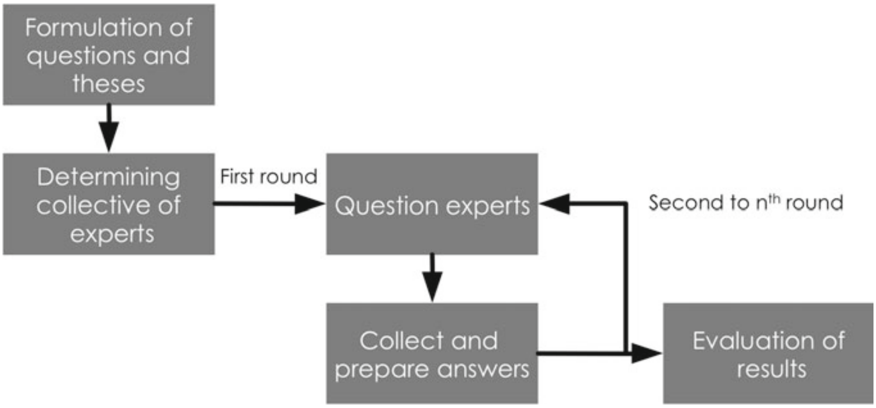

Fig. 20.3 Delphi method

20.2.2 Cross-Impact Analysis

The cross-impact analysis is a probabilistic approach of the Scenario Technique. In order to derive scenarios, the influence factors acting on an object of observation (market, technology, customer needs) are collected. Starting point are the estimated a priori probabilities of future developments ('projections')[2] for the influence factors. Anticipating the projections can be done using creativity techniques or methods such as the Delphi method [Mißl-1993, Götz-2006]. The effects of the occurrence of projections on the probability of the occurrence of other projections are recorded in the cross-impact matrix. The adjusted a posteriori probabilities of the other projections are then calculated on the basis of the cross-impact matrix as a function of the occurrence of the projections [Götz-2006]. The calculation of the a posteriori probabilities is based on the fundamental axioms of KOLMOGOROV'S probability theory[3] (see [Kolm-1977]). On the basis of these axioms, equation systems are defined, which are solved with mathematical algorithms. A scenario contains one projection[4] of each influence factor. As a result of the method, those scenarios are output, from the set of all possibilities, which have the highest total probabilities. The user thus receives scenarios that are as probable as possible. The development is strongly based on mathematical algorithms. In particular, an application without external help is only possible with a great deal of training effort.

[2]The projection of the influence factor 'unemployment rate in Germany' could be, for example, 'the unemployment rate will fall below the value 4%'.

[3]For an exemplary random experiment the probability of all conceivable events together is 1 and the probability of a specific event is between 0 and 1.

[4]Mathematically speaking, a scenario of cross-impact approaches is therefore a bundle of projections.

20.2.3 Consistency-Based Approaches

The consistency-based approaches, as well as the cross-impact analysis, are a model-based approach of the Scenario Technique [Miet-2009]. In contrast to cross-impact analysis, scenario development does not consider the probability of occurrence. Scenario creation is based on the pairwise consistency evaluation of the projections:

> The consistency value represents the extent to which the two assumptions exclude or tolerate each other. [Döni-2009]

Various authors have published different process models for consistency-based scenario development (see [Reib-1992, GaFS-1996, Götz-1993]). These process models have the following steps in common:

1. Analysis of the task of the scenario analysis: assessment of the observation period and objectives
2. Collection of influence factors
3. Evaluation of the interactions of the influence factors in the influence matrix
4. Selection of key factors[5]
5. Derivation of projections for key factors
6. Consistency assessment
7. Scenario building.

The first sub-step corresponds to the process models of the intuitive logic approach (Sect. 20.2.1) and the cross-impact analysis (Sect. 20.2.2). As with the cross-impact analysis, the second step is to collect influence factors for the observation frame. In the third step, these are evaluated for their interactions. In contrast to the cross-impact analysis, however, the interactions of the influence factors are recorded but not the effects of the occurrence of projections on the probability of occurrence of other projections. This influence matrix is the basis for the selection of key factors. These arise on the basis of the active sums from the individual values for the activity (row sum; *How many other influence factors are influenced by an influence factor?*) and the same sum formation in passivity (column sum; *How many other influence factors influence an influence factor?*). Other indicators such as dynamics (product of active and passive sum) or impulsivity (quotient of active and passive sum) can also be used. The selection is then made in the System Grid, in which the active total is plotted as a function of the passive total [GaFS-1996].

Table 20.1 shows an exemplary influence matrix. The entries of the matrix are to be interpreted as follows: Influence of influence factor X (row) on influence factor Y (column), where the scale is defined as follows: 0—no influence; 1—weak influence, 2—strong influence.

The respective sums from the influence matrix are transferred into a System Grid in Fig. 20.4. Within the System Grid, areas are distinguished into active system elements (AS) and passive system elements (PS). The explicit classification is done by comparing the respective sum with the average sum of all influence factors:

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[5] A key factor is therefore a selected influence factor.

Table 20.1 Exemplary representation of an influence matrix

	A	B	C	D	Active Sum
A	–	2	0	2	4
B	1	–	2	1	3
C	0	2	–	1	3
D	0	2	2	–	4
Passive sum	1	6	3	4	

Legend: – (endash): no influence (diagonal entry). 0: No influence. 1: Weak influence. 2: Strong influence

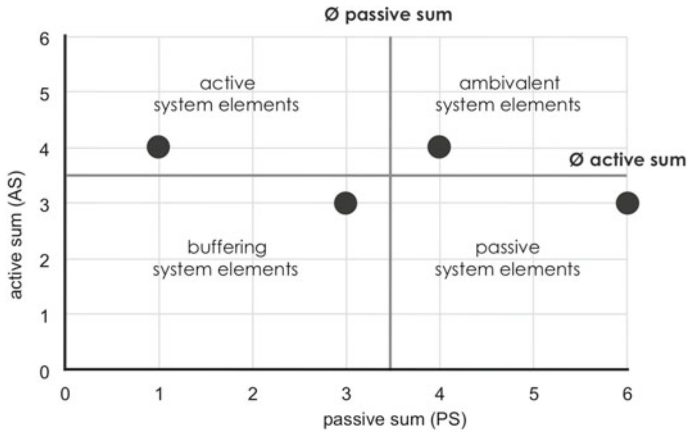

Fig. 20.4 System grid for the influence matrix in Table 20.1

- Active system elements, where AS > ØAS und PS ≤ ØPS
- Ambivalent system elements, where AS > ØAS und PS > ØPS
- Passive system elements, where AS ≤ ØAS und PS > ØPS)
- Buffering system elements, where (AS ≤ ØAS, PS ≤ ØPS).

The heuristic[6] order of the areas corresponds to the prioritization for the selection of the key factors [Reib-1992]. For this selection, indirect influence chains of higher order can be considered in addition to the direct influences. An indirect influence chain of the second order from A to C is, for example, that influence factor A influences influence factor B, which influences influence factor C. Various calculation methods exist for this (see [AGMR-1999, LiFr-2009]). The influence matrices are self-multiplied to calculate the influences of higher order. The MICMAC method according to GODET [AGMR-1999] uses unweighted matrices for this purpose. The information about the strength of the influences is thus lost. In the GODET

[6] Heuristic are procedures that are not mathematically reproducible and which come to a result with only incomplete consideration of the facts.

approach, the influence matrix is multiplied by itself until the prioritization of the influence factors no longer changes. The heuristic procedures according to Reibnitz [Reib-1992] or Gausemeier [GaFS-1996] can be used to determine the sequence. With the AVDIAN method according to Linss and Fried [LiFr-2009], an analogue procedure of multiplying the influence matrix by itself is used, in which, however, the strength of the influences is also considered.

The aim of the method for prioritizing influence factors is to select those key factors from the set of all influence factors that have a significant influence on the field of observation. Projections are derived from these key factors in the following step. The projections represent possible future developments of the key factors. The projections should not be defined one-dimensionally, but multi-dimensionally in order to meet the requirements of the multiple futures. Some authors (among them Reibnitz [Reib-1992] or Götze [Götz-1993]) use additional descriptors (or measurable variables) as indicators for the influence factors.

The projections are then developed for these descriptors. Gausemeier develops the projections directly for the influence factors without the intermediate level of the descriptors [GaFS-1996]. The projections are assessed for consistency in a pairwise manner in the following step. Consistency describes a ‘subjective, ordinal compatibility assessment of the relationship between two variables’ [Mißl-1993]. Dönitz [Döni-2009] uses the more general definition of consistency as a measure for the common occurrence of two projections in a scenario. There are different scales for the consistency assessment [Döni-2009]. For example, Reibnitz uses a scale from 1 to 5 (total inconsistency to very high consistency) [Reib-1992], whereas Gausemeier uses a scale from −2 to +2 with the same characteristics as Reibnitz [GaFS-1996]. An exemplary consistency matrix is shown in Table 20.2.

Scenarios are created on the basis of the consistency matrix. Similar to the scenarios of the cross-impact approach, each scenario contains a projection of each key factor. The following procedures are distinguished [Mißl-1993].

Table 20.2 Example excerpt of a consistency matrix

How consistent is the common occurrence of projection in a common scenario? 1: Total inconsistency … 5: Very high consistency		Influence factor: working environment		
		More home office	Mixture of home office and …	Concentration on fixed workplace
Influence factor: mobility	Better developed local transport network	2	4	5
	More Park and ride solutions	3	4	3
	Private cars only	4	3	3

With the full enumeration[7] all theoretically possible scenarios (also called raw scenarios) are formed and examined. The number of raw scenarios to be created increases exponentially with the number of influence factors. For a scenario project with n key factors each in three projections, the number of raw scenarios to be formed is 3^n. From the total number of scenarios, the scenarios are then filtered according to the consistency, variability and stability criteria [Mißl-1993]. During the first filtering, inconsistent scenarios (consistency value 1) are sorted out. The subsequent selection of scenarios is then based on the consistency sums. The consistency sum is the sum of the consistency values of all projection pairs in a scenario [Mißl-1993]. Subsequent clustering further reduces the number of scenarios. This means that similar influence factors are classified into common groups, so-called clusters. If the number of clusters is given, clusters can be formed using known cluster algorithms, such as k-means, and representatives of these clusters can be determined on the basis of the sum of consistencies [Mißl-1993]. By k-means similarly, large clusters are formed on the basis of the centre of the respective group. GAUSEMEIER et al. use the method of multidimensional scaling to display the scenarios [GaFS-1996].

In the case of partial enumeration, the scenarios are formed successively. Thus, further factors are gradually added from the first key factor and sub-scenarios that do not meet a set criterion are discarded. Such a branch-and-bound algorithm can be found in NITZSCH et al. [NiWW-1985]. GRIENITZ and SCHMIDT use evolutionary algorithms for this purpose [GrSc-2009]. The aim of the partial enumeration is to reduce the complexity of scenario formation by eliminating inconsistent scenarios from the set of raw scenarios at an early stage.

In both the full and partial enumeration, the identified representatives are then presented as selected scenarios and formulated accordingly as prose text [GaFS-1996]. Consequences in the form of opportunities and risks are derived from the scenarios [Reib-1992]. The scenarios are subsequently examined for possible disruptive events. For this purpose, possible disruptive events are collected and evaluated on the basis of their significance and the effects on the scenarios [Reib-1992].

20.2.4 Further Approaches

In addition, there are other, less widespread approaches to foresight. Examples of further methods of scenario development are the Trend Impact Analysis as a combination of two methods, Systems Dynamics as a method of predicting the future and Open Foresight as an example of future methods in the field of Scenario Technique.

- Trend Impact Analysis is a method that combines elements of the cross-impact analysis with those of the intuitive logic. Based on a narrowly defined observation

[7] All conceivable scenarios are written down a priori and only in the next step are some of them discarded.

space, the time series of a few influence factors are extrapolated[8]. The extrapolation is adjusted via probabilities of occurrence in order to obtain a basic scenario with upper and lower limits [Gord-1994].

- By considering the system of scenario analysis as a complex and dynamic system, scenarios can be calculated using the 'Systems Dynamics' methodology defined by Jay FORRESTER. Using the Systems Dynamics methodology, such dynamic systems can be holistically analyzed and simulated [Forr-2017].
- Analogue to Open Innovation, Open Foresight follows the idea of no longer conducting foresight only within the organization. Further developing the idea of networked thinking, DAHEIM and UERZ assume that the boundaries between technology, business, politics and culture are becoming increasingly fluid and that interaction with external parties must, therefore, be sought in the foresight [DaUe-2008].

20.2.5 Discussion of the Approaches

For comparison, the three most widely used approaches Cross-Impact, Intuitive Logics and Consistency-Based Approaches are considered (Sects. 20.2.1–20.2.3). These approaches are applied on an equal level. The choice of an approach must be based on the respective needs and the available resources. The following list—in particular Table 20.3—is intended to serve as a decision-making aid for the selection of one of the methods.

- The intuitive logic approaches (Sect. 20.2.1) use their own resources both in data collection and in team composition. External help can be consulted in the form of moderators. This independence from external resources, however, requires a high level of methodological competence on the part of the team members themselves.
- Cross-impact approaches (Sect. 20.2.2) require little methodological competence on the part of their own employees and only limited personnel resources of their own. On the other hand, there is a high dependency on external knowledge and consultants, who require high financial resources for the assignment. In addition, the probability of occurrence of known and available events is systematically overestimated [TvKa-1973].
- The consistency-based approaches (Sect. 20.2.3), on the other hand, represent a mixture with regard to these aspects. The data collection takes place in expert interviews and workshops in the company's own organization, while the scenarios are calculated using tools from external consultants.

The achievable quality of the results depends on the initial situation of the scenario development. Through the subjective and qualitative inputs, Intuitive Logics generates qualitative scenarios in prose-form. Due to a mixture of qualitative, consistent inputs and quantitative calculations, the results of consistency-based approaches

[8] Extrapolation is the calculation or deductive reasoning of the next value in a data series using the known values of this data series.

Table 20.3 Comparison of the most widespread Scenario Technique schools

	Intuitive logics	Cross-impact	Consistency-based
Methodology	Process-oriented and based on subjective assessment	Results-oriented, objective quantitative and analytical approach on a simulative basis; partly subjective	Results-oriented quantitative and qualitative approach; addition of subjective assessments
Scenario team	Internal scenario team with method competence	External scenario team, supported by expert interviews	Expert-led team, supported by internal experts
External demand	Possible facilitation by external	Scenario calculation and development by external consultants	Facilitation and provision of tools by external consultants
Scenario scope	Global or focused on a specific topic	Focused analysis of events and time series	Global analysis of all influence factors of a narrow field
Analysis of influence factors	Expert interviews and other qualitative methods	Expert interviews on collection and time series analysis to determine the key factors	Expert interviews on the collection and algorithmic determination of key factors
Scenario development	Thematic grouping of scenario logic on a qualitative basis	Monte Carlo simulation to determine the most likely scenario	Consistency evaluation in expert interviews and algorithmic scenario calculation
Selection criteria	Inner consistency, coherence, comprehensibility and novelty	Plausibility and Probability	Inner consistency, coherence and influence
Basis	Subjective (expert) opinions	Expert interviews, time and data series	Expert interviews, time and data series
Results	Multiple equally plausible qualitative prose scenarios	Quantitative basic scenario with upper and lower limits	Multiple, highly diverse, consistent prose scenarios

are quantitative, consistent scenarios in prose-form. Since the input for cross-impact approaches is strictly quantitative and probability-based, probabilistic basic scenarios with upper and lower limits are provided as results of these methods. A complete comparison of the approaches can be found in Table 20.3.

Regardless of the method used, the application of the Scenario Technique for forecasting the future offers considerable potential in corporate management. MIETZNER and REGER identify six method-independent advantages [MiRe-2005]:

- By means of foresight, various equally possible, feasible and desirable future scenarios are shown instead of trying to predict only one scenario as accurately as possible.
- Scenarios challenge people to think about unimaginable possibilities. Thus, fundamental strategic assumptions are reconsidered.
- Users can proactively adjust to new situations by anticipating disruptive events.
- A common communication strategy is promoted by the joint development of scenarios.
- The learning and decision-making process of the organization is improved by aligning strategy, risks and goals during scenario development.
- Scenario development is flexible and can, therefore, be tailored to a specific situation.

On the other hand, there are various weaknesses. MIETZNER and REGER name, in particular, the following four [MiRe-2005]:

- The scenario development is time-consuming.
- The quality of the scenario team required for qualitative scenarios is difficult to meet.
- Since very good knowledge of the observation field is indispensable, the necessary information may not be available or research may be very time-consuming.
- Desired scenarios or extreme scenarios can disturb the focus of the user on the most consistent scenario.

20.3 Agile Approaches

Consistency-based process models are particularly suitable for widespread corporate use. On the one hand, the high formalization of consistency-based process models offers an inexperienced user a high degree of support through the division into sub-steps. For these sub-steps, rules can be defined for the selection or development of scenarios. These rules can be formalized, which in turn supports inexperienced users. This structured approach is better suited for methodologically inexperienced users than the more unstructured approaches of Intuitive Logics [PoSG-2017]. Compared to the cross-impact approaches, bias phenomena[9] have a much smaller influence in the consistency-based approaches, since the estimation of probabilities is disregarded. These bias phenomena[10] occur in the cross-impact approaches mainly in the estimation of conditional probabilities (see [GrSc-2009]). Due to the bias phenomenon, the users estimate in particular conditional probabilities of an event higher than they are in reality [TvKa-1973]. A methodically structured approach based on consistency-based approaches meets the demand for learning, decision

[9] A distorted assessment of the event to be valued.

[10] For example, a user estimates the probability of winning the lottery to be higher if he knows someone who has won the main lottery prize.

and communication support (see Sect. 20.2.5) without claiming accuracy by using probabilities.

The main requirements are a reduction in the effort involved in creating the scenarios, a reduction in the dependency of the quality of the results on expert knowledge, an increase in the intuitiveness of the resulting scenarios, and (partially) automated scenario development.

20.3.1 Procedure Model for Agile Strategic Planning

Due to the potential, especially for inexperienced users, the agile process model for strategic planning by means of Scenario Techniques according to GRÄßLER and SCHOLLE is based on the consistency-based approaches (see [GrPS-2017]). The process model enables an iterative and agile[11] approach. The basic logic of the process model is based on the approach according to REIBNITZ as the first description of the consistency-based process models [Reib-1992].

The procedure for agile strategic planning using the Scenario Technique consists of seven process steps that, after initial sequential execution of the steps, are run through iteratively depending on the changes in the framework conditions in the meantime, Fig. 20.5:

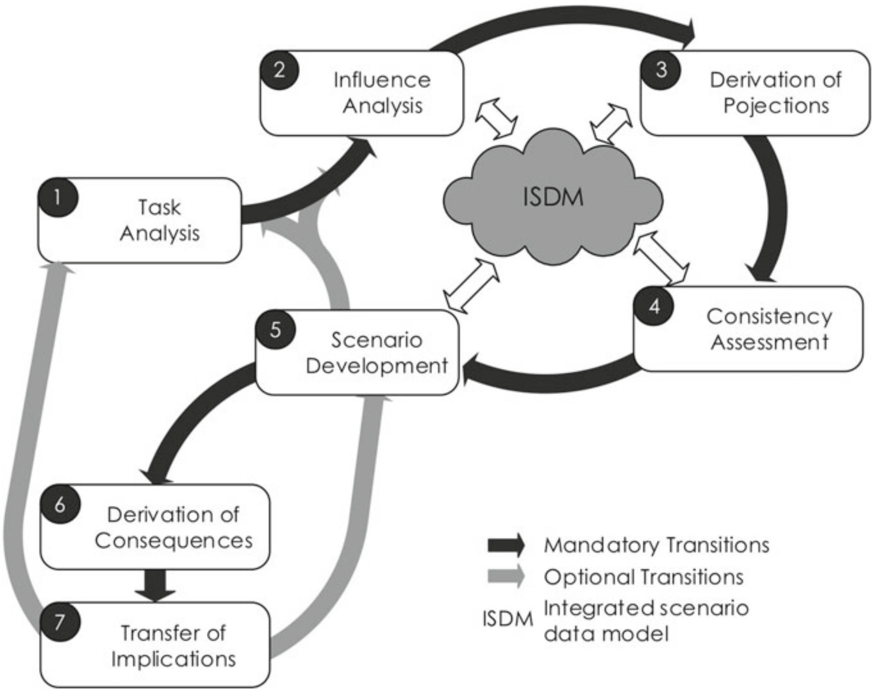

Fig. 20.5 Procedure model for agile strategic planning [GrPS-2017]

[11] https://agilemanifesto.org.

1. Task analysis: The goal and the time horizon of the scenario are defined in this step (see step 1 in Sect. 20.2.3). The cross-project influence factors are selected from the Integrated Scenario Data Model by GRÄßLER and POTTEBAUM (ISDM; see Sect. 20.2.3). These cross-project influence factors form a comprehensive database of all scenario projects in a topic area. If necessary, the cross-project influence factors are augmented by project-specific influence factors, which are then also mapped in the ISDM.
2. Impact analysis: The effective relationships between the influence factors are evaluated in an influence matrix (see steps 2–4 in Sect. 20.2.3). For the cross-project influence factors, an evaluation of the effect relationships is stored in the ISDM. This must be performed by the user for the project-specific influence factors. This data is then supplemented in the ISDM in order to achieve synergy effects with regard to the complexity of the influence analysis. The key factors are selected on the basis of a modified System Grid logic according to REIBNITZ [Reib-1992]. In addition, the relative weighting of the influence factors is integrated into the analysis. The ISDM contains transparent selection rules that reduce the dependence on the experience of the user. The results are the key factors as a subset of the influence factors. Key factors are those influence factors that have a significant influence on the future development of the field of observation.
3. Derivation of projections: For all key factors, development directions ('projections') are derived. These projections are possible future developments of the key factors. In the sense of a 'multiple future', these are to be designed openly, i.e. even with seemingly clear development directions (an obvious further increase of a key factor in the future), opposing developments (the decrease of which is considered unlikely)[12] are to be included as possible development directions. In ISDM, the projections of the cross-project influencing factors are instantiated. In addition, the projections are linked with relevant data from statistical databases[13]. The user derives the projections for the project-specific influence factors. Starting from the cross-project influence factors, a (partial) automation of subsequent process steps is possible (see step 5 in Sect. 20.2.3).
4. Consistency evaluation: The projections of the key factors developed in step 3 are evaluated in a pairwise manner with regard to consistency (see step 6 in Sect. 20.2.3). The interval for consistency evaluation in the consistency matrix is $[1, 5]$, where the value 1 corresponds to a total inconsistency. A joint occurrence of both projections in one scenario is then inconsistent and cannot occur. A value of 5 corresponds to a very high consistency. For the cross-project influence factors, the consistency evaluations are already stored in the ISDM; for the additional project-specific influence factors, the evaluations must, therefore, be carried out additionally. The user is supported by a partially automated consistency evaluation. Based on already estimated consistency values, missing consistency values

[12]Consider for example the gross domestic product. Over a 10-year horizon, this is very likely to rise. Nevertheless, further/other development opportunities must be considered.

[13]For example statista, https://de.statista.com.

are suggested to the user in order to reduce the effort of the consistency estimation. These consistency values are then stored in the ISDM in order to re-use them as proposed values in the following scenario projects.

5. Scenario development: All possible projection bundles are combined into raw scenarios. The selection rules defined in the ISDM directly reduce the number of projection bundles. First, those scenarios are eliminated which shows one or more total inconsistencies. The scenarios are then examined for their differences. The difference between the two scenarios is determined by the number of different projections. Clusters are then formed on the basis of consistency and difference. The aim is to select the most consistent and different scenarios possible as representatives. By means of a sensitivity analysis[14], possible stability of the scenarios can be integrated into the analysis. The result is a small number of scenarios (usually two to five; see step 7 in Sect. 20.2.3).
6. Derivation of consequences: Based on the scenarios developed in step 5, measures and consequences are now derived in step 6. This also includes the evaluation of possible disruptive events (see [Reib-1992]). The assumptions once made can be adapted for the selection of key factors and their projections as well as for scenario formation. An adjustment can neither be exploratory before (proactive) nor after the occurrence of a disruptive event (reactive). Within the framework of exploratory proactive adaptation, influence factors can be subsequently defined by the user as key factors. The effects on the selected scenarios are then presented to the user as part of a sensitivity analysis (see [Reib-1992]).
7. Transfer: Risks and reaction strategies are derived from the results and possible disruptive events are discussed. In addition, the premises previously made are adjusted. For example, additional key factors may be added or irrelevant factors may be dropped. The goal and time horizon of the scenarios are adjusted as required. This may result in changes to the selection rules in phases 2–5. In the selection of key factors, for example, if the time horizon is shorter, you should focus more on activity than on the passivity of the influencing factors (see [Reib-1992]).

The steps 1–7 are completed in a first pass (‘necessary transitions’ in Fig. 20.5). In the further course of strategic planning, optional transitions make it possible to vary and adjust assumptions once they have been made. In this way, the selection of key factors can be changed retrospectively on the basis of current developments. In this way, the previously generated scenarios are tested for sensitivity. This is the interactivity of the procedure model according to GRÄßLER and SCHOLLE. The relationships between assumptions made and their effects on the scenarios thus become transparent and comprehensible for the users. Analogue to agile engineering projects, changes in business and social conditions can be quickly reacted to, rescheduled and re-prioritized. This is the agility of this process model.

[14] Analysis for sensitivity of results to changes in data input.

These adjustments require a minimum of effort to change the scenarios. In particular, the adaptation of the influence factors must not require a completely new process run. For this purpose, the agile process model is supported by the Integrated Scenario Data Model (ISDM).

20.3.2 Integrated Scenario Data Model (ISDM)

The Integrated Scenario Data Model (ISDM) by GRÄßLER and POTTEBAUM provides the database for the approach to agile strategic planning [GrPS-2017, PoGr-2016]. The structure of the model is shown in Fig. 20.6.

The data required and generated in the individual steps of the agile strategic planning process are stored in the scenario data model. Within this database, there are various possible goals and tasks of scenario formation (step 1), influence factors (step 2), their interactions and selection rules (step 3), associated projections (step 4) as well as formation rules for scenarios (step 5) and possible reaction strategies or actions (step 6). These are linked to each other and to external data sources via a

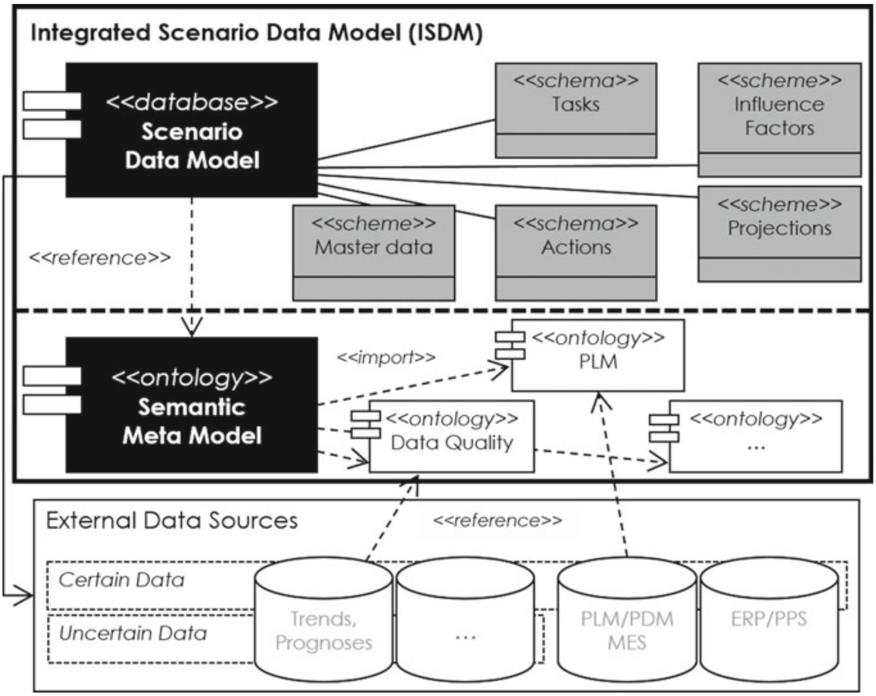

Fig. 20.6 Basic structure of the ISDM (see [PoGr-2016])

semantic meta-model modelled in Web Ontology Language (OWL)[15]. This allows meta-information such as data quality or about the data sources to be included in the analysis.

Via the semantic meta-model, external data sources such as statistical databases, trend forecasts, but also company-internal data sources such as enterprise resource planning (ERP) or product data management systems (PDM) are linked to the ISDM. The integration of external data sources provides the user with additional information along with the process model. For example, past developments are available in the form of statistics for an influence factor, which can be used to derive projections. Using statistical test procedures and parameters such as the correlation or cross-correlation between two data time series of influence factors, the values of the influence matrix can be determined semi-automatically. Initial projections can be derived from the historical data, which can then be supplemented by further projections (in the sense of the multiple futures).

By modelling and storing the data sets required and generated for the iterative procedure of the agile process model for strategic planning, the dependency of the quality of the results on the methodological expertise of the users can be reduced. The influence of heuristic selection rules on the quality of results is reduced by the formalized, parameterized selection rules stored in the ISDM. At the same time, the effort required to carry out the Scenario Technique is reduced by automatically integrating external data sources.

20.4 Case Study

This section explains the approach to agile strategic planning according to GRÄßLER and SCHOLLE using a case study from an automotive supplier. Based on general information on the case study (Sect. 20.4.1), Sect. 20.4.2 describes the individual steps in the process model including the resulting scenarios.

20.4.1 Background of the Case Study

Due to the shift in mobility, social trends towards urbanization, political influences and climate change, the automotive industry is confronted with extensive challenges [BFHR-2018]. This case study examines a fictitious German automotive supplier (Tier 1) in the automotive industry. The company aims at technology leadership according to PORTER [Port-2004]. For this reason, future scenarios are to be developed as a starting point for strategic planning. This is how the company wants to proactively meet the challenges. The target object of the scenarios is the future of mobility.

[15] http://vowl.visualdataweb.org/.

20.4.2 Strategic Planning with the Agile Process Model

Scenarios are created according to the agile process model for strategic planning. The contents of the individual steps are described in the following sections.

20.4.2.1 Step 1: Task Analysis

The scenarios should be the starting point for the medium- and long-term corporate and technological strategies. The time horizon is set at 5–10 years. Core of the targeted future mobility solutions should be technological leadership. For this reason, the future of mobility is chosen as the target object of consideration within the scenarios.

20.4.2.2 Step 2: Influence Analysis

In the influence analysis, six areas of influence are at first defined:

- Technology (e.g. new registrations of hybrid and electric cars)
- Sales market and customer (e.g. German trust in car brands)
- Political and legal framework (e.g. proportional investments in the road network)
- Competition (e.g. development of sales figures for bicycles in Germany)
- Environment (e.g. number of passengers on public transport)
- Company (e.g. value-added of the company per employee).

The influence factors are then collected within these areas of influence. For the area of influence 'Technology', the influence factors are listed in Table 20.4. These are stored in the ISDM and linked to corresponding data sources and statistics. The respective sources of the influence factors, which are linked in the ISDM as well as keywords for classification are shown in the last two columns of Table 20.4.

A total of 69 influencing factors from all six areas of influence are collected. The influence factors are now evaluated in pairs with regard to their mutual influence. An extract from the interactions is shown in the following influence matrix (Table 20.5). The numbers A1 … A10 contained therein correspond to the respective numbers of the influencing factors in Table 20.4.

The influence factors are analyzed and weighted in a pairwise comparison. An extract from the prioritized interactions of the 'Political and legal framework conditions' sphere of influence is shown in Table 20.6. Due to the chosen time horizon, short and medium-term aspects such as subsidies for companies as well as legal aspects such as potential changes in vehicle tax or a legally prescribed warranty period are given lower priority than long-term influence factors. These include, for example, investments in infrastructure both by competing mobility providers and for electromobility. Future framework conditions for working time models, which directly influence the availability of skilled workers, are also given high priority.

Table 20.4 Influence factors, projections and data sources of the 'technology' area of influence

Influence factor	Descriptor	Projections	Projection no.	Source	Keywords
Digitalization	Business potential through the digitalization of automobiles	Business potential declines	A1.1	Statista	Digitalization automobile
		Business potential remains unchanged	A1.2		
		Business potential increases	A1.3		
Development of e-mobility	New registrations with hybrid or electric drive in Germany per year	Number declines	A2.1	Traffic in numbers	Number of new registrations
		Number remains unchanged	A2.2		
		Number increases	A2.3		
R&D expenditure	Research budgets of automobile manufacturers per year	R&D budget declines	A3.1	Statista	Automotive R&D budget
		R&D budget remains unchanged	A3.2		
		R&D budget increases	A3.3		
Number of innovations	Number of innovations generated by the automotive industry	Number declines	A4.1	Statista	Innovations automobiles
		Number remains unchanged	A4.2		
		Number increases	A4.3		
Production volume gasoline cars	New registrations with gasoline engine in Germany per year	Number declines	A5.1	Federal Motor Transport Authority	New registrations automotive fuel types
		Number remains unchanged	A5.2		

(continued)

Table 20.4 (continued)

Influence factor	Descriptor	Projections	Projection no.	Source	Keywords
		Number increases	A5.3		
Production volume diesel cars	New registrations of diesel engines in Germany per year	Number declines	A6.1	Federal motor transport authority	New registrations automotive fuel types
		Number remains unchanged	A6.2		
		Number increases	A6.3		
Efficiency increase of processes	Share of cost reduction in automotive engineering through process innovations	Share of innovations declines	A7.1	Statista	Innovations automobiles cost
		Share of innovations remains unchanged	A7.2		
		Share of innovations increases	A7.3		
Standardization of components	Percentage of cross-variant component modules	Share of modules declines	A8.1	Automotive management	Modularization in automotive engineering

(continued)

Table 20.4 (continued)

Influence factor	Descriptor	Projections	Projection no.	Source	Keywords
		Share of modules remains unchanged	A8.2		
		Share of modules increases	A8.3		
Industry 4.0	Density of robots in companies on the number of employees	Density of robots declines	A9.1	Statista	Industry 4.0 automobile
		Density of robots remains unchanged	A9.2		
		Density of robots increases	A9.3		
Information and network technology	Share of vehicles with internet connection	Share of automobiles declines	A10.1	Digitalization within the automotive industry	Digitalization automobile
		Share of automobiles remains unchanged	A10.2		
		Share of automobiles increases	A10.3		

Table 20.5 Extract of the influence matrix

		Technology										A	B	C	D	E	F	
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	∑	∑	∑	∑	∑	∑	Active
Technology	A1		0	1	0	1	1	0	0	0	2	5	7	1	8	2	5	28
	A2	2		1	0	2	2	0	0	0	1	8	11	10	8	6	7	50
	A3	2	2		2	0	0	2	2	2	2	14	9	1	10	2	9	45
	A4	2	2	2		0	0	2	0	0	1	9	10	6	9	4	6	44
	A5	2	1	2	0		2	0	1	1	0	9	6	8	8	9	7	47
	A6	2	1	2	0	2		0	1	1	0	9	6	8	8	9	7	47
	A7	0	0	0	0	0	0		0	0	0	0	2	2	6	2	6	18
	A8	1	1	0	0	0	0	0		2	0	4	6	0	5	0	5	20
	A9	0	0	1	0	0	0	1	0		0	2	4	5	4	3	12	30
	A10	2	0	1	1	0	0	0	0	0		4	7	1	6	3	3	24
A	Passive	13	7	10	3	5	5	5	4	6	6							
Sales market/customer	B1	1	2	0	0	1	1	0	0	0	0	5	8	0	9	4	1	27
	B2	2	0	1	0	0	0	0	2	2	0	7	7	2	12	3	6	37
	B3	0	1	2	0	1	1	0	0	1	0	6	8	4	10	1	4	33
	B4	2	2	1	1	0	0	0	0	0	2	8	9	6	11	4	5	43
	B5	2	1	2	0	0	0	0	0	2	0	7	2	7	6	4	6	32
	B6	0	2	0	0	2	2	0	1	2	0	9	3	8	9	6	6	41
	B7	2	2	0	1	0	0	0	0	0	2	7	11	2	2	4	2	28
	B8	0	2	0	0	2	2	0	0	0	0	6	7	1	8	2	1	25
	B9	0	2	2	1	2	2	0	0	0	0	9	11	5	11	4	9	49

(continued)

Table 20.5 (continued)

		Technology										A	B	C	D	E	F	
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	∑	∑	∑	∑	∑	∑	Active
	B10	0	2	1	1	0	0	0	0	0	0	4	3	6	6	0	5	24
	B11	2	2	1	1	2	2	0	0	0	2	12	9	5	12	8	4	50
B	∑	11	18	10	5	10	10	0	3	7	6							
C	∑	7	12	9	4	9	9	1	1	4	2							
D	∑	10	12	11	2	11	11	1	4	4	2							
E	∑	7	14	7	4	13	13	1	0	5	7							
F	∑	8	2	11	6	0	0	6	3	8	0							
	Passive	56	65	58	24	48	48	14	15	34	23							

Table 20.6 Pairwise comparison of the influence factors of the sphere of influence 'political and legal framework'

	To relative importance	Employment models of the future	Amendment of vehicle taxes	Regulation CO_2 emissions	Infrastructure	Subsidies for companies	Guarantee period	Investments in cycle paths	Investments in cycle paths	Investments in the rail network	Charging stations for electric cars
Of relative importance		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Employment models of the future	C1	1	0.25	0.125	0.5	1	0.25	0.25	1	1	2
Amendment of vehicle taxes	C2	4	1	0.5	2	4	1	1	4	4	8
Regulation CO_2 emissions	C3	8	2	1	4	8	2	2	8	8	16
Infrastructure	C4	2	0.5	0.25	1	2	0.5	0.5	2	2	4
Subsidies for companies	C5	1	0.25	0.125	0.5	1	0.25	0.25	1	1	2
Guarantee period	C6	4	1	0.5	2	4	1	1	4	4	8

(continued)

Table 20.6 (continued)

	To relative importance	Employment models of the future	Amendment of vehicle taxes	Regulation CO_2 emissions	Infrastructure	Subsidies for companies	Guarantee period	Investments in cycle paths	Investments in cycle paths	Investments in the rail network	Charging stations for electric cars
Of relative importance		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Subsidies for alternative energies	C7	4	1	0.5	2	4	1	1	4	4	8
Investments in cycle paths	C8	1	0.25	0.125	0.5	1	0.25	0.25	1	1	2
Investments in the rail network	C9	1	0.25	0.125	0.5	1	0.25	0.25	1	1	2
Charging stations for electric cars	C10	0.5	0.125	0.06	0.25	0.5	0.125	0.125	0.5	0.5	1
SUMME		26.5	26.5	6.625	3.31	13.25	26.5	6.625	6.625	26.5	26.5

8: Column entry 8 times more important than row entry
1: Column entry as important as row entry
0.125: Column entry 0.125 times more important than row entry
…: Column entry … times more important than row entry

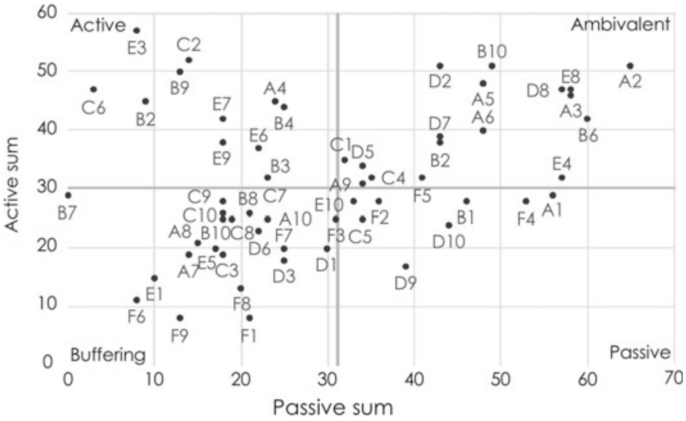

Fig. 20.7 System grid for determining key factors

Based on the influence matrix and the weighting, the key factors are selected in the following step. In addition to the System Grid, the key factors are also selected based on the weighting [Grie-2004]. The System Grid is shown in Fig. 20.7.

For further consideration, the eleven key factors with a high active sum of assets and a low passive sum are first selected. These represent the main drivers for future development. The key factors are then sorted according to the distance between the main diagonals in the respective fields and the weighting (see Fig. 20.7). This results in the following order of the key factors as active elements (top left in the System Grid):

- Share of urban population in total population (E3)
- Warranty period required by law (C6)
- Environmental awareness of customers (B9)
- Tax burden per litre of diesel and gasoline (C2)
- Number of innovations generated by the automotive industry (A4)
- Willingness of customers to possess new technologies in their vehicles (B4)
- Development of real wages compared to the previous year (E7)
- Cost of living (E9)
- Percentage of employed persons among the labour force (E6)
- Recall quantity of vehicles in Germany (B3).

The influence factors in the ambivalent (top right), passive (bottom right) or non-ambivalent range (bottom left) are not selected. Nevertheless, the data of all project-specific influence factors are stored in the ISDM and can be consulted for a later sensitivity analysis.

20.4.2.3 Step 3: Derivation of Projections

Projections are now determined for the key factors. Like the influence matrix, these are completely stored in the ISDM and linked to associated statistics via the semantic meta-model. The projections can be taken from Table 20.4.

20.4.2.4 Step 4: Consistency Analysis

Building on the key factors and their projections, this step assesses the consistency of the projections in pairs using the scale presented in Sect. 20.2.3. The first projections always represent a decrease, the last projections an increase of the key factor. An extract from the consistency matrix is shown in Table 20.7. In the case of the influence factors A4 'Number of innovations generated by the automotive industry' and B4 'Willingness of customers to possess new technologies in their vehicles' the simultaneous increase or decrease in the form of projections A4.1 and B4.1 or A4.3

Table 20.7 Extract from the consistency matrix

		A4			B4			C2			E2		
		A4.1	A4.2	A4.3	B4.1	B4.2	B4.3	C2.1	C2.2	C2.3	E2.1	E2.2	E2.3
A4	A4.1												
	A4.2												
	A4.3												
B4	B4.1	5	3	1									
	B4.2	2	4	2									
	B4.3	1	3	5									
C2	C2.1	2	3	4	3	3	3						
	C2.2	3	3	3	3	3	3						
	C2.3	4	3	2	3	3	3						
E2	E2.1	4	3	2	4	2	2	5	1	1			
	E2.2	3	4	3	3	4	3	1	5	1			
	E2.3	2	3	4	2	3	4	1	1	5			
E3	E3.1	2	3	4	4	3	2	2	3	4	3	3	3
	E3.2	3	4	3	3	3	3	3	3	3	3	3	3
	E3.3	4	3	2	2	2	4	4	3	2	3	3	3

1: total inconsistency
2: partial inconsistency
3: neutral
4: weak consistency
5: strong consistency

and B4.3 is evaluated as consistent, whereas the combination of an increasing projection with a decreasing projection (A4.1 and E2.3 or A4.3 and E2.1) is evaluated as inconsistent.

20.4.2.5 Step 5: Scenario Development

The ten key factors, each with three projections, and the eleventh key factor, each with two projections, give a total of:

$$3^{10} \times 2^{1} = 118.098$$

raw scenarios. This is used to select the scenarios after the cluster analysis. The distribution of the consistency sum in the case study is shown in Fig. 20.8. The consistency sum of the scenarios is normally distributed. The majority of the scenarios have a consistency sum between 150 and 175. For the user, the scenarios that are most relevant in the following are those that have a very high consistency sum (>170), since after the following reduction only scenarios with a very high overall consistency are considered.

In the next step, the diversity of the scenarios is evaluated. For this purpose, the different projections in the raw scenarios are determined and used as a starting point for the distance matrix. If two raw scenarios differ in exactly two projections (for example, for the key factors A4 and B2), a distance measure of 2 is assumed. The difference between the two scenarios is thus recorded in an evaluable manner. Both the consistency sum and the distance matrix are then input parameters for cluster analysis. Conventional algorithms such as k-Means [Stei-1951] or linkage methods are used. The number of clusters is specified by the user. In the case study, three scenarios from the set of raw scenarios are considered.

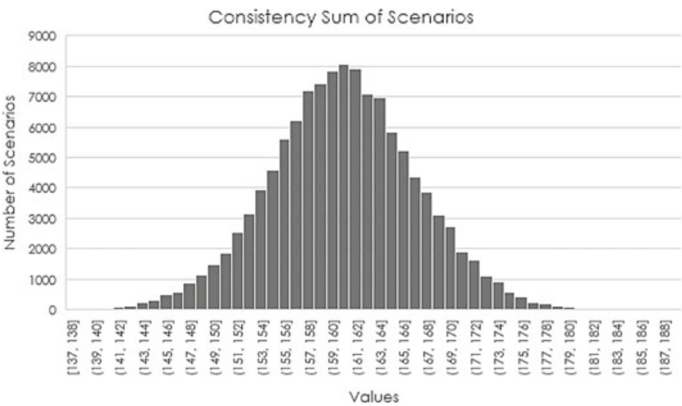

Fig. 20.8 Distribution of consistency sums

Table 20.8 Projections of the scenario with the highest consistency sum

Projection number	Projection
A4.1	Number of innovations on the rise
B3.3	Complaint rate per vehicle increases
B4.2	Customers want new technologies
B9.3	Increasing environmental awareness among customers
C2.1	Tax burden on petrol and diesel increasing
C6.1	Warranty obligation increases to more than 2 years
E2.1	Fuel costs rising
E3.3	Proportion of urban population increasing
E6.1	Percentage of employed persons rising
E7.3	Real wages increase
E9.1	Cost of living rising

20.4.2.6 Step 6: Derivation of Consequences and Step 7: Scenario Transfer

In the following steps, the scenario with the highest consistency sum of the three selected scenarios is now considered. The selected projections are shown in Table 20.8.

In the following, the projections are formulated as prose text to increase comprehensibility and acceptance by the user. From this scenario, consequences for strategic planning can now be derived. For example, the company must prepare itself for a constant purchasing power. At the same time, the number of inhabitants in cities is increasing, who, due to the rising tax burden, may show less inclination to own vehicles but will instead use them in Car-Sharing fleets. At the same time, the trend towards electromobility is creating increasing pressure for innovation.

In step 7, the scenarios are also examined for disruptive events. A disruptive event is an event of low probability, which has a very big impact [Reib-1992]. A possible disruptive event in the case study carried out before the diesel emissions scandal could be, for example, a loss of registrations of diesel vehicles due to non-compliance with exhaust gas values. The scenario is then reassessed against the background of the disruptive event. The agile procedure allows the adjustment of assumptions made in the previous steps in the context of optional transitions. If the disruptive event is considered, new influencing factors may result. In the sphere of influence 'political and legal framework conditions', this could be the influencing factor 'loss of registration of diesel vehicles' with the projections 'non-occurrence' (projection 1) and 'occurrence of a comprehensive and area-wide driving ban for diesel vehicles' (projection 2). The agile procedure model allows an immediate consideration of this change in the selection of the key factors and the resulting scenarios. For the scenario described above, there will be an even greater demand for new technologies when projection 2 takes effect. This is accompanied by a further increase in the pressure to innovate.

References

[AmDJ-2013] Amer, M., Daim, T., Jetter, A.: A review of scenario planning. Futures, S. 23–40, 46. Jg (2013)

[AGMR-1999] Arcade, J., Godet, M., Meunier, F., Roubelat, F.: Structural analysis with the MICMAC method and actors' strategy with the MACTOR method. In: Futures Research Methodology: American Council for the United Nations University (Hrsg.) The Millennium Project, S. 1–69 (1999)

[BFHR-2018] Bormann, R., Fink, P., Holzapfel, H., Rammler, S., Sauter-Serves, T., Tiemann, H., Waschke, T., Weirauch, B.: Die Zukunft der deutschen Automobilindustrie. Transformation by Disaster or by Design? (2018)

[BWBC-2005] Bradfield, R., Wright, G., Burt, G., Cairns, G., Van Der Heijden, K.: The origins and evolution of Scenario-Techniques in long range business planning. Futures, S. 795–812, 37. Jg (2005)

[Clau-1832] Clausewitz, C.: Vom Kriege (1832)

[DaUe-2008] Daheim, C., Uerz, G.: Corporate foresight in Europe. From trend based logics to open foresight. Technol. Anal. Strateg. Manag. S. 321–336, 20. Jg (2008)

[Döni-2009] Dönitz, E.: Effizientere Szenariotechnik durch teilautomatische Generierung von Konsistenzmatrizen. Empirie, Konzeption, Fuzzy- und Neuro-Fuzzy-Ansätze. Gabler Verlag (2009)

[Forr-2017] Forrester, J.: Industrial dynamics. J. Operation. Res. Soc. S. 1037–1041, 48. Jg (2017)

[GaFS-1996] Gausemeier, J., Fink, A., Schlake, O.: Szenario-management. Planen und Führen mit Szenarien. Hanser (1996)

[Gord-1994] Gordon, T.: Trend impact analysis. Fut. Res. Methodol. (1994)

[Götz-2006] Götze, U.: Cross-impact-analyse zur Bildung und Auswertung von Szenarien. In: Wilms, F. (Hrsg.) Szenariotechnik. Vom Umgang mit der Zukunft. Haupt, S. 145–182 (2006)

[Götz-1993] Götze, U.: Szenario-Technik in der strategischen Unternehmensplanung. Dt. Univ.-Verl. [u.a.] (1993)

[GrPS-2017] Gräßler, I., Pottebaum, J., Scholle, P.: Integrated process and data model for agile strategic planning. In: Vajna, S. (Hrsg.) 11th International Workshop on Integrated Design Engineering, IDE Workshop (2017)

[Grie-2004] Grienitz, V.: Technologieszenarien. Eine Methodik zur Erstellung von Technologieszenarien für die strategische Technologieplanung. HNI (2004)

[GrSc-2009] Grienitz, V., Schmidt, A.-M.: Weiterentwicklung der Konsistenzanalyse auf Basis evolutionärer Strategien für die Entwicklung von Markt- und Umfeldszenarien. In: Gausemeier, J. (Hrsg.) Vorausschau und Technologieplanung. HNI, S. 409–433 (2009)

[Kolm-1977] Kolmogorov, A.: Grundbegriffe der Wahrscheinlichkeitsrechnung. Springer, Berlin (1977)

[LiFr-2009] Linss, V., Fried, A.: Advanced impact analysis: the ADVIAN® method—an enhanced approach for the analysis of impact strengths with the consideration of indirect relations (2009)

[Mead-1974] Meadows, D.: The limits to growth. A report for the Club of Rome's Project on the Predicament of Mankind. Universe Books (1974)

[Miet-2009] Mietzner, D.: Strategische Vorausschau und Szenarioanalysen. Methodenevaluation und neue Ansätze. Gabler (2009)

[Mißl-1993] Mißler-Behr, M.: Methoden der Szenarioanalyse. Dt. Univ.-Verl (1993)

[MiRe-2005] Mietzner, D., Reger, G.: Advantages and disadvantages of scenario approaches for strategic foresight. Int. J. Technol. Intell. Plan. S. 220–239, 1. Jg (2005)

[NiWW-1985] Nitzsch, R.v.; Weber, M., Wietheger, D.: KONMACA - Ein Programmsystem zur Unterstützung der Szenarioanalyse. In: Arbeitsberichte des Instituts für Wirtschaftswissenschaften, S. 1–56 (1985)

[PoGr-2016] Pottebaum, J., Gräßler, I.: Reliable input for strategic planning: the integrated scenario data model. In: Villmer, F.-J., Padoanao, E. (Hrsg.) 6th International Conference Production Engineering and Management. Proceedings of 6th International Conference Production Engineering and Management, S. 99–110 (2016)

[Port-2004] Porter, M.: Competitive strategy. Techniques for analyzing industries and competitors. Free Press (2004)

[PoSG-2017] Pottebaum, J., Scholle, P., Gräßler, I.: Vorgehens- und Datenmodell zur strategischen Planung innovativer Dienstleistungen im Katastrophenschutz. In: Eibl, M., Gaedke, M. (Hrsg.) INFORMATIK 2017. Gesellschaft für Informatik, S. 1339–1352. Köllen Verlag (2017)

[Rand-2015] Randt, N.: An approach to product development with scenario planning: the case of aircraft design. Futures, S. 11–28, 71. Jg (2015)

[Reib-1992] Reibnitz, U.: Szenario-Technik. Instrumente für die unternehmerische und persönliche Erfolgsplanung. Gabler (1992)

[Stei-1951] Steinhaus, H.: Sur la division des corp materiels en parties. In: Colloquium Mathematicum, S. 282–285 (1951)

[Stei-1997] Steinmüller, K.: Grundlagen und Methoden der Zukunftsforschung. Szenarien, Delphi, Techikvorausschau. WerkstattBericht 21 (1997)

[TvKa-1973] Tversky, A., Kahneman, D.: Availability. A heuristic for judging frequency and probability. Cogn. Psychol. S. 207–232, 5. Jg (1973)

[Wack-1985] Wack, P.: Scenarios: shooting the rapids. Harvard Bus. Rev. 139–150, 63. Jg (1985)

Chapter 21
Marketing in Integrated Design Engineering—Fundamentals and Effects on Development

Hanns-Joachim Schweizer

> *The business purpose of a company is to win customers, therefore a company has only two—and only these two—basic tasks: Marketing and Innovation. Marketing and innovation generate results; everything else is costs.*
> —Peter F. Drucker [Druc-1973]

This chapter introduces the topic of marketing within IDE and conveys basic knowledge of the function of marketing and sales in companies.

Even if marketing is generally associated with the consumer goods industry (business-to-consumer relationship, B2C, 1:n relationship), this also applies in a modified form to the capital goods industry (business-to-business relationship, B2B, 1:1 relationship). The latter accentuates the marketing focus differently. The focus here is on the design of the *corporate image*, i.e. the development and definition of the company's impact strategy on the market and society and the presentation of the added value it generates for the economy. Further focal points are relationship marketing to customers and suppliers as well as product marketing. On the other hand, the market survey of capital goods is less pronounced than that of consumer goods research (consumer survey, test markets, consumer behaviour).

The general public often associates the term "marketing" with advertising slogans, such as "the tenderest temptation since chocolate was invented", used by a chocolate company from 1973 to 2011. Marketing is particularly visible in the consumer goods sector. Every day, consumers are overwhelmed with advertising that is intended to address them with targeted, sometimes emotional messages, and that awake their will to buy, or to influence their attitudes towards certain topics.

For a long time, marketing was known in the German-speaking countries under the term "Industrial marketing" and also other terms (e.g. sales theory, sales policy, etc.) [Bidl-1973]. According to BIDLINGMAIER, "modern marketing is characterized by the strict alignment of all entrepreneurial activities to market requirements. While in the older concept the focus was still on the provision of services, the results of which had to be sold, in the new concept all decisions are geared from the outset to the

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demanders, their needs and wishes" [Bidl-1973]. According to WÖHE, "marketing has the task of breaking sales resistance." [Wöhe-2013].

The American Marketing Association defines: "Marketing is the activity of influencing patterns of behaviour and processes for communication, provision and exchange of offers that are beneficial to customers, principals, partners and society in general" [AMA-2013].

Today, marketing is an essential concept of corporate management, which can partly include other entrepreneurial activities (e.g. strategic purchasing marketing, personnel marketing, development marketing and financial marketing). In other words: at the beginning of the decision-making process, marketing stands as a means of shaping the market and satisfying the needs of market participants such as customers, interested parties and other stakeholders (which are summarized under the term "stakeholders"). All downstream processes are subordinated to the marketing strategy. For the Austro-American economist PRINTER, marketing "… is so fundamental that it should not be seen as a separate operational function. Marketing encompasses the entire company, from the end result—that is, from the customer's point of view." And "the real goal of marketing is to make selling superfluous. The goal of marketing is to understand the customer and his needs so well that the product developed fits exactly and therefore sells itself." [Druc-1956].

The second statement from DRUCKER needs to be supplemented. Since the markets are partially saturated, it is no longer sufficient in the consumer goods sector to understand customers and their needs alone. Rather, the art consists in creating and shaping a market. The entrepreneur must be a visionary and must awaken the consumer's longing for an attitude to life[1]. Here, the statement of PRINTERS applies: "Marketing and innovation generate results…" [Druc-1973]. The focus must be on the innovation or invention of products.

Marketing includes all measures that are necessary to market any product (see Chap. 2). These are in particular the product, price, distribution and communication policy with the instruments of advertising and public relations (the four elements of marketing, 4P, are discussed below). While in the past, the product was in the foreground, today marketing has the customer in the focus, so that his needs and expectations can be fulfilled.

Market research companies are analysing the market and consumer wishes in an increasingly comprehensive way. For example, in 2004, a well-known advertising agency built the typical living room of the average German Müller family (two adults and a son of 16). Since then, the agency has been continuously investigating changes in the average living room. Meanwhile, the couch was renewed, since the average German buys every eight years a new set of seats. The TV now has a flat screen. Laptop and smartphone are ready, and the coffee table got recently a glass plate. Similarly, in 2011, the agency set up Germany's most frequent youth room [JvMa-2013, VWUV-2018].

[1] Following SAINT-EXUPERY: "If you want to build a ship, don't drum up men together to procure wood, assign tasks and divide up the work, but teach men the longing for the vast, endless sea." [Exup-1996].

Since, in addition to many other data on the average family, the first name (the most frequently assigned name of a year group) and the average age and weight of the average Germans are known, the available primary research data can be used to forecast the changes to be expected in the residential environment in the future: for example, if the carpet was the most popular floor covering yesterday, today, there is a desire for laminate flooring. Such information is important for producers so that they can adapt to tomorrow's market in good time.

21.1 History of Marketing

Actually, it was the Japanese Mitsui family who invented marketing as early as 1673 in Japan. They were traders and opened the first department store in Tokyo. They bought for their customers, offered them the product tailored to their needs, set up production, offered their customers a wide range of goods and financing. Customers paid back their debts twice a year [Mits-2018].

In the nineteenth century, Cyrus H. McCormik (1809–1884) was a pioneer of marketing in Chicago. He was the inventor of mechanical harvesting and mowing machines, but also showed commercial skill. It investigated the market, offered loans, hired maintenance personnel and supplied spare parts and accessories to its customers [McCO-2018]. In Europe, marketing was introduced to England in the 1920s by Marks and Spencer [Druc-19735].

At the beginning of the twentieth century, lectures on distribution were introduced in the USA. The curricula describe the lecture content as "marketing goods" [Tauc-2013]. Erhard was[2] involved in the introduction of marketing in Germany. Together with others, he founded the Gesellschaft für Konsum-, Markt- und Absatzforschung in Nuremberg. In 1935, he organized the first "sales course" in Nuremberg [Wirt-2020, Gfk-2013].

Although the term "marketing" was not used until 1905, Lewis[3] developed the AIDA formula [Lewi-1903], Fig. 21.1, as early as 1898 as part of a study on the use of drugs.

McCarthy[4] divided marketing as part of the business process into four simplified parts, which form the so-called marketing mix, also known as the 4 Ps [McCa-1960]. Using tools derived from this, the marketing strategy or marketing plans are to be translated into concrete actions, Fig. 21.2.

The four Ps are Product (product policy), Price (pricing policy), Promotion (communication policy) and Place (distribution policy), which will be discussed in the following sections.

[2]Ludwig Erhard (1897–1977) created the social market economy as Federal Minister of Economics (1949–1963). From 1963 to 1966, he was Federal Chancellor in Germany.

[3]Elias St. Elmo Lewis (1872–1948) is considered one of the pioneers of marketing and the first American advertising strategist.

[4]Jerome E. McCarthy (born 1928), American economist.

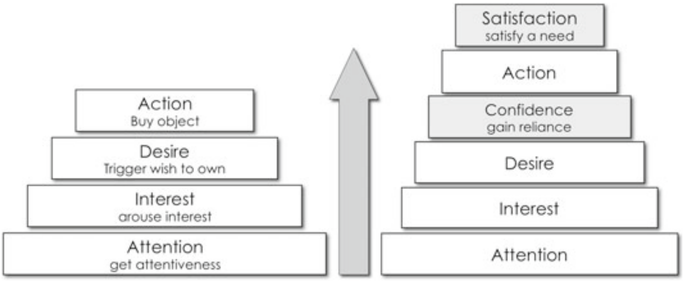
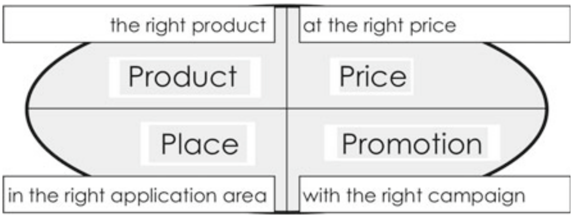


Fig. 21.1 AIDA model from LEWIS, left the original model, right with extensions to the AIDAS or AIDCAS model (extensions highlighted in grey)

Fig. 21.2 Four elements of the marketing mix (4 P)



21.2 Product Policy

A product comprises everything that can be offered to market participants, i.e. physical goods, services, experiences, events, people, places and organizations and combinations thereof (see Chap. 2). In today's markets, it is no longer sufficient to provide only material goods. Rather, companies must offer the core product with additional tangible (e.g. design, packaging) and intangible characteristics (e.g. customer service, leasing, product with a service, PSS).

Product policy is mainly concerned with the design of the company's product range. It affects all areas of the product life cycle (see Sect. 2.2 and Fig. 2.2), with capital goods and consumer goods being treated essentially equally. The focus is on the fact that in the broader sense, needs can be satisfied by the product, problems should be solved and benefits should be created.

The simplified product life cycle from Fig. 2.3 can also be viewed from a business perspective with regard to turnover, profit and profit rate, Fig. 21.3. It thus serves as an information basis for product policy and is divided into six phases from provision (development and production) to degeneration and subsequent product return.

The product policy pays particular attention to the analysis of contribution margins by means of contribution margin accounting. The contribution margins of the product or products are used to analyse the operating result of each individual product. The contribution margin is calculated on the basis of the scheme shown in Fig. 21.4.

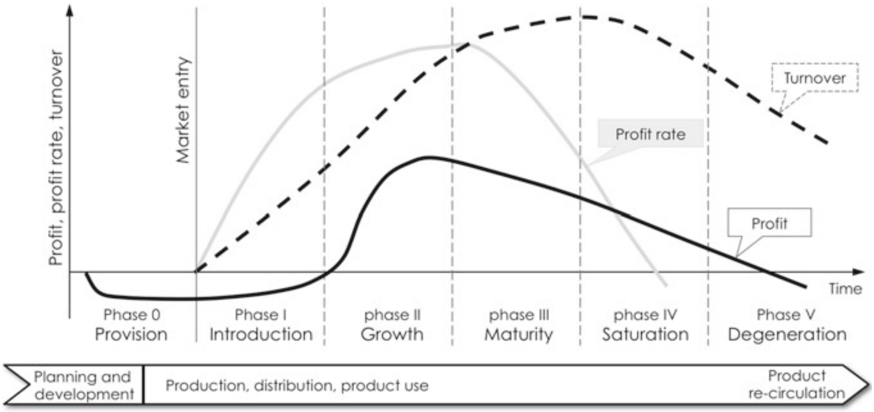


Fig. 21.3 Business product life cycle (see also Fig. 25.4)

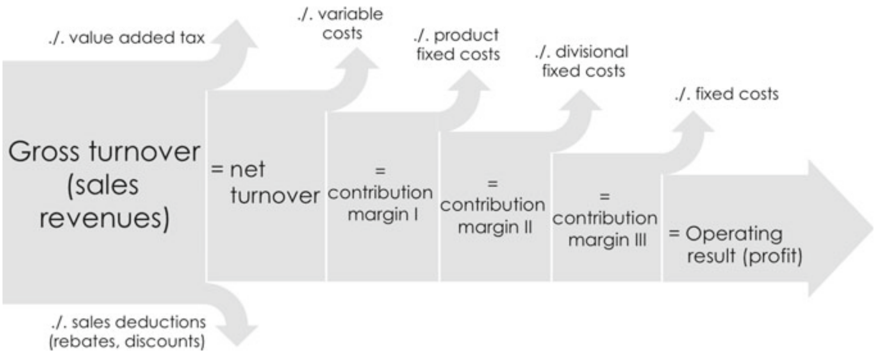


Fig. 21.4 Contribution margin accounting schema

21.3 Pricing Policy

The award is one of the most important components of the marketing mix. It is the only component that generates revenue, and it can be adapted quickly.

The pricing policy (or contracting policy) is intended to ensure that profits are achieved through market- and company-oriented targets. In this context, the company's objectives are, for example, to achieve an even utilization of production capacity and to increase its market share. The objectives relating to the sales market are pricing, conditions policy and contract design. The price policy deals with the determination of prices, price differentiation, the enforcement of prices in the market and the contract conditions used for this purpose. The following is an explanation of the above-mentioned instruments:

- Price fixing: the company can, for example, base itself on the market form (monopoly, oligopoly, polypol), supply and demand and its cost structure.
- Price differentiation: prices are determined according to spatial, temporal, factual and target group-oriented aspects.
- Price enforcement: in order to justify a certain price, the added value and the price/performance ratio must be comprehensibly presented to the customer.

Other corporate objectives may include increasing the company's own external image (corporate image design) and customer loyalty programmes (e.g. frequent traveller programmes of airlines, bonus programmes of oil companies).

Pricing may be based on different pricing strategies:

- With the high-price or premium-price strategy, the price of the product is kept high according to the motto that quality has its price.
- In the case of the lowest price or promotion strategies, prices are kept low in the long term, for example, PC sales at discounters. The high number of pieces purchased guarantees a low price.
- In the skimming strategy, the price is initially high and then gradually lowered. However, the market thus degenerates into a mass market. Powerful PCs, for example, are expensive to start with and their price decreases over time.
- With the flexible pricing strategy, the price is adjusted to demand. An example of this is the chip market.
- In yield management, demand governs the price. However, the supplier tries to market the goods at a maximum price that depends on the capacity utilization. An example of this is flight pricing policy, where flights are cheaper in off-peak times than in peak times and the last free seats are sold at low prices.

Finally, pricing policy includes conditions policy. In addition to defining delivery terms (free domicile, freight collect, observance of contractual formulae in international trade, the so-called *Incoterms*) and payment terms (credit limit, cash purchase, payment terms), this also includes the bonus policy (e.g. three pieces for the price of one piece) as well as warranty periods and leasing contracts. The discount policy (winter and summer sales, volume discounts) rounds off the price policy. All this can culminate in the motto: "Stinginess is awesome" (advertising of an electric market chain 2002–2011).

21.4 Communication Policy

The communication policy (promotion) aims to present the company and its products to market participants through information control. The information should directly or subconsciously influence opinion and behaviour and trigger emotions. For this purpose, the target group, message and the communication process must be defined: Who (transmitter) says what (message) to whom (receiver) on which channel (medium) with which effect?

Advertising as a mass appeal to consumers through print media, radio and other electronic media is the most well-known means of communication among market participants.

Other tools for communicating and obtaining information are:

- Sales Promotion: sales promotion to address potential buyers in a targeted manner. It is intended to stimulate interest in a product.
- Public Relations, Marketing Communications: public relations work to control communication, both externally and internally within the company.
- Trade fairs for the presentation of goods from one or many suppliers on a marketplace.
- Event Marketing: at an event, customers and interested parties are generally invited by a manufacturer. This also includes sporting events.
- Sponsoring: promotion of individuals or clubs, mainly in the sports sector, but also in the artistic environment. The names and logos of the sponsors are emblazoned on the jerseys of the athletes.

The advertising industry today distinguishes between advertising *above* and *below the line*.

- *Above the line* is advertising via print media, electronic media, radio and television advertising.
- *Below the line* comprises sales promotion, sponsoring, product placement, direct advertising (with a defined target group) and event marketing (events).

In communication policy, attempts are made to persuade consumers to behave in a certain way by using empirically determined data. Advertising psychologists analyse buying behaviour and try to generate consumers' need for a product or lifestyle. In this context, reference is also made to the AIDA formula (Fig. 21.11).

The most important definitions for the advertising under consideration of the creative strategy (Copy Strategy) are

- the (target) group and the advertising target,
- the positioning as the highlighting of special features and the differentiation from competitors (unique selling proposition),
- the elements of advertising, namely benefits, media, advertising message,
- the reason why the offer is so good (reason why) as well as
- tonality (verbal, non-verbal, mood, colour).

According to Nielsen's advertising statistics, advertising expenditure for *above the line* advertising amounted to 21.5 billion euros in 2011, 26.2 billion euros in 2012, 31.87 billion euros in 2017 and 16.8 billion euros by July 2018 [Niel-2018].

Figure 21.5 shows the development of total expenditure on advertising measures between 2003 and 2013.

Not to forget are the legal requirements for communication policy. The German law against unfair competition ("Gesetz gegen den unlauteren Wettbewerb", Unfair Competition Act, UWG) should be mentioned here in particular (such laws are to be

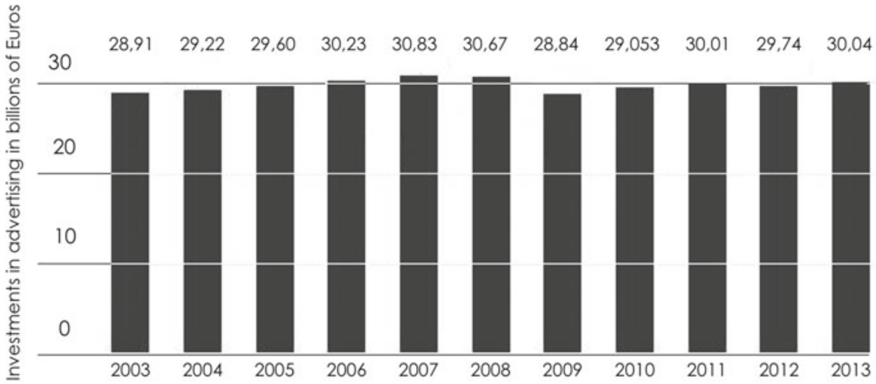


Fig. 21.5 Investment by German industry in advertising (fees, production of advertising material and media switching costs) from 2003 to 2013 (in billions of euros) [StBa-2013]. In 2017, the total turnover of the German advertising industry was approximately 46 billion euros [ZAW-2018]

observed as they exist with similar content in every country). It is intended to protect competitors, consumers and the general public from unfair commercial practices. The Act on the Protection of Trademarks and Other Signatures (MarkenG) and the Copyright Act (UrhG) must also be taken into account (see Sect. 21.12).

21.5 Distribution Policy

The distribution policy (Place) as part of the marketing mix deals with the transfer of goods and services from the producer or service provider to the end customer or consumer[5]. A distinction is made between transport, warehousing and sales (strategy and process). Thereby

- *Distribution* direct distribution and distribution via third parties (indirect distribution),
- *Multi-channel sales,* direct and indirect sales via the Internet,
- *Logistics* the provision of goods, services, energy type, money and the organization of the process as well as
- *electronic trading centre* (e-commerce) is the electronic processing of the company's sales activities on a virtual marketplace.

The physical distribution (logistics) will be dealt with here only briefly on the basic types of sales channels, Fig. 21.6.

[5]In the doctrine, the term sales policy instead of distribution policy is currently gaining more and more acceptance.

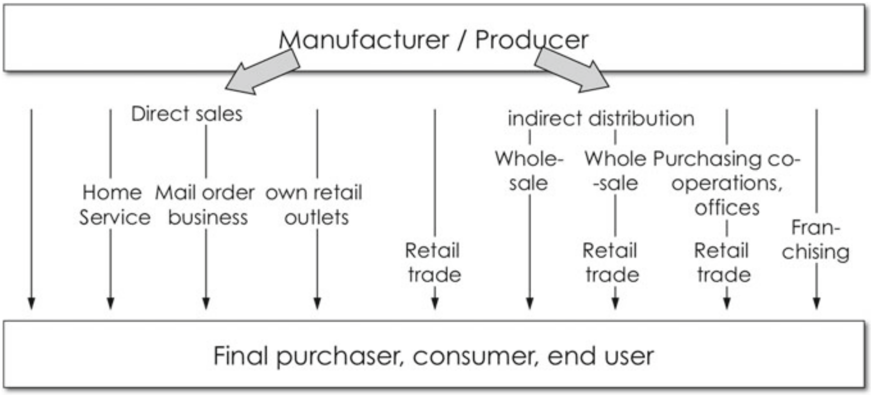


Fig. 21.6 Basic types of sales channels [DaWM-2003]

21.6 Offensive Marketing as a Supplement to the Marketing Mix

According to MEYER, marketing comprises more than the 4 Ps (Fig. 21.2), which are expanded as follows: "Marketing means creating superior customer benefits in an efficient manner with the participation of all employees in order to achieve sustainable above-average profits" [MeDa-2001]. It introduces the concept of *offensive marketing* as a counterpart to *defensive marketing*.

While defensive marketing manifests itself through administrative activities and introversion (inward actions), where change is seen as a threat, MEYER sees offensive marketing as a mindset, as an activity in different areas of the company and as a coordinating function. The goal of offensive marketing is to achieve above-average profits through superior customer benefits. The focus here is on entrepreneurial action, innovative thinking and the unconditional will to win. MEYER explains this as follows: "Offensive marketing means tapping and exploiting the full potential of marketing." [MeDa-2001] "Offensive marketing means… leading markets, delivering superior customer value, taking risks and forcing competitors into the imitation position." [MeBl-2002].

The concept of offensive marketing begins with the definition of goals with which (future) markets can be proactively shaped in order to be the first to exploit the resulting potential. As an example, we would like to mention the goal of having a computer in every household. Offensive marketing gives the customer orientation, shapes customer expectations, drives the market, presents possible (and desirable) benefits and thinks ahead (be always ahead)[6].

[6]Examples of this concept are the creation of a previously non-existent need for smartphones and their establishment by Steve Jobs on the one hand and a Swedish furniture store that has fundamentally changed customer behaviour on the other. Classic furniture is delivered and assembled by the supplier. For the Swedes, the motto is: Do it yourself. The result is cost savings for both sides,

The offensive marketing is implemented as follows:

- *Business analysis* must look at technology, laws, trends and growth potential at the macro-level. Indirect factors such as upstream supplier markets, laws and complementary areas must be assessed (in the case of measures in aviation, for example, these are the other modes of transport bus, train and car). Prices, consumers, trading partners and competitors are directly compared.
- In the next step, all company activities are examined during the *internal audit*. These are in particular the knowledge generation (conversion of the information into action strategies), the performance evaluation (economy), the attitude audit (attitude of the co-workers to the product/company), the enterprise strategy and their conversion.
- Key points in the *competition and customer analysis* are the competition survey (are there already competitors and, if so, who are they?), the question about the customers (who, today, tomorrow, expectations, satisfaction, loyalty, value of the customer, key figures?), the short-, medium- and long-term setting of objectives as well as the question about the necessary level of investment. In addition, there are questions about the importance of the market, the strengths and weaknesses analysis of the competition, an analysis of the threat and possibly vulnerability of the own company (determined by a SWOT analysis, see Fig. 2.5).

From these steps, the effects on the marketing strategy are recorded. This means that the company must concentrate on the key success factors in its industry, such as cost factors and cost structures, competitive successes and failures and undiscovered opportunities that have not yet been exploited.

The definition of the market strategy is driven by factors such as the compulsion to innovate, the key to the company's success, the brand strategy, the availability of the product or service on the market (time to market) as well as the combination of opportunities, capabilities, new markets and sales channels (examples of offensive marketing strategies can be found in trade, IT industry and in the beverage sector).

21.7 E-Commerce

E-commerce is the term used to describe electronic trading on the Internet (Internet trading, online trading). Online sales are now an important part of most companies' sales strategies. It is obvious that e-commerce will increase. Companies not only want to open online shops, but also want to integrate these activities into their retail stores. This has advantages for the buyers. Online shopping saves time, offers a wider choice of products and enables cost savings.

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the modular principle (combination option) and the possible promotion of creativity (the customer must think when setting up). All of these go hand in hand with considerable savings in packaging and distribution logistics.

Advantages of e-commerce over traditional trade are:

- reach across borders (national barriers are eliminated)
- win new customers through the Internet (search engine)
- lower costs (storage costs, sales, personnel)
- find the product faster (if not available in Hamburg, then in Munich)
- reduction of travel time and costs
- price comparison (comparison shopping)
- offer bargains, redeem coupons, etc.
- target group approach
- 24 h/365 days open
- create sales for niche products.

21.8 The Markets

On the market, supply and demand for a good or service, or combinations thereof, come together. In economics, a distinction is made between the factor market (labour market, capital and money market, real estate market) and the goods market (consumer and capital goods as well as services).

In the following, the consumer goods market, the capital goods market and the service market are considered because of their relevance for marketing.

21.8.1 Consumer Goods Market

In the consumer goods market, the product is delivered to the end customer or end consumer (B2C, relationship 1:n). Although the consumer goods market is a mass market (strong competition and strong demand), it is a relatively heterogeneous group of end users. Further characteristics of the consumer goods market are

- distribution (distribution from producers via wholesalers and retailers to consumers),
- intensive advertising,
- the differentiated use of marketing methods. This includes product recommendations, quality seals, e-mail marketing, customer ratings, error-tolerant search ("Bamter" results in "Beamter"), product bundles, retargeting (cookies), automatic price optimization (e.g. hotel rooms), search engine advertising, social networks, blogs, press releases, online videos.
- the price war and
- short innovation cycles, because new products, such as mobile phones, must be launched at short intervals in order to maintain the attractiveness of the product.

21.8.2 Capital Goods Market

The capital goods market is dominated by relationships in which products are manufactured in which other industries invest in order to produce additional products for different markets or industries (B2B, relationship 1:1). The capital goods sector differs from the consumer goods market primarily in the direct sale of individual solutions in individual production or series production (limited quantities). This can lead to tensions between marketing, sales and technology, since sales often promise the customer products that the technology still has to develop. Increasingly, products are therefore being developed cooperatively between manufacturers, variant developers, suppliers and engineering service providers, increasingly on a development platform available to all participants. Further characteristics are

- internationality (export orientation),
- the buying centres (purchasing platforms, mergers),
- the reciprocity of business relationships,
- the high proportion of services,
- various financing models (leasing, rental) as well as
- State influence (e.g. aerospace and defence industries).

21.8.3 Services Market

The services market has expanded strongly in recent years. In addition to the shifts in a company's value added caused by globalization, the reasons for this are the increase in complete solutions due to changes in consumer behaviour resulting from the use of value-added services for capital and consumer goods (product-service systems PSS, value-added services, VAS). Not only the product, but also all related services are offered from a single source, such as a machine tool for a specific product family, whereby installation, commissioning, preventive maintenance and telephone support (hotline) are included in the price.

Further characteristics of the services market are the demographic factor and technological change, with a tendency towards products that are increasingly in need of explanation, as well as changes in employment relationships through temporary contracts and temporary work.

21.9 Differentiation of Marketing According to Sales Territory (Domestic and Foreign Trade)

The German economy is highly dependent on exports. At the same time, Germany is a country poor in raw materials and has to import most of its raw materials. Due to the efficiency of the German economy there has been an export surplus for years, since although goods worth 1034 billion euros were imported in 2017, goods worth 1279 billion euros were exported in the same year [Stat-2018].

For a variety of reasons, companies decide to offer their services and products abroad. The limited growth opportunities on the domestic market play a major role, and image reasons are also decisive. Some customers produce abroad, and the products have to be exported for further processing or production. Access to resources can also be a reason for export efforts.

Foreign trade differs from domestic trade in a large number of parameters. These are foreign regulations, export and import regulations, the foreign language, the mentality, the requirements for packaging and labelling. The marketing tools for the foreign markets are identical to those of the domestic market. In export planning, once the company has made a decision to export and is now entering the foreign market, it will be able to assume that the company's objectives have been established; in other words, it will start from the existing products. Based on this, the sales and profit targets and the targeted market shares must then be determined. However, the investment costs for market development must be included in the target setting.

When deciding on the operation of foreign trade, a company must consider the following questions and make decisions based on them:

- Do you want to export directly or indirectly by involving an importer in the target area?
- Is there a need to manufacture abroad under licence? Can this take the form of cooperation through majority or minority shareholdings or through a joint venture[7]?
- What does the political system look like in the target area, does it have different legal systems? What are the political risks?
- Are there legal regulations for foreign trade or even trade barriers? Are there domestic taxes and fees?
- How can further financial risks (currency risk and credit default risk) be covered?
- Is it necessary to adapt the product attributes to the foreign market due to communication risks (e.g. language barriers), different infrastructures, standards, culture, society and religion, climate zones, environmental factors, etc.?
- What are the cost ratios (transport costs, insurance, customs duties), the associated risks and the lower price limits?

The current competitive pressure triggers marketing measures, because what one manufacturer can do today, the other can do tomorrow! The competitor will also be able to offer every innovation within a very short time. With the old marketing methods, market participants no longer achieve a competitive advantage. The offer is mostly technically comparable, and the flexible price adjustment is not necessarily successful. The motto "Stinginess is awesome" (advertising of an electrical store chain in the years 2002–2011) no longer convinces the consumer. The best example of this is an American hardware and software company that offers an attitude to

[7] A joint venture is a joint subsidiary of two independent companies that may even be competitors.

life with high-priced and high-quality products. Also, the shower of an Austrian manufacturer "gives wings".

This forces manufacturers to use marketing as a continuous process of corporate strategy to plan their success. The following must be done

- mission and vision of the company,
- strategic goals agreed,
- the actual state is analysed,
- a SWOT analysis (Sect. 2.2.3) has been carried out and
- the product portfolio can be reviewed.

From this follows the definition of the marketing goals and the marketing strategies.

21.9.1 Definition of Mission and Vision

The mission of a company or a division describes a task with which a certain vision (target state) is to be fulfilled in the long term. In general, the marketing of the mission and vision is based on a statement that is intended to represent the company's direction to the consumer, for example "Vorsprung durch Technik" ("Leading by Technology", advertising of an automobile company). The mission must be both realistic and visionary; it must be tailored to the company, highlight its competence and motivates the recipient of the message to work with the company or purchase its products.

21.9.2 Marketing Planning

The task of marketing planning is to implement predefined goals. Planning has the following steps:

- Condition analysis (as-is analysis) and the analysis of the product and service portfolio,
- Target setting,
- Identifying competitive advantages, i.e. which factors differentiate the company from the competition,
- Development of the marketing mix (e.g. 4 Ps, Sect. 21.11) and finally
- Control of the defined activities.

21.9.3 Strategic Marketing Planning

Strategic planning determines the positioning of the company and the product. For illustration, some examples from the current advertisement:

- Automobile manufacturer: "Vorsprung durch Technik" ("Leading by Technology" technical superiority)
- Automobile manufacturer: "The ultimate driving machine" (sportiness and lifestyle)
- Automobile manufacturer: "I am there for you. Your service partner" (reliable and efficient service)
- Automobile TV spot: "Think Blue—Small is big. The new Eco Up!" (reference to the ecological advantages of the advertised vehicle)
- "Nothing is impossible…" (Suggestion of the fulfilment of very many wishes)
- Shower manufacturer: "… gives wings" (relaxed attitude to life in which everything succeeds).

21.9.4 Market Research

Marketing goals and strategies must be constantly reviewed. This means that the company systematically collects and evaluates information through market research. In contrast to market research, *market exploration is,* according to HÜTTNER, the "merely random, occasional scanning of the market." [Hütt-1979]. Market research can be defined as follows:

- For FRÖHLICH, market research is "the term for a branch of applied psychology in which the needs and wishes of potential consumers are investigated […] in connection with market analyses" [Fröh-1987].
- For HÜTTNER, market research is the "systematic, purposeful investigation of a concrete submarket" [Hütt-1977].
- For HAMANN and ERICHSON, it is the "[…] systematic, empirical investigation activity with the purpose of obtaining or improving information about objectively or subjectively conditioned market facts and phenomena as a basis for procurement and sales policy decisions" [HaEr-1997].

Nowadays, so-called e-market research is becoming increasingly important, taking advantage of the fact that users leave[8] their data on the Internet, sometimes voluntarily and sometimes unnoticed.

Market research is divided into primary and secondary research.

- *Primary research is* defined as direct market research (direct investigation of market participants).

[8]For example, Microsoft and Nielsen are now working together to identify consumer trends more quickly.

- *Secondary research is* defined as indirect data collection (desk research, i.e. the evaluation of the existing data).

For example, Gesellschaft für Konsumforschung (GfK) investigates[9] consumer behaviour in test markets. Here, the cause–effect relationships are determined on the basis of

- preference research (benefit/total benefit),
- the advertising effect (emotional and informative) and
- of customer satisfaction and loyalty

and checked it out.

The results of the studies show that customer satisfaction is crucially dependent on the company's employees and not on the product.

In 2015, the worldwide turnover of the market research industry was over 44 billion US dollars, an annual increase after a slight decline in 2009[10].

21.10 Marketing and Product Development

Companies that understand the preferences of their customers are very successful in developing new products, and they are innovative. In many companies, however, the influence of marketing on the product development process is still very small. As a rule, product development dominates the development process. However, if the product is not successful on the market, marketing is held responsible because it has not provided the right information about the market and consumers. The question is how marketing can help to support the company's ability to innovate.

A successful enterprise must be able to translate customer needs and expectations into product specifications. And there must be close cooperation between the marketing staff and those involved in product development.

Within IDE, marketing has the task of identifying, selecting and evaluating new products in cooperation with development, sales, production and finance. The data obtained from such an assessment therefore forms the basis for product development and not for internal debates and assumptions.

Neuro-marketing is a new discipline in price calculation. One of the central statements of this process is that potential customers would not do or buy what they say.

[9] www.gfk.com.

[10] In 2015, North America accounted for the largest share of market research sales with 44%, closely followed by Europe with 37%. These regions were also at the top in terms of annual growth. The world's leading market research companies include Nielsen Holdings (USA), Kantar (UK), Ipsos (France) and GfK (Germany). In 2015, Nielsen was by far the largest market research company in the world in terms of sales. In that year, the company's sales amounted to around 6.17 billion US dollars—almost twice as much as the sales of its nearest competitor Kantar with 3.71 billion US dollars.

Besides, they would not know what they were thinking or feeling. What customers really want to buy and at what price, on the other hand, their brain waves showed. These can be recorded using an electroencephalogram (EEG). With this approach, only 40–50 test persons are needed to find out the truth about their willingness to pay. This procedure is also more accurate than any customer survey that requires at least 1000 people to be representative [Häus-2011, Schu-2020].

21.10.1 Why Products or Innovations Can Fail

Studies show that about 60–80% of new products fail when they enter the market. However, there is a high number of unreported cases. It is therefore difficult to determine the exact figures. Who likes to talk about their innovation flops? But knowing the reasons would be valuable. If the causes of a failure are known, management can take the right measures that lead to success.

A new product can initially fail because nobody needs it or it is not considered necessary. Or it can fail because the innovation processes in the company do not function properly.

The four most important reasons why new ideas and new products fail are [Tagw-2016]:

Reason 1: Wrong decisions are made because

- Corporate and innovation strategies are lacking,
- Insufficient information is used as a basis for the joint decision-making process outlined above,
- Facts are neglected because management prefers to rely on its gut feeling.

Reason 2: innovation has a low priority, because

- The day-to-day business in the company takes precedence and innovation is therefore of secondary importance, especially since the future is far away and one is in the present.
- Innovation generates fear and is therefore regarded as a danger.
- Innovation is not mentioned in the job description.
- Innovation is not part of the employee incentive plan.

Reason 3: lack of market orientation because market and customer requirements are unknown. Only those who really know customers and markets can develop products that inspire, are competitive and successful. This leads to the following requirements:

- No exclusive focus on technology.
- Carefully prepare customer analyses and product specifications, not under time pressure. Specify the actual budget required.
- Finding a first customer or reference customer (Launching Customer).

Reason 4: Organization of the company

The larger a company, the slower the decision-making process, usually. The organization influences success. This can be seen in start-ups. Due to their size, they are less complex and therefore more agile. They have lean hierarchies and little bureaucracy and can therefore act more quickly. The employees know each other. This improves collaboration and accelerates processes. Cultural factors (openness, willingness to take risks, willingness to succeed) also play a key role.

21.10.2 Digital Marketing

Since 1991, when the first website on the market became available and the Internet and the Web grew rapidly, marketing has changed dramatically.

More than 3 billion people around the world regularly use the Internet to find products, consume entertainment products and communicate with friends and family. The sheer amount of information available has changed the way people buy and companies market their products.

In this rapidly changing digital world, companies need specialists with the ability to deliver the message of the brand, products and services to the market.

Today, no company can do without digital marketing. It is not enough just to know the customers. You have to know them better than any competitor. Therefore, an overall view of customer preferences and expectations is necessary on all available communication platforms. These include, for example, the Web, social media, mobile data (mobile), direct contact by e-mail (direct mail) and the point of sale (point of sale). The customer is accompanied through the purchase process.

What is Digital Marketing now?

- Digital marketing serves to promote the sale of products or brands through the targeted use of electronic media.
- For example, marketing activities defined as part of a company's digital marketing strategy may include advertising on the Internet, social media, the mobile phone market, electronic billboards, television and radio stations.

Why digital marketing is important:

- Today, digital media are so widespread that consumers have access to information anytime and anywhere (Fig. 21.7).
- Digital media is an ever-growing source of entertainment, news, shopping and social interaction, and consumers are now not only reliant on company statements, but are informed about the media, friends and colleagues. And consumers are more likely to believe in their peers than in company statements.

Figure 21.8 shows the most important digital marketing instruments.

The individual instruments in Fig. 21.8 are:

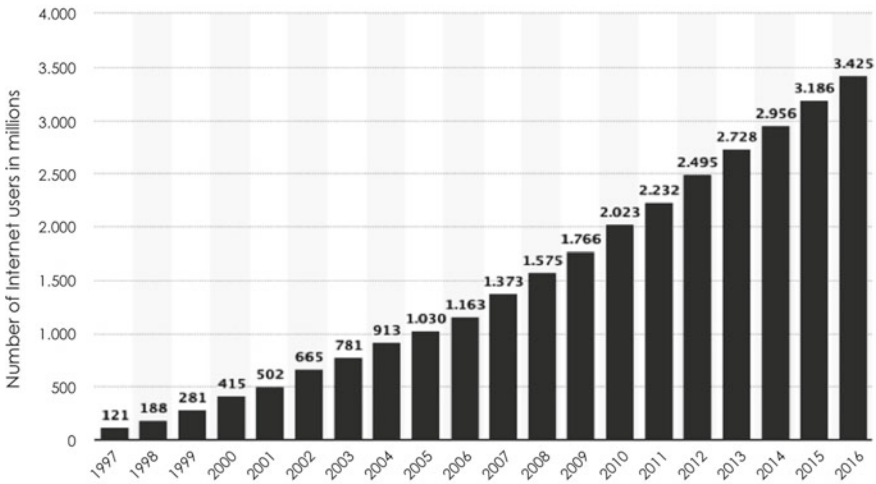

Fig. 21.7 Number of Internet users worldwide (in millions) with an estimate for the years 2015 and 2016 [Stat-2018]

Fig. 21.8 Instruments of digital marketing

- Branding: development of the brand or brand name as a quick and long-term identification of the company.
- Social media: address via networks or communities where users interact with each other (including Facebook, Twitter, LinkedIn, Flickr, YouTube, Xing).
- E-mail marketing: products and services are offered to customers by e-mail in direct contact.
- Web Design: design of the Website on the Internet.
- Content Marketing: addressing target groups through informative and entertaining messages on company Websites, in blogs or social media.
- Video Production: Creation of commercials.

- Search Engine Optimization (SEO): a measure to ensure that your Website appears as far ahead as possible in the search engine ranking.
- Search Engine Marketing (SEM): the salesman tries to increase his visibility on the net by paid advertisement on the result lists of the search engines.
- App Development: Development of application software.

21.11 Sales as a Key Component of Marketing and as Part of Distribution Policy

As mentioned in Sect. 21.1, distribution is a component of the marketing mix, the "place" component in the 4P model (Fig. 21.2). For each product, the company must decide which sales channel it should use best for its business purpose. In Sect. 21.8, a distinction was made between direct sales and indirect sales. In direct sales, sales are made directly to the end customer, in indirect sales via a sales intermediary (such as a retailer or sales representative).

Figure 21.9 shows the differences between marketing and sales:

21.11.1 Key Account Management

In the capital goods industry, direct sales are an indispensable component in addressing customers. Particularly important is the support of key customers (key accounts) as a form of direct sales, which will be discussed in the following. For BELZ, key account management means "systematically analysing, selecting and processing current or potentially important key customers of the company" [Belz-1998].

The strategy of key account management is to develop integration and synergy potential for both sides, to identify the relevant contact persons for potential customers and to establish contact with the decision makers. Continuity in the support of key accounts is essential for the continuous and future-oriented safeguarding of corporate goals in terms of sales targets, innovation boost and earnings.

Marketing	Distribution
Ratio: 1:n	Ratio: 1:1
1 (one) marketing information reaches n people	motivates and leads a single customer
takes care of the branding (brand)	builds up the relationship with this customer
is responsible for monitoring the general market and possible target markets	is responsible for sales and profit with this customer
collects and analyzes data on markets and the people operating in them (Big Data)	is a partner of the customer and translates the needs into requirements for the company

Fig. 21.9 Differences between marketing and sales

Customers who have a corresponding significance for the manufacturer are worth it that the forces are bundled specifically on them. Key accounts must be worth this investment.

21.11.2 Necessity of Key Account Management

Key account management in the capital goods sector is necessary because, on the one hand, customers demand tailor-made products and services and, on the other, concentration processes take place in the customer structure, such as company acquisitions and the associated mergers to create synergy effects. In addition,

- Markets are liberalized (reduction of trade restrictions, free market access),
- Monopolies (telecommunications, railways, postal services, monopoly on explosives, monopoly on spirits),
- The competitive pressure forces commercial customers to take measures to improve customer loyalty, for example, with a differentiated pricing policy and the shortening of delivery times (time to market) and
- Procurement is centralized and professionalized (establishment of so-called buying centres).

Markets have changed at different speeds in different industries. 75% of the markets in the highly developed countries are saturated [NaKn-2011]. Sales growth can therefore only be achieved through cut-throat competition. Price pressure and extensive benchmarking are the result.

At the same time, products are becoming more and more interchangeable. Quality and performance are no longer seen by customers as unique selling points, but as a matter of course. Products must be supplemented by service, consulting services and the assumption of customer tasks in order to be successful in the market.

In a globalized environment, sales activities are becoming increasingly international. Cultural diversity must be taken into account, customers must be served internationally and the need for coordination therefore increases.

In order to address and support important customers, marketing and sales costs rise disproportionately in relation to sales. This results in lower profits, which in part leads to cost-cutting programs.

The willingness to enter into partnerships, both on the supplier side and on the customer side, is growing. Accordingly, key accounts are increasingly looking for partners instead of just suppliers. They recognize that partnerships with suppliers can help them build their own core competencies.

Examples for the selection of key customers by NAIL and KNOB HOLE [NaKn-2011]:

- The major customer has a considerable significance for sales and must therefore not be neglected.

- The image customer has a considerable image significance that can be used positively for one's own business.
- The reference customer is considered an important address in the market and is willing to serve as a reference.
- The know-how customer has a high know-how potential, which can be important for his own development.
- The leader customer is one of the opinion leaders on the market.
- The cross-regional customer has a branch structure with different responsible persons. In this case, key account management should be responsible for central control in order to develop a uniform concept and procedure.
- The development customer gains market share in his market segment.
- The customer relationship with the refurbishment customer is weakening, but the own supply share of the purchasing potential of this customer is very high.
- A strategic goal is pursued with the strategic customer.

21.11.3 Sales Management According to the ABC Analysis

According to this common method of prioritization in business administration, customers, tasks, etc., are divided into the categories very important (A), important (B), less important (C) and initially negligible or not in focus (D). It is based on the Pareto principle (80% result can be achieved with 20% expenditure).

- The key customers (A customers) are looked after by key account management.
- Major and B customers are handled by the classic sales organization.
- C customers are maintained by telephone or e-mail.
- D customers are sold to other sales channels or sales partners.

21.12 Legal Basis for Advertising and Marketing

As mentioned in Sect. 21.4, marketing must take into account competition law, trademark law and copyright law. Competition law is regulated by the Unfair Competition Act (in German: Gesetz gegen den unlauteren Wettbewerb, UWG) [UWG-2004]) and the Act against Restraints of Competition (in German: Gesetz gegen Wettbewerbsbeschränkungen, GWB) [GWB-1998][11]. The latter is also known as the Cartel Act.

The purpose of the UWG is to protect competitors, consumers and the general public from "unfair business practices" and "undistorted" competition (paragraph 1 UWG). In the following sections, selected parts of the UWG will be presented.

[11] The description of this German law, which is in accordance to correspondent European legislation, is exemplary, as there exist different laws and approaches worldwide that handle competition. The reason for presenting the German UWG quite at length here is to draw attention to analogue legislation in the home country of the estimated reader.

21.12.1 § 3 UWG: Prohibition of Unfair Business Practices

§ 3.2: "Business acts directed at or reaching consumers are unfair if they are not carried out with due business care and are likely to significantly influence the economic behaviour of the consumer.

(3) The business acts towards consumers listed in the Annex to this Act are always inadmissible."

Inadmissible business acts within the meaning of § 3 paragraph 3 are

(1) The false statement by an entrepreneur that he is one of the signatories to a code of conduct;
(2) The use of quality marks, quality labels or the like without the required approval;
(3) The false pretence that a code of conduct has been approved by a public or other authority;
(4) The untrue statement that an entrepreneur, a business act carried out by him or a good or service has been confirmed, approved or authorized by a public or private body, or the untrue statement that the conditions for the confirmation, approval or authorization are met;
(5) Offers of goods or services within the meaning of § 5a (3) at a specified price, if the entrepreneur does not inform that he has sufficient reasons to believe that he will not be able to provide or have provided these or similar goods or services for a reasonable period of time in a reasonable quantity at the specified price (bait offers). If the stockpiling is shorter than two days, it is up to the entrepreneur to prove the appropriateness;
(6) Offers of goods or services within the meaning of § 5a (3) at a certain price, if the entrepreneur then, with the intention of selling another good or service instead, presents a faulty execution of the good or service or refuses to show what he has advertised or refuses to accept orders for it or to provide the advertised service within a reasonable period of time;
(7) Falsely stating that certain goods or services are available generally or on specific terms and conditions for a very limited period of time in order to induce the consumer to make an immediate transactional decision, without the consumer having the time or opportunity to make a decision on the basis of information;
(8) After-sales services in a language other than that in which the negotiations were conducted before the conclusion of the transaction, if the language originally used is not an official language of the Member State in which the trader is established; this shall not apply where consumers are informed before the conclusion of the transaction that these services will be provided in a language other than the language originally used;
(9) The false indication or creation of the false impression that a good or service is marketable;

(10) The untrue statement or the creation of the incorrect impression that legally existing rights is a special feature of the offer in question;
(11) The use of editorial content financed by the entrepreneur for the purpose of sales promotion, without this connection being clearly evident from the content or from the type of optical or acoustic representation (advertising disguised as information);
(12) Untrue statements about the nature and extent of a risk to the personal safety of the consumer or his family in the event that he does not advertise the goods offered or does not make use of the service offered;
(13) Advertising for a product or service which is similar to the product or service of a particular manufacturer, if this is done with the intention of deceiving about the commercial origin of the advertised product or service;
(14) The introduction, operation or promotion of a sales promotion system which requires a financial contribution from the consumer for the possibility of obtaining rewards, either directly or principally through the introduction of other participants in the system (snowball or pyramid scheme);
(15) The false statement that the trader is about to go out of business or move his premises;
(16) The statement that a certain good or service increases the chances of winning at a game of chance;
(17) A false statement or the creation of the false impression that the consumer has already won or is about to win a prize or will win a prize or obtain some other advantage through a specific act, if such a prize or advantage does not actually exist, or if, in any event, the possibility of obtaining a prize or other advantage is made conditional upon the payment of a sum of money or the assumption of costs;
(18) The false claim that a good or service can cure diseases, functional disorders or malformations;
(19) A false statement about market conditions or sources of supply in order to induce the consumer to buy or use a good or service at conditions less favourable than the general market conditions;
(20) The offer of a competition or contest if neither the promised prices nor a reasonable equivalent is awarded;
(21) The offer of a good or service as “free”, “gratis”, “free of charge” or similar, if costs are nevertheless to be borne for this; this does not apply to costs which are unavoidable in connection with the acceptance of the offer of goods or services or for the collection or delivery of the goods or the use of the service;
(22) The transmission of advertising material accompanied by a request for payment if this gives the incorrect impression that the goods or services advertised have already been ordered;
(23) 21. The false indication or creation of the false impression that the company is a consumer or is not acting for purposes relating to its business, trade, commerce or profession;

(24) The false statement or the creation of the false impression that after-sales service is available in connection with goods or services in a Member State of the European Union other than that in which the goods or services are sold;
(25) Creating the impression that the consumer cannot leave certain premises without prior conclusion of a contract;
(26) In the case of a personal visit to the home, failure to comply with an invitation by the person visited to leave or not to return to the home, unless the visit is justified for the lawful enforcement of a contractual obligation;
(27) Measures intended to prevent the consumer from asserting his contractual rights under an insurance relationship by requiring him, when making his claim, to produce documents which are not necessary to prove that claim, or by systematically failing to reply to letters in support of such a claim;
(28) The direct invitation to children included in an advertisement to purchase the advertised goods or services themselves or to induce their parents or other adults to do so;
(29) The request to pay for goods or services not ordered but delivered or rendered or a request to return or store items not ordered; and
(30) The explicit indication that the job or livelihood of the business is at risk if the consumer does not take delivery of the goods or services.

Unfair acts are dealt with in paragraphs 4 (Protection of competitors) and 4a (Aggressive commercial acts) of the UWG and misleading by omission in paragraph 5.

21.12.2 § 4 UWG: Protection of Competitors

Anyone acts in bad faith, who

(1) Disparages or denigrates the marks, goods, services, activities or personal or business circumstances of a competitor;
(2) Alleges or disseminates facts about the goods, services or enterprise of a competitor or about the entrepreneur or a member of the management board which are liable to damage the enterprise's business or the credit of the entrepreneur, unless the facts are demonstrably true; if the information is confidential and the communicator or the recipient of the information has a legitimate interest in it, the act is unfair only if the facts are alleged or disseminated contrary to the truth;
(3) Offers goods or services which are an imitation of the goods or services of a competitor, if he;

    (a) Causes avoidable deception of purchasers as to the commercial origin;
    (b) Unreasonably exploits or damages the reputation of the counterfeit goods or services; or

(c) Has obtained the knowledge or documents necessary for the imitation in bad faith;

(4) Deliberately obstructs competitors.

21.12.3 § 4a UWG: Aggressive Commercial Acts

(1) A person is acting unfairly if he is engaged in an aggressive commercial activity that is likely to lead the consumer or other market participant to take a transactional decision which he would not have taken otherwise. A commercial act is aggressive if, in the specific case, taking account of all the circumstances, it is likely to significantly impair the consumer's or other market operator's freedom of choice by

(a) Harassment,
(b) Coercion, including the use of physical force; or
(c) Undue influence.

An undue influence exists if the trader exploits a position of power vis-à-vis the consumer or other market participant to exert pressure, even without the use or threat of physical force, in such a way that the consumer's or other market participant's ability to make an informed decision is substantially restricted.

(2) In determining whether a commercial act is aggressive within the meaning of subsection 1 phrase 2, the following shall be taken into account

(a) The time, place, nature or duration of the act;
(b) The use of threatening or offensive language or behaviour;
(c) The deliberate exploitation of specific misfortune situations or circumstances of such gravity that they impair the consumer's or other market participant's judgement in order to influence the consumer's or other market participant's decision;
(d) Onerous or disproportionate obstacles of a non-contractual nature by which the trader seeks to prevent the consumer or other market participant from exercising his contractual rights, including the right to terminate the contract or to switch to another good or service or another trader;
(e) Threats of unlawful actions.

The circumstances to be taken into account under point 3 include in particular mental and physical handicaps, age, business inexperience, credulity, fear and the predicament of consumers.

21.12.4 § 5 UWG: Misleading Commercial Acts

(1) A person is acting unfairly if he is guilty of a misleading commercial practice which is likely to mislead the consumer or other economic operator to take a transactional decision that he would not have taken otherwise. A commercial act shall be regarded as misleading if it contains false information or any other information likely to mislead as to the following circumstances:

   (a) The essential characteristics of the goods or services, such as availability, nature, design, advantages, risks, composition, accessories, process or time of production, delivery or provision, fitness for purpose, possibility of use, quantity, quality, after-sales service and complaint handling, geographical or trade origin, results to be expected from the use or the results or essential elements of tests of the goods or services;
   (b) The reason for the sale, such as the existence of a particular price advantage, the price or the manner in which it is calculated or the conditions under which the goods are delivered or the service is provided;
   (c) The person, characteristics or rights of the trader, such as identity, assets including intellectual property rights, the scope of obligations, qualifications, status, authorization, memberships or relationships, awards or honours, motives for the commercial act or the manner of distribution;
   (d) Statements or symbols that are related to direct or indirect sponsorship or that refer to an approval of the company or the goods or services;
   (e) The need for a service, spare part, replacement or repair;
   (f) The observance of a code of conduct to which the entrepreneur has made a binding commitment if he refers to this commitment, or
   (g) Rights of the consumer, in particular those based on guarantee promises or warranty rights in the event of service disruptions.

(2) A commercial act is also misleading if, in connection with the marketing of goods or services, including comparative advertising, it creates a likelihood of confusion with another product or service or with the trade mark or other distinguishing marks of a competitor.
(3) Information within the meaning of paragraph 1 sentence 2 shall also include information in the context of comparative advertising as well as pictorial representations and other events which are aimed at and suitable to replace such information.
(4) It shall be presumed that it is misleading to advertise by reducing a price if the price has only been demanded for an unreasonably short time. If it is disputed whether and in what period of time the price was claimed, the burden of proof shall rest with the party who advertised with the price reduction.

21.12.5 § 5a UWG: Misleading by Omission

(1) In assessing whether the non-disclosure of a fact is misleading, particular account shall be taken of its significance for the commercial decision according to the perception of the public and of its capacity to influence that decision.
(2) Any person who, in a specific case, withholds material information from the consumer, having regard to all the circumstances, is acting unfairly.

   (a) Which the consumer needs, according to the circumstances, to take an informed transactional decision and
   (b) The withholding of which is likely to cause the consumer to take a transactional decision which he would not have taken otherwise.

   The following shall also be deemed as withheld

   (a) The concealment of essential information,
   (b) The provision of material information in an unclear, incomprehensible or ambiguous manner,
   (c) Failure to provide essential information in a timely manner.

(3) Where goods or services are offered, by reference to their characteristics and price, in a manner appropriate to the means of communication used and in such a way that the average consumer is able to conclude the transaction, the following information shall be regarded as material within the meaning of paragraph 2, unless it is directly apparent from the circumstances:

   (a) All the essential characteristics of the product or service, to the extent appropriate to the product or service and the means of communication used;
   (b) Ihe identity and address of the trader and, where appropriate, the identity and address of the trader on whose behalf he is acting;
   (c) The total price or, where such a price cannot be calculated in advance owing to the nature of the goods or service, the method of calculating the price and, where appropriate, any additional freight, delivery and delivery costs or, where such costs cannot be calculated in advance, the fact that such additional costs may be incurred;
   (d) Terms and conditions of payment, delivery and service as well as procedures for dealing with complaints, insofar as they deviate from the requirements of entrepreneurial diligence, and;
   (e) The existence of a right of withdrawal or revocation.

(4) Information which may not be withheld from the consumer by virtue of Union regulations or under legislation transposing Union directives on commercial communications, including advertising and marketing, shall also be regarded as material within the meaning of paragraph 2.
(5) In assessing whether information has been withheld, account shall be taken of

(a) Spatial or temporal limitations imposed by the means of communication chosen for the commercial activity, and
(b) Any measures taken by the trader to provide the consumer with the information other than by the means of communication referred to in point 1.

(6) Any person who fails to indicate the commercial purpose of a commercial act is also acting unfairly if the commercial purpose is not immediately apparent from the circumstances and the failure to indicate is likely to lead the consumer to take a transactional decision which he would not have taken otherwise.

Further provisions can be found in paragraphs 6 et seq. (comparative advertising, unreasonable harassment, right to injunctive relief in case of infringements, damages).

Also worth mentioning are the Trademark Act, which protects trademarks, business designations and geographical indications [Mark-1994] and the Copyright Act, which regulates the protection of authors of literary, scientific and artistic works [Urhe-1965].

21.13 Checklist for Creating a Marketing Plan

In order to sum up this chapter, Fig. 21.10 presents an exemplary checklist for setting up a marketing plan.

1. Marketing / company stretch

Market observations / situation analysis / challenges / target market / goals

1.1 *The following information is required to take advantage of growth opportunities:*

- Who is the competition,
- Where is he with what products,
- with which positioning,
- in which market?

- How big is the market for us,
- with which products,
- whith which positioning,
- are we going to which market?

1.2 *Determination of the degree of efficiency*

Example:

- little efficiency
- despite high commitment
- but through lack of influence on product development

2. Product strategy definition

- Is product integration possible and sensible?
- Are products in line with the market or not anymore?
- Is the variety of products internally and externally unmanageable?
- Further product development possible / planned / financially feasible?
- Adaptation to local needs necessary?
- Long-term conception is important
- Who influences the product development and how?

3. Which sales tools are available?

- Product illustration
- Marketing task: Argumentation development
- Product specifications
- Conceptual presentation
- Trust in product information
- Which sales tools are missing?

4. Definition of marketing strategies

- Professional product announcement
- Advertising activities
- Identify product conflicts in sales strategy
- Sell what we have?
- Develop a closed marketing strategy for all products

5. Collection and analysis of competitive information and attitudes

- Examine market opportunities
- Carry out competition analysis
- Perform differentiation from the competitive product
- Collect information about the competition
- Markets: a.) Which ones? b.) Requirements c.) Products?
- Set competitive price (competitive pricing)
- Product, price and profit development analyse
- Processing market requirements
- Define maintenance costs
- Determine profit expectation

Fig. 21.10 Checklist for creating a marketing plan

References

[AMA-2013] American Marketing Association: https://www.ama.org/AboutAMA/Pages/Definition-of-Marketing.aspx. Zugriff am 5 Sept 2018

[Bidl-1973] Bidlingmaier, J.: Marketing I, rororo Reinbek (1973)

[DaWM-2003] Dannenberg, M., Wildschütz, F., Merkel, S.: Handbook Advertising Planning, Schäfer Poeschel Stuttgart (2003)

[Druc-1956] Drucker, P. F.: The practice of management. Econ Düsseldorf (1956)

[Druc-1973] Drucker, P.F.: Management, Tasks, Responsibilities, Practises, New York (1973)

[Exup-1996] de Saint-Exupéry, A.: The city in the desert. Citadelle', Ullstein Berlin (1996)

[Fröh-1987] Fröhlich, W.D.: Dictionary of Psychology, 15th edn, dtv Munich (1987)

[Gfk-2013] GfK Association: Forward-looking research on markets and consumers. http://www.gfk-verein.de/files/gfk_verein_brosch__re_web.pdf. Accessed 10 Sept 2013

[GWB-1998] Act against Restraints of Competition (GWB). Date of issue: 26 Aug 1998. www.gesetze-im-internet.de/bundesrecht/gwb/gesamt.pdf. Accessed on 15 Nov 2013

[HaEr-1997] Hammann, P., Erichson, B.: Market Research. UTB, Stuttgart (1977)

[Hess-2013] http://www.hesse-marketing.de/marketing/unser-verstaendnis.html. Accessed 11 Nov 2013

[Hütt-1977] Hüttner, M.: Fundamentals of market research, 3rd edn, Oldenbourg Munich (1977)

[Hütt-1979] Hüttner, M.: Information for marketing decisions. Oldenbourg Munich (1979)

[Host-2013] https://www.wirtschaftslexikon24.com/e/gfk/gfk.html. Accessed on 1 Sept 2013

[JvMa-2013] Homepage of Jung von Matt AG: Germany's most frequent living room. http://www.jvm-wozi.de/. Accessed 9 Sept 2013

[KASW-2011] Kotler, P., Armstrong G., Saunders, J., Wong, V.: Fundamentals of Marketing, 3rd edn, Peasrson Studies Munich (2011)

[KoBl-2001] Kotler, P., Bliemel, F.: Marketing Management, 10th edn, Shepherd Poeschel Stuttgart (2001)

[Lewi-1903] Lewis, E.: Catch-Line and Argument. The Book-Keeper, vol. 15, p. 2 (1903)

[Mark-1994] Law on the Protection of Trademarks and Other Distinctive Signs (MarkenG). Date of issue: 25 Oct 1994. www.gesetze-im-internet.de/bundesrecht/markeng/gesamt.pdf. Accessed on 15 Nov 2013

[McCa-1960] McCarthy, J.E.: Basic Marketing. A Managerial Approach. Richard D, Irwin Homewood IL (1960)

[McCO-2018] https://de.wikipedia.org/wiki/Cyrus_McCormick. Accessed 5 Sept 2018

[MeBl-2002] Meyer, A., Blümelhuber, C.: Offensive Marketing. In: Absatzwirtschaft, special issue for the German Marketing Day (2002)

[MeDa-2001] Meyer, A., Davidson, H.: Offensive Marketing: Winning with POISE. Shaping markets—exploiting potentials, Haufe, Freiburg 2001 (POISE stands for profitable, offensive, integrative, strategic and effective)

[Meff-2000] Meffert, H.: Marketing, 9th edition. Gabler Wiesbaden (2000)

[Mits-2018] Mitsui Homepage. www.mitsuipr.com/en/history/index.html. Accessed 5 Sept 2018

[NaKn-2011] Nagel, K., Knobloch, J.: Toolbox Practical company management (on USB stick). OLZOG-Munich (2011)

[NiDH-2002] Nieschlag, R., Dichtl, E., Hörschgen, H.: Marketing, 19th edition. Duncker & Humblot Berlin (2002)

[Niel-2018] https://www.wuv.de/medien/mobile_growing_slower. Accessed 5 Sept 2018. Nielsen-Consumers-DE-pdf-dt.pdf (Download 5 Sept 2018. Nielsen_Top Ten Trends_July_2018.pdf)

[Niel-2018] https://www.wuv.de/medien/mobile_growing_slower. Accessed 5 Sept 2018. Nielsen-Consumers-DE-pdf-dt.pdf (Download 5 Sept 2018. Nielsen_Top Ten Trends_July_2018.pdf (Download from 5 Sept 2018

[Stat-2018] https://de.statista.com/statistik/daten/studie/77151/umfrage/deutsche-exporte-und-importe-nach-laendergruppen/. Accessed 5 Sept 2018

[StBa-2013] Federal Statistical Office: Yearbook of the Federal Statistical Office 2013. Accessible via https://www.destatis.de/DE/Publikationen/StatistischesJahrbuch/StatistischesJahrbuch.html

[Tagw-2016] Tagwerker-Storm, M.: http://www.inknowaction.com/blog/innovationsmanagement/gruende-fuer-das-scheitern-von-innovationen-6091/. Accessed 8 Sept 2018

[Tauc-2013] Tauchnitz, J.: Marketing: The Origin of Marketing. http://www.marketing-tauchnitz.de/de/marketing.html. Accessed 14 Nov 2013

[Urhe-1965] Copyright and Related Rights Act (UrhG). Date of issue: 09 Sept 1965. www.gesetze-im-internet.de/bundesrecht/urhg/gesamt.pdf. Accessed 15 Nov 2013

[UWG-2004] Law against Unfair Competition, date of issue: 03 Jul 2004. www.gesetze-im-internet.de/bundesrecht/uwg_2004/gesamt.pdf. Accessed 14 Nov 2013

[VWUV-2018] Publisher Werben & Verkaufen GmbH, Munich https://www.wuv.de/agenturen/banalitaet_des_droegen_das_wohnzimmer_von_jung_von_matt. Accessed 6 Sept 2018

[Wöhe-2013] Wöhe, G.: Introduction to General Business Administration, 25th edition, Vahlen Munich 2013

[ZAW-2018] https://zaw.de/branchendaten/wirtschaft-und-werbung-2018/ Accessed 5 Sept 2018

[Wirt-2020] http://www.wirtschaftslexikon24.com/e/gfk/gfk.html. Accessed on 26th July 2020

[Belz-1998] Belz, C.: Akzente im innovativen Marketing. THEXIS Verlag St. Gallen 1998

[Schu-2020] Schuch, M.: Neuromarketing. https://www.planet-wissen.de/gesellschaft/wirtschaft/konsum/pwieneuromarketinghirnforscheruntersuchenwerbereize100.html. Accessed on 26 July 2020

[Häus-2011] Häusel, H. G.: Die wissenschaftliche Fundierung des Limbic® Ansatzes. Gruppe Nymphenburg München 2011

Chapter 22
Methods for Supporting IDE

Sándor Vajna

A method describes a procedure, process or action (prescriptive part) structured with rules, according to a plan and consequent in order to achieve one or more goals (intentional part, following [Frei-2001, Wahr-1978]). In the field of product development, there are various collections of methods and procedures for the design of products, e.g., [EhMe-2017, Dubb-2018, Hütt-2007, BeGe-2020, Otto-2013, SAKR-2005 and VWZH-2018] as well as standards and guidelines (e.g., from national and international standardisation bodies such as DIN, EN and ISO [Klei-2008], professional associations such as VDI, VDE and ASME as well as industrial associations such as VDMA and VDA[1]), which are also accessed within IDE.

It is hardly possible to deal adequately with the diversity and variety of methods, especially since their selection and application always depends on the current task. Figure 22.1 shows the basic structure of the assignment matrix of possible methods and tools to the activities of the IDE procedure model presented in Fig. 22.2. Methods and tools were compiled on the basis of [Neut-2010, Frei-2001] and experiences of more than ten years of IDE project work. Figure 22.2 may serve as a guide for the selection of suitable methods and tools when editing the individual activities within IDE (see also Fig. 16.5).

This chapter presents a selection of such methods that can be used profitably within IDE. After a short overview on innovation management, suitable methods for mastering personal work are described, then methods for supporting the development process, and finally approaches of how to present work results. However, a description

[1]DIN: German Standardisation Institute, EN: European Standard, ISO: International Standardisation Organization, VDI: Association of German Engineers., VDE: Association of Electrical Engineering, Electronics and Information Technology, ASME: American Society of Mechanical Engineers, VDMA: German Mechanical Engineering Industry Association, VDA: German Association of the Automotive Industry.

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1.	Personal support
2.	Project work in the broadest sense
3.	brainstorming, evaluation and fixation of ideas
4.	analytical methods
5.	Capturing, consolidating and documenting customer demands (required performance and performance of the product) as well as requirements from the given environment
6.	Research, knowledge acquisition
7.	Conception and implementation
8.	Methods, aids and tools for all activities in the IDE procedure model (Fig. 18.2)
9.	Computer aided methods and tools
10.	Methods and tools for documenting intermediate and final results

Fig. 22.1 Overview of the assignment matrix in Fig. 22.2

of all methods and tools that can be used within IDE would go beyond the scope of this chapter. For questions on the integration of different aspects and especially for methods and tools for the realisation of requirements with the focus on Functionality, please refer to [EhMe-2017, BeGe-2020].

22.1 Management of Innovations

The term *innovation* was derived from the Latin word "innovatio" meaning "renewal". In the technical environment, innovation has always meant the realisation of new ideas or processes as well as the fundamental renewal of products or processes, provided that these two are successfully introduced into the targeted market and perceived as such (otherwise it is not an innovation) [Otto-2013]. Innovation differs from a new development, and in that the market success plays a key role. The term is also intended to emphasise that the development of an innovative product which cannot be achieved through routine activities alone. Therefore, innovative elements can always be found also in an adaptation development.

The IDE is primarily used for the development of novel products and services that must be successful in the market. That is why IDE and innovation strengthen each other. Especially the neutral description of the expected performance of the product in connection with a corresponding performance behaviour by the IDE attributes is

		General	Research	Develop	Design	Integrate	Model	Configure	Synthetise	Evaluate	Compare	Select	Present	Complete	Type
1	Time management	•													M
	Presentation techniques	•													M/T
2	Project definition and project assurance	•													M/T
	Dynamic Navigation: process modelling, project management	•													M/T
	Team organisation, work, communication and moderation	•													M
	Distributed amd intercultural team work	•													M
	Forms of E-Collaboration	•													M/T
3	(Mind Mapping, Relation diagram	•													M/T
	Brainstorming, topic storage, gallery method	•													M
	Generation of product and business ideas	•													M
	Innovation management	•													M/T
	Check lists	•													M/T
	Verbal evaluation procedures	•													M
	Weighted scores / score evaluation	•													M
	Instructions and regulations	•													M/T
	Simultaneous calculation	•													W
4	Market analyses and trend studies		•												M/T
	Analyses of as-is states, demands and weak points		•	•	•	•	•	•	•	•	•				M
	User and buyer analyses		•	•	•	•	•	•	•	•	•	•			M/T
	Analyses of environments of application, operation, legislation, ...		•	•	•			•		•	•	•			M
	Product market matrix		•												M
5	Analyses of performance description and requirements		•	•	•	•	•	•	•	•	•	•	•		M
	Set up and update usage scenario		•	•	•	•				•	•	•			M
6	Literature, patent and property right searches		•			•			•						M
	Standards, norms		•			•		•		•	•			•	M
	Product catalogues, data sheets, brochures		•												M
	Engineering design catalogues		•	•				•			•			•	M
	Performance comparisons (benchmarking, best practices)		•	•				•		•	•	•			M
	Empirical characteristics, empirical knowledge		•	•	•	•	•	•	•	•	•	•	•		M
7	Black box analysis			•				•							M
	Create attribute profile from customer demands and environments		•	•	•	•	•	•		•	•	•			M/T
	Structuring attributes and their inter-dependencies		•	•	•		•	•		•		•			M
	Coarse and fine layout of attributes			•	•	•	•	•	•		•	•	•		M
	Attribute fulfillment level (safety, reliability, quality)			•	•	•	•	•	•	•	•	•			M
8	Morphological box			•		•		•	•	•	•	•			M/T
	Similarity laws, analogy methods			•	•	•		•	•	•					M
	Design for X (DfX), X for Design (XfD)			•	•	•	•	•	•	•	•	•		•	M
	Cause-effect diagram (Ishikawa)			•	•			•		•					M
	Failure mode and effect analysis (FMEA)			•				•		•	•	•			M/T
	Risk analysis			•				•		•	•	•			M
	Value and impact analysis			•				•		•	•	•			M/T
9	CAx modeling, creation of the Digital Twin						•	•		•	•			•	M/T
	Calculations (analytic, FEM, BEM, CFD,...)						•	•	•	•	•	•			M/T
	Simulation, Animation, Virtualisation				•	•	•	•	•	•	•	•	•		M/T
	Optimisation strategies and algorithms				•	•	•	•	•	•		•			M/T
	Fault tree analysis (FTA)							•		•		•		•	M
10	Sketching			•	•		•					•	•		M
	Creation of drawings and further documentation												•	•	M
	Concept modelling, additive manufacturing						•						•		W
	BOM generation													•	W
	Generation of work plans													•	W
	Entire documentation of all activities and results	•													M/T

Fig. 22.2 Assignment matrix of methods (M) and tools (W) to activities within IDE procedure model (Chap. 16)

very beneficial for the development of an innovation, because in IDE the concrete realisation of the product has to be determined only at a very late point in time (namely during process planning). IDE thus provides a much larger time window and thus much more opportunities for finding and developing innovations to meet the requirements that is the case with traditional approaches or rigid specifications for development projects (e.g., Sect. 15.3.1).

As a precursor, an innovation initially has an idea from which an invention arises that can lead to an innovation.

- An idea is a deliberate decision to look more closely at a (research) subject or a vague idea that promising innovations are possible within a still very blurred area.
- If these innovations show potential for success, then an invention can emerge that incorporates new findings from science and research or from daily use. It may also consist of a new combination of known knowledge or of a new arrangement of products and services in a previously unknown form. There is no direct model for an invention.
- Innovation management combines corporate research with product planning, marketing and generating new product and business ideas and product development. As soon as an idea or an invention shows market potential, the further activities are controlled by the product management, so that the successful market entry and a high market penetration (diffusion) can be achieved.

An innovation can also be defined as a synergy of idea, invention and diffusion [MüDö-2009]. It is always successful when disruptions (discontinuity, destabilisation and/or break with proven procedures in product development and production) are consciously accepted, so th [Otto-2013] at something new can emerge. Today, it can be assumed that only every seventh or eighth idea becomes an innovation [2].

Figure 22.3 shows the development and life cycle of an innovative product.

The triggers are discoveries, ideas and inventions, but also the fulfilment of latent needs in the market. In addition, needs can be created by the provider (Sect. 2.2.2) or by new technologies (technology push). This leads to the development of an innovative product. Since their outcome is not certain at first, the character of the situation is chaotic at the beginning. As the situation becomes more manageable with the increasing realisation of the product, development stabilises so that the market can be supplied. For the management of innovation activities and processes, there are numerous tried and tested approaches, for example, the dynamic approach of OTTOSSON [Otto-2016] or the methodical approach of LINDEMANN [GüLi-2016], so that there is no need to go into them in detail here[3]. During the product's lifetime,

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[2]Today, it can be assumed that on average, about 100 of 500 ideas are treated in research and development, of which 57 lead to a product. Of these, 31 are launched on the market, but only 12 (i.e., 2.4%) become successful on the market [GüLi-2016].

[3]One should, however, be aware of the fact that a well-running innovation management approach cannot guarantee an innovation if neither the idea, nor the invention, nor the marketing activities are neither promising nor appropriate.

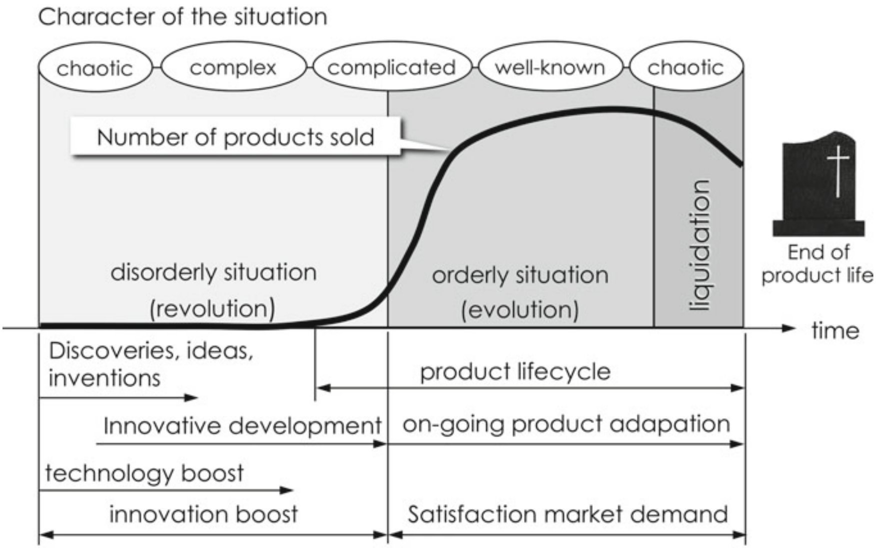

Fig. 22.3 Emergence and life cycle of an innovative product [Otto-2013]

the product is usually continuously adapted until the market demand is satisfied, and the product has reached the end of its life.

In sum, the success of an innovation is not only due to a good idea or an appealing invention, but also to the courage of the entrepreneur, the Quality of the employees, but also to the current situation in the market and the general social environment, and finally to the stamina of the company in the form of capital investment for marketing the new product.

22.2 Time Management

Time management and project management (Sect. 15.2.3 and for example [Hahn-2001]) are comparable in many respects. In both cases, objectives are formulated, and tasks, scope of work and completion date are defined. While a project should have a concrete result at the end, time management deals with the art of planning and using the time available in the best possible way according to the respective situation.

The goal of time management is not to be dominated by time, work and external circumstances, i.e., only to react to what is coming your way. Rather, time is to be arranged in such a way that one can control it oneself. This requires planning the time available to one, improving one's working methods, recognising one's individual strengths and weaknesses in the use of time, setting the right priorities, improving cooperation in one's own environment and reducing disruptions and so-called "time wasters".

However, time management is not about planning the entire time. On the one hand, this would leave no time for spontaneous things such as ideas and creativity. On the other hand, there are always unplanned, but not always avoidable disturbances of all kinds, for example, suddenly necessary appointments or a reaction to external events. For this reason alone, only about 60% of the actually available working time should be planned, while the remaining 40% of the time should be kept in equal parts as free space and as a buffer.

Most importantly, there should be regular and sufficient opportunities to recover from an effort and enjoy the satisfaction of a job well done. In the *Therblig* approach of the couple Lillian M. and Frank B. GILBRETH to structuring and optimising activities [Ferg-2000], described in Sect. 15.7, the 18th Therblig is called *rest for overcoming fatigue*. Its purpose is to provide a reasonable balance between effort and free space[4], so that job satisfaction and performance levels can be maintained overall (see also Chap. 4).

It makes sense to keep a list of open items and tasks to be completed (action list) and to focus time management not only on a working day, but also on weeks, months, and years. One should also update the action list and schedule whenever either a task has been completed or a new task is to be processed.

In the action list, on-going prioritisation of the contents is required. The benchmark for this is a balanced ratio of effort (= time, degree of target achievement) and benefit (= success, Quality, recognition) in completing the task. Prioritisation is based on the excellence of the task execution, which can be

- perfect,
- good (but not perfect) in the sense of the 80:20 rule of PARETO (Chap. 1) and
- sufficient with minimum effort.

The basis of daily time management is, on the one hand, the distribution of human performance over a day (the performance course) and the course of concentration during the performance of a task (the concentration course). Figure 22.4 shows the typical progression of the two courses. Both have individual characteristics[5].

- The performance course shows the two high phases of performance in the late morning and early evening, with the area of increase of the course better suited for creative activities, while routine tasks can also be performed during the decline of the performance or at the low point of the course. One low point is at the end of the night, another in the early afternoon.
- The drop in the concentration course shows that it is recommended in the sense of the 18th Therblig to take a break of 5–10 min after a working time of 45 min, so that the ability to concentrate can recover. This also applies to meetings, which should not last any longer without breaks.

[4]The GILBRETH couple called this free space *time out for happiness* [Lanc-2004].

[5]For example, the performance course differentiates between whether someone can get up early (“early morning lark”) or work longer in the evening (“nocturnal owl”).

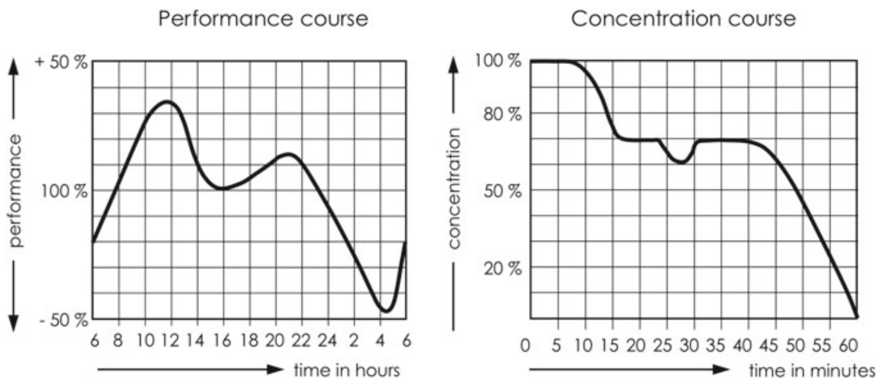

Fig. 22.4 Performance course and concentration course according to REFA (quoted from [Seiw-1987])

- Although some people (preferably managers) today consider parallel work and multitasking skills to be necessary, only one task should be done at a time, so that people are focused on a single, not fragmented goal, and thus given the chance to complete it successfully. In addition, the susceptibility to errors during parallel work increases due to the continuous toggling back and forth between the simultaneously processed topics[6]. The ability to concentrate decreases correspondingly faster.
- A time range should be provided daily as a "silent hour" without fixed planned contents, in which one should not be disturbed.

A daily plan (or daily schedule) is created at the start of the workday or (better) the evening before. Even though today there is a large number of computer-aided planning systems available, it makes sense to carry out the daily planning in writing on paper, because by combining intellectual examination with the planning and its written fixation, the plan is better memorised than simply moving blocks on a screen [Jans-2012].

The current tasks to be processed are compiled for daily scheduling. This approach contributes to a proactive rather than reactive approach. A realistic daily schedule contains only such a number of tasks that can be completed on that day. One can sort it according to the ALBEC method[7] [Seiw-1987]. ALBEC stands for the first letters of the terms **a**ctivities, **l**ength of processing, **b**uffer time, d**e**cisions and follow-up **c**ontrol. First, all activities are listed (= A). This includes tasks, appointments, routine tasks and unfinished business. In the second step, the length of processing is estimated for each activity (= L). The buffer time mentioned above is reserved

[6]This also applies to simultaneous telephoning, listening to music and watching video clips in the private environment, which means that none of these activities can be adequately devoted to.

[7]The original German name is "ALPEN", which is composed of the first letters of the German terms **A**ktivitäten (activities), **L**änge der Bearbeitung (length of processing), **P**ufferzeit (buffer time), **E**ntscheidungen (decisions), **N**achkontrolle (follow-up control).

for unforeseen events (= B). This is followed by decisions on priorities, reductions and delegation of tasks to others (= E), as tasks should be carried out by those who can do it best. The prioritisation can be done with an ABC analysis [Krie-2013][8], whereby the focus is on the respective contribution of the work to the achievement of the objectives.

- A: 15% of the tasks bring 65% contribution,
- B: 20% of the tasks bring 20% contribution and
- C: 65% of tasks bring 15% to the achievement of objectives.

In the schedule, for example, about three hours are provided for one to two A tasks[9]. Two to three B-tasks can be processed in one hour. 45 min are scheduled for C-tasks. This means that about 60% of the working time is planned. During processing, external and internal changes can cause importance and urgency to be adjusted if, for example, A tasks suddenly become B tasks due to new circumstances.

Unpleasant tasks play a special role. They should be completed first, regardless of their (more technical or strategic) prioritisation, so that psychological pressure gives way, and the following tasks can be dealt with more easily.

At the end of a work phase (end of a project, end of the day), the follow-up check (= F) takes place. It must be critically questioned whether the task or the day went as intended and why there were differences between the schedule and the actual workflow. In the process, unfinished tasks can be re-prioritised and carried forward to the following day.

Not every working day will go as planned because of unforeseen disruptions and time wasters. Disturbances include telephone interruptions, unannounced visitors, inappropriate communication requiring additional work, lengthy meetings, unpleasant working environment (noise, climate, lighting, smells), unwillingness to work, chronic disorder and other distractions [Hirt-2009].

Typical time wasters are shown in Fig. 22.5. This presentation should help in the search for individual time wasters and show how to avoid them.

The management of one's own working time has the same objectives and similar effects as dynamic navigation (Sect. 15.7) and the planning of production processes at the end of product development (Sect. 2.2.8). In both cases, a plan for processing the upcoming tasks is created first. By restructuring the processing, by free space and buffer times, flexibility is created to achieve a satisfactory result for everyone (even with changing targets) without overcharging oneself.

[8]General Electric developed the ABC analysis in the 1950s. It is a procedure for the classification of units, whereby the limits of the individual classes can be defined according to the area of application. The ABC analysis uses elements of the Pareto rule and other unequal distributions, such as the Lorenz curve [Krie-2013].

[9]The time specifications used in the example can differ individually. When planning, however, the (individual) duration of the ability to concentrate should always be taken into account, as this makes it difficult to spend more time on a task without breaks.

Time-eaters	Possible reasons	Relief
No goals, priorities, daily schedules	No planning system	Implement time management
	Successful without planning	Planned activities usually are more successful than unplanned ones
	"Days can't be planned"	Planning creates free space for priorities and unforeseen events
	Action orientation	Success also means knowing when to do something, why and how
Doing too much at once	No time management	Formulate goals, set priorities, manage the working time
	Focus on the urgent	Consider importance as well as urgency
	Interests ranges too broad	Limitation to the essentials
Indecisi-veness	Mistakeophobia	Recognized and corrected errors lead to increased knowledge
	No rational decision-making process	Collect facts, examine alternatives, evaluate, decide
	Perfectionism	Include unavoidable risks and ambiguities in decisions
	Lack of initiative and motivation	Find out the reasons and fix any problems that cause it
Haste and impatience	No planning of the working day	Daily planning on the previous day
	No evaluation of tasks	Create ranking based on importance and urgency
	Want to do too much in too short a time	Delegate tasks, if possible
	Taking care of every detail	Perform tasks consistently and correctly
be incapable of saying no	Fear of insulting someone	Politely refuse request and offer serious alternative
	No excuse ready	Rejection with reference to planned activities
	Demand for support	Rejection with reference to planned activities
	Desire to please others	Weighing up according to importance, urgency and compatibility
	High willingness to help	Weighing up the own benefits against the own disadvantages

Fig. 22.5 Typical time wasters [Seiw-1987]

22.3 Work Structuring Possibilities

Any form of work organization is only effective if it provides the user with a structure in which a uniform approach is pursued. Some possibilities for work structuring are briefly presented here. These are working methods and forms of presentation that can help in the work on complex problems [Neut-2010].

As a basis for an efficient project flow, the structuring methods described in the following have proven to be helpful in many applications. However, they are only a selection among innumerable methods of work structuring. Their importance is not only evident in the literature, but also in student IDE projects in which they help students to keep track of complex situations.

22.3.1 *Mind Mapping*

Although already over 30 years old, the creation of a mind map has been a recognised and helpful method to promote one's own creativity, to concretise goals, to structure complex contexts as well as to present these holistically and nevertheless clearly [ScSS-2006].

In a mind map, relationships between different terms are displayed graphically. The theme of the mind map is positioned in the middle of the display (usually on an unlined sheet of paper in landscape format). Various main strands with further ramifications are attached to the theme. Keywords and core terms are noted on or

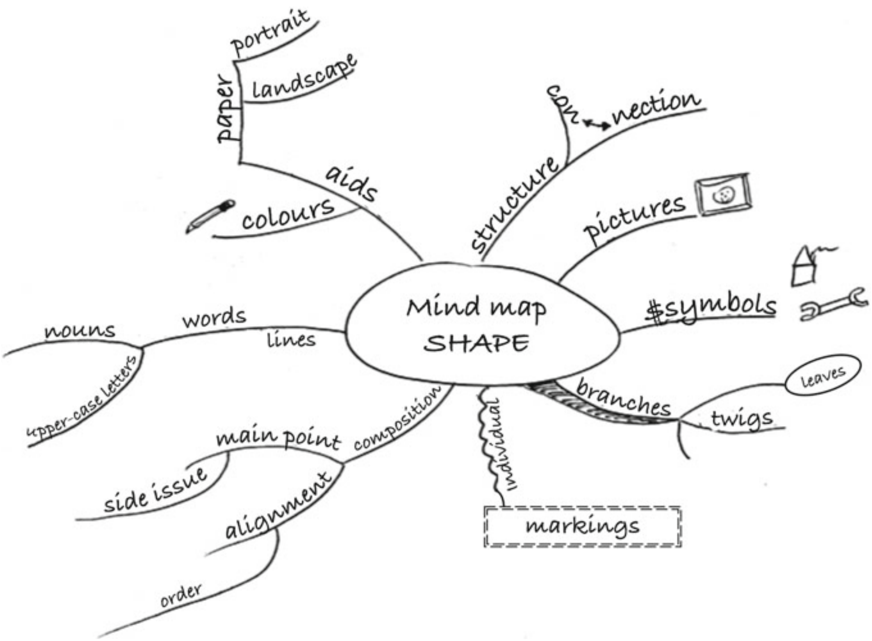

Fig. 22.6 Elements and basic structure of a mind map (thought map, based on [MeHu-2007])

near the branches [Dahm-2008]. Colors, hatchings, sketches and stickers can be used to clarify and visually highlight lines of thought, Fig. 22.6.

With this combined graphic and textual representation, different areas in both brain hemispheres are stimulated simultaneously, since the optical stimulus of drawing (arrangement and combination of terms) is combined with the thoughts and movements of writing down. This leads to an increased perception, faster reception (learning effect) and a better networking of the topic in the brain, so that the topic is forgotten less quickly.

In spite of the seemingly limitless design possibilities of a mind map, the following hints should be observed during the creation, which make this method even more effective [ScSS-2006]:

- A mind map should always be created by hand and with a pencil. Compared to a computer support (for example MindManager, FreeMind), the following advantages are offered:
  - The drawing area is fully usable, texts and graphics can be changed easily with a pencil.
  - Hand-drawn symbols, colors and images can be used without restriction to clarify the facts.
  - Immediate and unrestricted readability (no software conflicts).
  - Spontaneous use at any place.

- Use the paper in landscape format because, on the one hand, it optically opens the space or the surface (unconscious promotion of creative thinking). On the other hand, a portrait format would automatically trigger the learned constraint of left-to-right writing. In addition, the portrait format drives the view into the upper left corner of the sheet and thus possibly weights it more strongly than intended.
- When creating a mind map, one should be as uncritical and undemanding as possible when it comes to execution. A mind map is not a work of art but serves primarily as a personal tool for structuring facts and thoughts. Too high demands are often disruptive and inhibit creativity in the creation process.

This representation technique is particularly suitable for processing and networking new information whose structure is still unknown. Particularly advantageous is the free graphical structure, which allows every user to add something at any position at any time during the creation. Thus, mind maps can also be used as a transcript for brainstorming or other team work [MeHu-2007].

22.3.2 Schedule and Task Lists

Schedule lists originate from the building industry[10]. They are mainly used for the planning and presentation of projects and for the exchange of information. Their advantage lies in the good legibility. Even for an observer who is not involved in the project, the clear representations of the work processes and the assigned execution times are easy and clear to recognise. In schedule lists, work processes cannot only be tracked in terms of time, but also the required manpower and equipment can be assigned. The aim of the list display is therefore primarily the creation of easy-to-read and manageable specifications for the executive divisions of the company. The independence from specific software (although such a software is available) is also an advantage, as scheduling and task lists still are created mainly with programs for word processing and spreadsheets.

Standardised scheduling and task lists usually contain the following information:

- Number of the operation
- Start of operation (date)
- Operation description
- End of operation (date).

Their most common application is the quick and easy display of calculation results when working with networks (e.g., critical path, CPM). As Fig. 22.7 shows,

[10] One of the first documented applications of scheduling and tasks lists can be found in the book *Field System* [Gilb-1908] published by the couple Lillian M. and Frank B. GILBRETH in 1908, a collection of 573 rules (with justification) for rational procedure for the employees of their own construction company (the book, however, appeared only with the author Frank. B. GILBRETH, because at the time it was assumed that it would be detrimental to success if an author who was not a specialist was also involved [Grah-1998]).

Process no.	Activity	Start of processing		End of processing	
		Target time	Actual time	Target time	Actual time
101	research	14.10.19		30.10.19	
102	concept design	25.10.19		06.12.19	
103	detail	28.11.19		19.12.19	
104	realise	20.12.19		30.01.20	
...	...				

Fig. 22.7 Extract from a scheduling and tasks list (after [Bern-2008])

lists of dates can also be used for process control to compare target and actual dates [Bern-2008, Keßl-2008]. Scheduling and task lists are designed in the same way as appointment lists.

22.3.3 Network Maps

A network map is a graphical representation of the schedule dependencies of all individual activities belonging to a larger project with the aim of making the complicated meshing manageable even in the case of larger projects.

The basis for the network planning technique is the graph theory. Nodes and arrows are used for display, and their meanings are defined differently depending on the method used. Figure 22.8 shows the three different possibilities of element arrangement and their meaning.

Events and procedures can be represented by nodes and arrows. A process defines the change of a state within a period of time and an event defines the occurrence of a certain state. In addition, further information can be conveyed through the network through relationships of events and activities ([Hahn-2001, Keßl-2008]).

The three methods of the network map technique shown in Fig. 22.8, of which components are used in dynamic navigation (Sect. 15.7), are the following:

- CPM, critical path method, that run through the network is identified in which the time shifts of individual steps along the path lead to a shift of the end date.

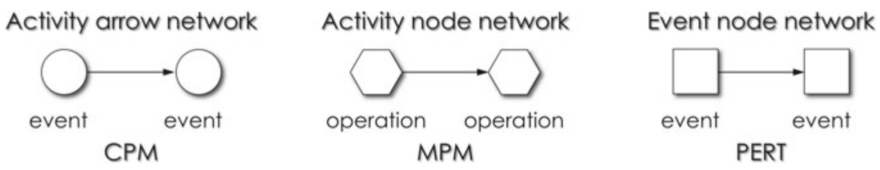

Fig. 22.8 Graphical representation of network plans (according to [Hahn-2001]). CPM: Critical path method, MPM: Metra potential method, PERT: Program evaluation and review technique

The focus of the run is on avoiding disturbances along the critical path, so that the deadline can be met.

- MPM, method of process node representation (Metra[11] potential method). Each activity (node) has a processing duration, a predecessor and a successor, so that a complete run is possible. The links between the activities (arrows) capture the shortest possible time interval between an activity and its successor (earliest possible start date of the next activity) and the longest time interval (latest possible end date of the processing of the next activity). From this, one can determine the latest possible start date and the earliest possible end date of the project using forward and backward calculations.
- PERT, program evaluation and review technique, is applied for those projects for which little experience is available so far with regard to processing time, resource requirements and task fulfilment of the individual nodes. The run through is simulated in advance with estimated values, which are successively replaced by current results during processing, thus making the project process more and more precise.

22.3.4 Gantt Charts

Gantt charts graphically represent project workflows as a chronological sequence of activities. They use horizontal and vertical structuring for this purpose[12]. Usually, the work steps and sequences (operations) are displayed on the vertical and the assigned machining times on the horizontal. It is useful to list the operations that have a significant influence on the workflow in the sequence in which they occur. The creation of a bar chart is usually done in the following steps [Bern-2008]:

- Clarification of the planning level (level of detail),
- Definition of the time scale as a function of the planning level (division of the time axis),
- Determination of all required procedures and
- Time allocations by drawing a bar from the beginning to the end of each operation. Thus, the length of the bar indicates the duration of the process.

In practice, the Gantt chart is very often used. It is just as simple and understandable as a schedule list but offers a visual advantage, and in that the respective processing periods and dates of the various processes are displayed graphically. The user can select a specific date on the time axis and read directly from the bar display which processes must already have been completed, which are still in progress and

[11]Named after the French company Metra (now Atos), which developed this method.

[12]According to their developer Henry L. GANTT, who belonged to the circle of friends of the GILBRETH couple, bar charts are referred to as Gantt diagrams.

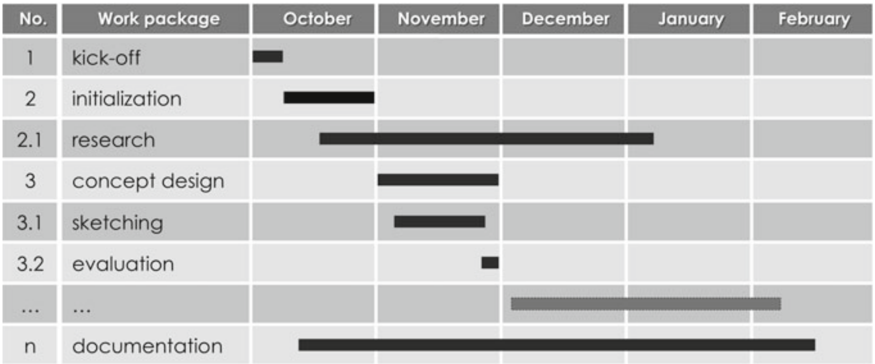

Fig. 22.9 Schematic of a gantt chart (according to [Bern-2008])

which work packages will be started in the future. A disadvantage of Gantt charts is the missing display of dependencies between the individual operations. This can be avoided by using connecting arrows between the work packages. By linking the work steps, it is thus possible to document planning considerations [Bern-2008]. Figure 22.9 shows a typical bar chart as a rough schedule.

22.4 Presentation Techniques

A presentation is a lecture on results, products, ideas, concepts, etc. (usually media-supported in a technical environment). During the presentation, the presenter builds relationships with the audience at the factual and personal levels. At the factual level, the presenter provides information to which the audience can react or provide feedback. On the personal level, the significance and credibility of the information presented are conveyed.

The presentation focuses on the presenter as the decisive factor for the success of the presentation. The presenter is supported by a clear goal of the lecture as well as by the selection of the right media, a suitable environment and applying rhetorical means adapted to the audience.

Media are tools to transport information to the listeners:

- Technical presentations are usually supported with images (slides) or short video clips. Both serve to visualise the essential statements in order to implement them in an optically appealing and cognitive way.
- In order that the audience is not distracted by the spoken word, there should be no continuous text on slides (for example, sections from an accompanying article), but only the core statements of the lecture as confirmation and support for thought.

- Excessive and playful background images on slides are not advisable, as they impair clarity. Note: The slide does not have to please the presenter, but has to provide the participant quickly and precisely with the information.
- The “degree of blackness” of a film should be very low and the font height is so large that all content can be easily recognised from the last row. This usually means that the font size should be at least 12 points. Serif-free fonts are the best choice for a presentation.
- Slides can be animated within limits for better clarity, for example, statements can appear one after the other or more complex graphics build up step by step for better understanding.
- As a guideline for the number of slides in a presentation, a new slide should be used approximately every two minutes (important facts should be presented on a separate slide, respectively). As an upper limit, no more slides should be used which are available as lecture minutes (e.g., no more than 20 slides with 20 min of lecture time excluding the question and answer session).

The environment of the lecture should be appropriate to the topic of the lecture.

The means of rhetoric serve to draw the attention of the listeners to the speaker and to keep them there (concentration) as well as to captivate them (identification with the lecture and with the presenter), so that the audience finally takes over the opinion of the presenter (persuasion). There are verbal (language, examples, questions) and non-verbal means (posture, eye contact, gestures, facial expressions, speaking speed, tone of voice). The following applies to verbal means:

- The language should be clear and simple. This means that the use of main clauses, preferably no subordinate clauses and no endless sentence monsters. Language also should not be too theoretical, but quite pictorial (even theoretical statements can be supported by pictures). Irony and jokes should only be used specifically.
- The voice should be varied and appropriate to the meaning of the statement. Pauses in the sentences should follow the punctuation. Since people with little presentation experience are nervous, they should consciously speak slowly, loudly, clearly and unambiguously. Even if a lecture is usually held in high-level language, it can be useful and relaxing to use sometimes a dialect to emphasise certain statements.
- During the lecture, the presenter should be natural and avoid any showmanship. The speech should be delivered freely, not read from a written text. To keep the speaker from losing the red thread, notepads are permitted (but not necessarily recommended) as a reminder.
- Examples should come from the professional or private environment of the audience.
- Rhetorical questions can be asked by the speaker and answered by the audience. If possible, the names of the listeners should be used for questions or direct contact.

Regarding the non-verbal means:

- The posture usually symbolises the inner attitude and self-esteem of the speaker. Even if one feels insecure inside, one should not transport it to the outside, but stand upright and be relaxed.
- Eye contact to individual listeners should always exist (but never to the same), so that the presenter delivers the lecture in the direction of the listeners. The presenter should always be aware that the slides used in the lecture are not intended to support him/herself, but rather to guide the audience. As a consequence, one resists rather the temptation to turn away the view from the listeners and to focus too strongly on the presentation wall.
- Gestures are used to support or emphasise certain statements. They are expressed by arms and hands which, depending on the culture, symbolise opening, rejection, trust or mistrust. They can refer directly to current verbal communication in terms of time and content, supplement it or even replace it if the speaker communicates only through gestures.
- The facial expression, especially by changing the eye and mouth area, allows for a much more nuanced form of expression, which often says more about the inner experience of the speaker than words do. If, however, the verbal message does not correspond to the non-verbal facial expression, then the credibility of the speaker is at risk.

There are different forms of a lecture. In the technical environment, lectures and presentations are the most common.

- In a lecture, the focus is on conveying information. It is coupled with the presentation of one's own point of view and with information that should convince the listener [Stud-1999].
- In a product presentation, the focus is always on the products to be presented and never on the person giving the presentation. Therefore, the presenter should avoid the "I" form. If presenting in second place, the speaker's introduction should be only briefly[13] as this draws the auditorium's attention too much away from the product and towards the presenter.
- A product presentation should always be formulated positively. Also in evaluations of analyses and comparisons rather, advantages (also from competitors) should be compared (then possibly in deviant quantity). On the one hand, the listeners always keep a positive basic mood towards the speaker, and on the other hand, one leaves the formation of opinion (apparently) to the audience, which is just as advantageous.

For the lecture to succeed, it is necessary that the speaker attunes himself positively and is not afraid of the auditorium (or at least does not show it). The speaker should be on time. The presentation media should have been set up and tested for Functionality beforehand. A lecturer should only work with media that he or she can

[13] The gladly used phrase "also from me once again a warm welcome" is superfluous.

master[14]. The lecture should begin and end at the times indicated. Its duration should take account of the audience's decreasing ability to concentrate (see Fig. 22.4).

A presentation can be structured according to the so-called C-A-I-S formula (quoted and translated from [Seiw-1987])[15]:

- Contact phase (C): Making contact with the listeners, for example through personal words, an anecdote from the environment of the listeners, etc. (the so-called "icebreaker").
- Attention phase (A): "picking up" the audience, naming lecture topics and objectives, indication of the planned duration of the lecture.
- Instruction (I): Work through the individual topics one after the other without mixing topics. An interim conclusion after each topic helps the listeners not to lose the thread despite the wealth of detail.
- Substantiation (S): All important points are repeated at the end, so that the listener can see the overall context of the presentation and remember the last words best. In the end, the speaker thanks the audience.

In the run-up to the lecture, it has to be decided for which audience the lecture is for, how many listeners are expected, what similarities the listeners have and what their expectations are. During the preparation, topics and goals are defined and the lecture material is collected. The material should be prepared in such a way that the listeners can immediately grasp the content and statements during the first listening (and with the support of pictures). It is therefore always helpful to rehearse a presentation beforehand, for example, in front of one's own mirror image or in front of a camera.

During the lecture, a tension curve should be built up in order to arouse and hold the interest of the listeners. For understanding, it is helpful if the statements of the lecture are embedded in a suitable story, Fig. 22.10.

According to the C-A-I-S formula, the listeners are picked up at the beginning (C), for example by associating their expectations with the topic of the lecture (A). Then, the first culmination of the lecture will be prepared, during which the key messages will be taught (I-1). In order that the listeners can better understand and internalise what has just been said, it makes sense to lower the tension by detailing the statements just made and by telling a short story (S-1), so that the listeners can recover briefly and increase their ability to concentrate again[16]. This prepares the audience for the next highlight of the lecture (I-2). This interplay of instruction and confirmation (including recovery) can be repeated several times. Finally, the tension curve is lowered further to say goodbye to the listeners with a summary and a joke (S-2).

[14]There is hardly anything more embarrassing than a lecturer who fails to get a computer or presentation program up and running in a reasonable amount of time.

[15]The original German formula is called K-A-U-B, where K stands for "Kontakt" (contact), A for "Aufmerksamkeit" (attention) U for "Unterrichtung" (instruction), B for "Bekraeftigung" (substantiation).

[16]This is in analogy to the application of the 18th Therblig, see Sect. 22.2.

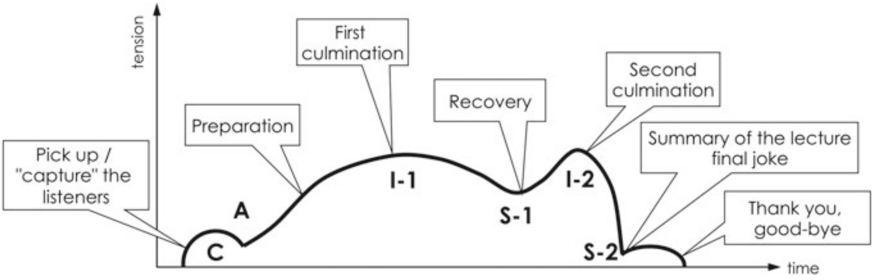

Fig. 22.10 Tension arc in a lecture (C, A, I, S: Elements of the C-A-I-S formula and their application times)

References

[BeGe-2020] Pahl, G., Beitz, W., Bender, B., Gericke, K: Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung 9. Springer, Berlin (2020)

[Bern-2008] Berner, F.: Grundlagen der Baubetriebslehre 2: Betriebsplanung. Vieweg+ Teubner–Verlag, Wiesbaden, 1. Auflage (2008)

[Dahm-2008] Dahms, M.: Motivieren, Delegieren, Kritisieren—Die Erfolgsfaktoren der Führungskraft. Betriebswirtschaftlicher Verlag Dr. Th. Gabler, Wiesbaden, 1. Auflage (2008)

[Dubb-2018] Dubbel, H.: Taschenbuch für den Maschinenbau, 25. Auflage. Herausgegeben von K.-H. Grote, D. Bender und D. Göhlich. Springer Heidelberg 2018

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, sechste vollständig überarbeitete und erweiterte Auflage. Carl Hanser Verlag München (2017)

[Ferg-2000] Ferguson, D.: Therbligs: The Key to Simplifying Work. The Gilbreth Network, http://gilbrethnetwork.tripod.com/therbligs.html. Zugriff am 06 Sept 2013

[Frei-2001] Freisleben, D.: Gestaltung und Optimierung von Produktentwicklungsprozessen mit einem wissensbasierten Vorgehensmodell. Dissertation Otto-von-Guericke-Universität Magdeburg (2001)

[Gilb-1908] Gilbreth, F.B.: Field system, Myron C. Clark New York 1908 und Management History Series No. 30

[GüLi-2016] Gürtler, M., Lindemann, U.: Innovationsmanagement. In: Lindemann, U. (Herausgeber): Handbuch der Produktentwicklung. Hanser München (2016)

[Grah-1998] Graham, L.: Managing on her own: Dr. Lillian Gilbreth and women's work in the interwar area. Engineering & Management Press Norcross (1998)

[Hahn-2001] Hahn, R.: Projektmanagement für Ingenieure. Wiley-VCH-Verlag, Weinheim (2001)

[Hirt-2009] Arbeitsunterlagen zur Hirt-Methode. Hirt-Institut Zürich (2009)

[Hütt-2007] HÜTTE—Das Ingenieurwissen, 33. Auflage. Herausgegeben von H. Czichos, M. Hennecke, Akademischer Verein Hütte e.V.. Springer Heidelberg (2007)

[Jans-2012] Janson, S.: Elektronische Planung und Papier müssen keine Feinde sein. Beitrag vom 31. 11. 2012 auf http://imgriff.com/2012/11/21/daten-optimal-organisieren-elektronisch-vs-papier/. Zugriff am 06. Sept 2013

[Keßl-2008] Keßlau, K.: Weiterentwicklung des generischen IPE-Prozesses. Interner Bericht Lehrstuhl für Maschinenbauinformatik, Otto-von-Guericke-Universität Magdeburg (2008)

[Klei-2008] Klein, M.: Einführung in die DIN-Normen, 14. Auflage. Herausgegeben vom DIN Deutsches Institut für Normung e.V.. Springer Heidelberg (2008)

[Krie-2013] Krieger, W.: Stichwort ABC-analyse. In: Gabler Wirtschaftslexikon, herausgegeben vom Springer Gabler Verlag. http://wirtschaftslexikon.gabler.de/Archiv/76978/abc-analyse-v8.html. Zugriff am 10. Sept 2013

[Lanc-2004] Lancaster, J.: Making time. Lillian Moller Gilbreth—A life beyond "Cheaper by the Dozen". Northeastern University Press Hanover (USA) (2004)

[MeHu-2007] Messing, B., Huber, K.-P.: Die Doktorarbeit—Vom Start zum Ziel, 4th edn. Springer, Berlin (2007)

[MüDö-2009] Müller-Prothmann, T., Dörr, N.: Innovationsmanagement. Strategien, Methoden und Werkzeuge für systematische Innovationsprozesse. Hanser München (2009)

[Neut-2010] Neutschel, B.: Adaption des generischen Prozessmodells der Integrierten Produktentwicklung für den Industrieeinsatz. Interner Bericht Lehrstuhl für Maschinenbauinformatik, Otto-von-Guericke-Universität Magdeburg (2010)

[Otto-2013] Ottosson, S.: Frontline Innovation Management (zweite Auflage). Tervix Göteborg (2013)

[Otto-2016] Ottosson, S.: Developing Sustainable Product Innovations. Tervix Göteborg (2016)

[SAKR-2005] Schäppi, B., Andreasen, M.M., Kirchgeorg, M., Radermacher, F.J. (Herausgeber): Handbuch Produktentwicklung. Hanser München (2005)

[Seiw-1987] Seiwert, L.: Mehr Zeit für das Wesentliche. Moderne Industrie Landsberg (1987)

[ScSS-2006] Schmitz, R., Spilker, U., Schmelzer, J.A.: Strategische Verhandlungsvorbereitung. Be-triebswirtschaftlicher Verlag Dr. Th. Gabler, Wiesbaden, 1. Auflage (2006)

[Stud-1999] Studer, J.: Erfolgreich Reden halten. Buch und Zeit Köln (1999)

[VWZH-2018] Vajna, S., Weber, Ch., Zeman, K., Hehenberger, P., Gerhard, D., Wartzack, S.: CAx für Ingenieure, eine praxisbezogene Einführung (dritte völlig neu bearbeitete Auflage). Springer, Berlin (2018)

[Wahr-1978] Wahrig, G.: Deutsches Wörterbuch. Bertelsmann Lexikon-Verlag Gütersloh (1978)

Chapter 23
Mechatronics

Klaus Zeman

The term 'mechatronics' was first coined in 1969 by KIKUCHI in Japan [VDI-2206, HaTF-1996]. This artificial word merges the English terms *mechanism* ('mechanics') and *electronics* and thus primarily expresses the connection between mechanisms (mechanics or mechanical engineering) and electronics (including electrical engineering). Due to the progress in the field of microelectronics and microprocessor technology, information technology later became an essential part of mechatronics [VDI-2206]. This is not the only reason why the meaning of the term mechatronics has been subject to continuous change since its emergence. In line with the progress made in the various technical disciplines, it now encompasses significantly more areas than at the beginning and is still in a state of flux. This is proven by the numerous, partly different definitions and explanations in [Desi-2005, EhMe-2017, HeGP-2007, Iser-2005, Rodd-2006, VDI-2206, VWZH-2018].

One of the broadest definitions was initiated by TOMIZUKA and reads: '*Mechatronics is the synergistic integration of physical systems with information technology and complex decision-making in the design, manufacture and operation of industrial products and processes.*' [Tomi-2000, VDI-2206]. This definition allows not only mechanisms or mechanical systems as basic systems, but all physical (material) systems, for example, thermodynamic, chemical, biological, agricultural or economic systems. It includes not only the integration of such basic material systems including elements of information and communication technology (ICT), but also with complex decision-making processes, for the realisation of which computer-aided methods of artificial intelligence (AI) or machine learning (ML) from ICT have been used for some time. The inclusion of (automated) decision processes in the definition shows that, according to TOMIZUKA'S understanding, autonomous behaviour in the form of high adaptability to changing environments and situations,

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learning abilities or the capability for self-regulation [DGSC-2018] can be an essential property of mechatronic systems. TOMIZUKA's definition does not only refer to the development and design of such systems, but also to the production, realisation and operation of industrial products and processes. It requires only little imagination to extend this understanding to all phases of the product life cycle and to Product Service Systems (PSS) as well, thus achieving an even more integrated, holistic view.

Although a generally accepted definition of the term mechatronics has yet to be established, there is a largely uniform understanding of at least some key aspects of mechatronics and mechatronic systems today. According to this definition, mechatronics refers to the synergetic integration of Mechanical Engineering, Electrical Engineering/Electronics, Control Engineering and Information and Communication Technology (ICT) for the development, manufacture and operation of innovative products and processes. From its very beginning, mechatronics has denoted an interdisciplinary field of engineering sciences, whereby the extent of interdisciplinarity is constantly increasing, since more and more disciplines are to be integrated. The development of communication technologies can serve as an example of the permanent expansion of interdisciplinarity. With the introduction of the Internet towards the end of the twentieth century, completely new possibilities to interconnect any objects such as people, technical systems, things, animals or plants have opened up. Terms and abbreviations like Internet of Things (IoT), Internet of Humans (IoH), Internet of Systems (IoS), Internet of Animals (IoA), etc. account for this [AbHe-2016]. Analogous to the abbreviation CAx, which stands for 'Computer-Aided anything' [VWZH-2018], the abbreviation IoX, which stands for 'Internet of everything' or 'Internet of anything', is intended to express that everything can be networked with anything and anyone via the Internet.

Mechatronic systems have been using the possibilities of networking for quite some time as well; they increasingly interact among each other, with other technical systems and with their environment and must develop, accordingly.

Regardless of the further development of mechatronic systems, it is useful to distinguish between two different 'types' of integration [Iser-2005, VDI-2206, VWZH-2018]:

- The first type concerns the material components (hardware) from the different disciplines and denotes a physical, material and therefore also spatial integration. At the beginning of mechatronics, this spatial integration in the sense of 'miniaturisation' was in many cases the main focus. Due to the increasing ability especially of electronics to realise more and more memory, computing power and integrated circuits (and thus also functions, see next bullet point) within ever smaller space, the importance of miniaturisation is undergoing a certain change. This is becoming obvious, for example, when devices could be built much smaller than the market demands, which has long been the case with mobile phones. Technically, it would be possible to make a mobile phone much smaller than a matchbox, but then it would hardly be possible to operate it. In return, the 'surplus' space that might be gained through miniaturisation is used to integrate more and more functions or components within the available space. Regardless of spatial integration in the

sense of incorporation within the smallest or at least very limited space, the physical, material integration in the sense of a material 'interconnection' of components and parts by means of connecting elements and interfaces remains, which can be arbitrarily complex even if there is sufficient space available.
- The second type of integration refers to the (immaterial, intangible) functions that are increasingly information-driven (mainly by software). It is therefore often referred to as functional integration and has an immaterial character: Hence, in contrast to the material integration described above, it could also be called immaterial integration. Due to the progressing miniaturisation, it is becoming possible to accommodate more and more functions within the smallest space, which means that the functional density of mechatronic systems is constantly increasing.

Mechatronics, just like IDE, thus encompasses integration, interdisciplinarity, heterogeneity, complexity, but also communication, cooperation and teamwork, which is why a systematic approach to the development of such products is particularly important. The main differences between IDE and mechatronics are the human-centred nature of IDE and the use of equivalent attributes to describe and determine product behaviour.

Mechatronic systems usually consist of the following elements [EhMe-2017, Iser-2005, VDI-2206, VWZH-2018], Fig. 23.1.

- The *basic system* is often a mechanical, electromechanical, electrical, fluid-technical (hydraulic or pneumatic) or thermo-dynamical system. In a somewhat broader sense, however, any physical, chemical, biological, even economic system may be considered as a basic system.

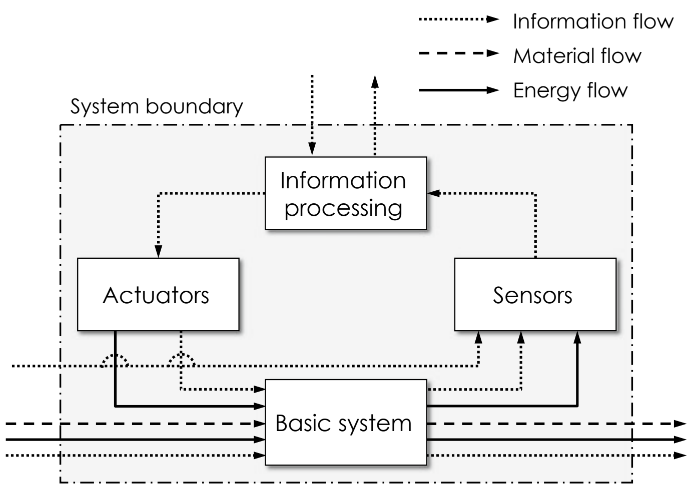

Fig. 23.1 Basic structure of a mechatronic system. Continuous line: energy flow. Dashed line: material flow. Dotted line: information flow. Dash dotted line: system boundary (based on [VDI-2206])

- The task of *sensors* is to provide information about the current properties of the basic system (e.g. its state), but also about the input and output variables (e.g. process variables such as heat or material flows) and the environment including the users of the system, for which purpose selected variables of the basic system or the environment are collected. This can be done directly by metrological detection (via sensors) or indirectly via so-called observers (state observers, estimators), with which the missing variables are reconstructed (estimated, reproduced) from the existing measured values using suitable models [HeGP-2007, Föll-1994, VDI-2206, VWZH-2018]. The signals formed by the sensors represent the input variables for information processing.
- By means of *Information processing*—using the sensor signals—control interventions for the existing actuators (see the following bullet point) are determined. This is performed with the target to influence both state and behaviour of the basic system just as it is actually intended—possibly depending on the environment, a super-ordinate system, a user of the system or other systems with which the mechatronic system is interconnected. The information processing unit can itself receive and process signals from the environment (again via sensors) as well as information from super-ordinate systems or from a network, and vice versa can send information to these systems. Thus, the mechatronic system can also be part (subsystem, system element or agent) of a super-ordinate system or a cyber-physical system (Sect. 23.2). Today, information processing is performed mainly digitally, i.e. by microprocessors and signals that are discrete in time and value. In special cases where, for example, signals have to be processed with particularly high speed, analogue technologies are still used because they enable the fastest possible processing. The determined control interventions represent output variables of the information processing and simultaneously input variables to the actuators.
- *Actuators* realise the control interventions (effects on the basic system) determined by information processing and intervene directly in the basic system or in the process running there. It makes sense to regard the actuators as parts of the basic system.

Mechatronic systems thus represent technical systems (object systems). The interaction of the various components typically results in control loops with the aim of improving the behaviour of the basic system so that it can be regarded as optimal in the respective context. For this purpose, sensors are used to collect information about the basic system (for example, its state, input and output variables) and about its environment. An environmental system can, for example, be a user of the mechatronic system, a super-ordinate system in which the mechatronic system is embedded, or even the environment (also user) of the super-ordinate system. Processors analyse this information and determine control interventions for the actuators in such a way that the basic system behaves as it is currently intended to [VDI-2206]. In [HeGP-2007] it is aptly formulated: ‘It is typical for mechatronic systems that a change of the system states is actively desired. For this purpose, the input variables is used to influence the system[1]'. Therefore, a significant feature of mechatronic systems is that their behaviour is influenced in a targeted manner so that the function of the system is realised in the best possible way. According to [Hubk-1984, HuEd-1996], the function of a system is understood as the desired behaviour of the system. Behaviour, in turn, is the conversion of the input variables to the output variables of the system. A distinction is made between static and dynamical systems: In dynamical systems (e.g. torsional vibration system of a drive train), the conversion of input variables (e.g. external torques) to output variables (e.g. rotational movements) depends not only on the input variables but also on the state of the system itself. To determine the output variables, a time integration is necessary which, in addition to the input variables, also has to consider the dynamics of the system itself including its initial state at the beginning of the time integration (at time $t = 0$) in the sense of initial conditions. For static systems (e.g. massless levers), however, no time integration is required; the inputs are quasi 'directly' converted into the output variables without 'eigendynamics' of the system. The targeted influencing of the system behaviour is inseparably connected with the temporal change of system variables (e.g. state variables, input variables, output variables), which is why mechatronic systems always represent dynamical systems.

23.1 Objectives of Mechatronisation

The objectives of mechatronisation are primarily support functions that are integrated into devices, machines and systems in order to support the user in application, usability, operation, maintenance, etc., to relieve him, increase safety, release him from tiresome or dangerous tasks, by taking over these tasks and fulfilling them better through the device or machine. There are numerous examples of this, such as autofocus and automatic exposure systems for photo cameras, ABS (anti-lock braking systems), airbags, anti-skid control systems, ESP (Electronic Stability Program), automatic operation of the windscreen wiper ('rain sensors'), automatic dipped beam control ('light sensors'), automatic differential gears, engine management, tyre pressure sensors, driver assistance systems, navigation systems for motor vehicles, autopilots for airplanes, automatic roasting, etc. Sub-functions or subtasks are performed by machine equipment, thus establishing the *functional integration* within mechatronic systems [ZeHS-2006].

For many devices, which the customer wants to be small, handy and light, the new functions sometimes have to be integrated within a very small space, so that, as described above, *spatial integration* is achieved.

At the same time, components can be massively reduced in size, making miniaturisation possible. Some products are unique simply because they are particularly small, light or compact (see digital cameras, mobile phones, memory cards, GPS transmitters, music players, etc.). With such miniaturised products, however, it is

[1] Here, the basic system is meant.

usually only possible to realise functions with very low power (e.g. sensor functions or control interventions).

In the past, the packing density and thus the functional density of electronic circuits was limited by the size of the individual components. With microelectronics, a radical change in electronics occurred. Components were no longer manufactured and joined mechanically, but were optically transferred and copied by photolithography onto the work piece, the silicon wafer. This led to an exponential decrease in the cost of computer processing power and storage capacity of hard discs. Studies show that since about 1960, CPU costs have been decreasing by a factor of at least 10 within 5 years, i.e. they have decreased to less than $1/10^{12}$ within 60 years. This shows the enormous increase in available CPU power. For data transfer rates in the Internet and storage capacities of hard discs, the cost developments are very similar (exponentially decreasing).

23.2 Mechatronic Products

Compared to conventional products, mechatronic products are characterised by extended, improved and new functions, which can only be achieved through the interaction of methods, technologies, functions, solutions and components from the various disciplines of mechatronics, resulting in enormous innovation potential. Heterogeneous components and knowledge from the various disciplines of mechatronics are thus integrated in mechatronic products to form an optimised solution for the overall product. These products often differ from conventional products by a higher number of heterogeneous, coupled elements and an associated higher complexity, which is not always apparent at first glance, as is shown by numerous products of daily use. Examples are photo and video cameras, hearing aids, mobile phones, copiers, TV sets, DVD players, PCs, cars, motorcycles, active wheel suspensions in Formula 1, airplanes, household appliances, ski lifts, etc. Figure 23.2 shows some mechatronic products for whose realisation the accommodation in a very limited space is a decisive prerequisite, which is why miniaturisation is an important objective for these products.

Another characteristic of mechatronic products is that their properties are determined to a considerable extent by non-material elements (software) [HeGP-2007, VDI-2206]. This in the first instance leads to a shift in functions from the physical (often mechanical) ‘basic product’ to electronics or information processing. Subsequently, products (systems) are enabled that have a certain ability to adapt, learn and decide. Accordingly, they are called ‘intelligent products’. Such products can, for example, autonomously optimise processes, adapt to changing conditions (e.g. changing environments), recognise critical operating states, or stop or start certain processes depending on the current product state or on events that have occurred. They, therefore, have intelligent or autonomous (self-contained) functions [Desi-2005, GGSA-2004, HeGP-2007, Iser-2005, VDI-2206, DGSC-2018].

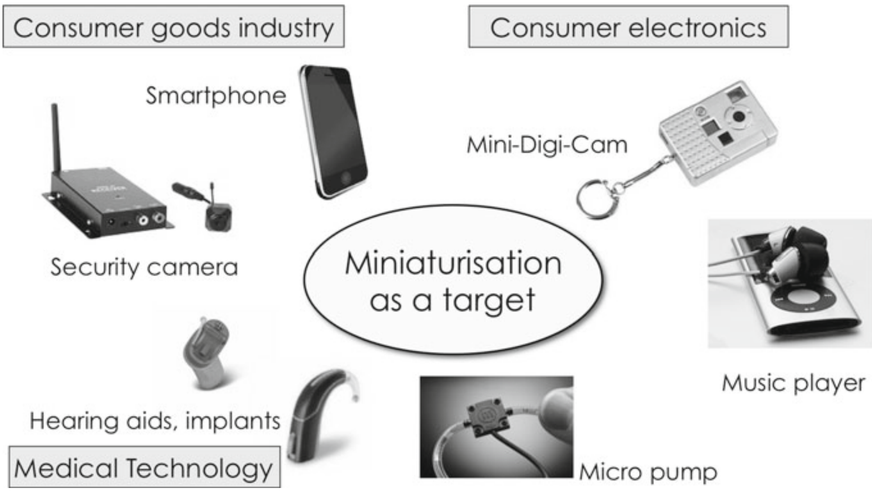

Fig. 23.2 Mechatronic products where miniaturisation is an important goal [ZeHS-2006] (using free available images from Apple, Bartels, Canon, Nokia, Phonak, Visotech)

A logical (further) development of mechatronic systems leads to so-called *Cyber Physical Systems*, which arise when material systems (physical systems) are connected to each other via a local or global network in order to communicate with each other, to jointly perform tasks in a network and to make decisions on the further procedure (control) by evaluating feedback (cybernetics). In the case of cyber-physical systems, the material (physical) systems can also be other than mechatronic systems (e.g. living beings), which is why this approach is even more general than if only mechatronic systems are networked with each other [Lee-2006, Lee-2008, GeBr-2012]. The integration of physical (material, real) systems and virtual systems (computers) into cyber-physical systems is shown in Fig. 23.3.

To capture, describe and map the physical systems in the virtual world (in computers, in 'cyber space'), models and measurements of the physical systems are required. Networking enables a variety of desirable but also questionable possibilities of influencing the physical (material, real) systems, including humans and animals.

A new feature of cyber-physical systems is the emphasis on the fact that the resulting system, similar to the Internet, can have a previously unknown number of subsystems ('participants', 'agents') that change over time during operation. The definition of TOMIZUKA [Tomi-2000, VDI-2206] (see the beginning of this chapter) already includes such systems.

Examples of cyber-physical systems include traffic control systems, modern production systems, logistics systems, energy distribution systems or driver assistance systems in their gradations up to fully autonomous driving, etc. if the systems involved are able to perform tasks much more efficiently in a network than would be possible with isolated solutions.

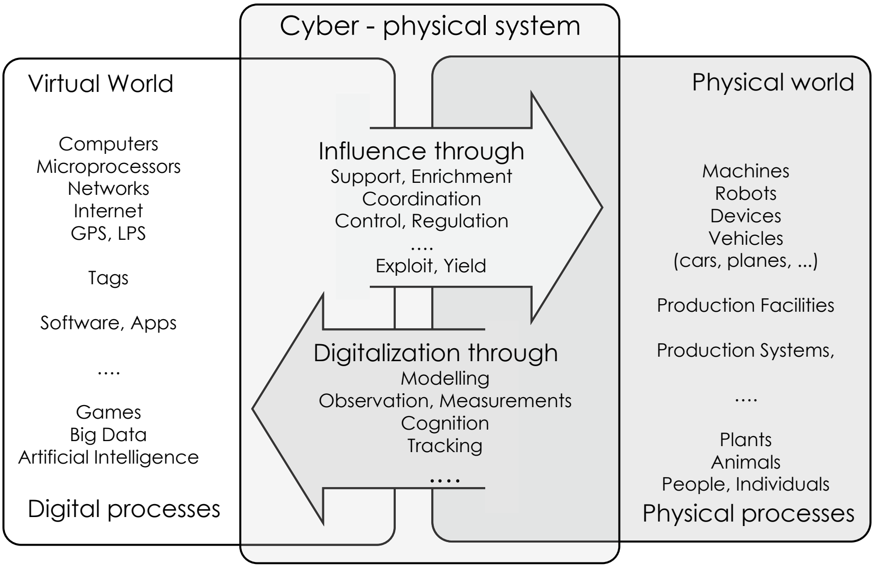

Fig. 23.3 Cyber-physical system: Integration of physical (material, real) systems and virtual systems (computers); modelling for computer-internal acquisition and implementation, possibilities for influencing physical (material, real) systems

It is above all the interactions between the individual product elements from very different areas that have a significant influence on the functionality of the overall product. Interactions are used specifically to create innovative products such as machines, devices, systems, etc. by combining (interconnecting, linking) elements from the disciplines of mechanics, mechanical engineering, electrical engineering, electronics, information technology, communication technology as clever as possible. Finding, designing and creating such solutions is a synthesis process that can be aptly summarised under the term *mechatronic design.*[2]

In conclusion, it should be noted that mechatronics is penetrating more and more areas of automotive engineering, production technology and the entire field of mechanical and plant engineering, but also medical technology and biology (e.g. exoskeletons). This can be seen from the fact that most of today's products from these areas represent more or less complex mechatronic systems and would hardly be conceivable without mechatronics.

[2]This term refers to the development process in the sense of a procedure and not to its result, the mechatronic system or the mechatronic product.

23.3 Development Methodology for Mechatronic Products

Design, development and realisation of mechatronic products—and thus mechatronics in general—require an integrative approach and interdisciplinary thinking as well as thinking in systems. This also places new demands on communication and cooperation between representatives of the various disciplines, on a common language and on integrated, computer-aided development environments [VDI-2206, Desi-2005]. Especially the last point mentioned above cannot be regarded as satisfactorily solved at present.

Numerous practical experiences prove that the composition of the development team is essential for the success of mechatronic design. Interest in and basic understanding of the respective 'foreign' disciplines, respect for the other disciplines, knowledge of inter-disciplinary relationships and the effects of definitions and changes of 'common', inter-disciplinary parameters and the identification with the 'common task' are critical factors for the success of mechatronic design. The equal treatment of all involved disciplines represents a high value and is established as a culture. It goes without saying that this also places increased demands on the ability of the people involved to work in a team (see also Sect. 15.6).

The development of a mechatronic product or system is, therefore, a complex process due to the different participants and the interacting disciplines of mechatronics. Therefore, before such a product or system can be developed, the reasons and objectives of mechatronic product development must be critically questioned. Typical questions include:

- Do requirements on the performance of the product contain such content that can no longer be realised merely mechanically?
- Should a product be reduced in size for reasons of space limitations (miniaturisation, spatial integration) or should additional functions be accommodated in a product if space is available, so that the behaviour of the product can be adapted to new requirements (functional integration)?
- How can new or extended functions, special features or a particularly low price be achieved for a product in general through mechatronisation in order to differentiate it from competing products and make it particularly attractive to the market? Are certain components, effects and functions of a product to be 'hidden' for reasons of, for example, knowledge protection by realising them with a non-mechanical technology?
- Should performance be made possible that requires materials with flexible or adjustable material properties (smart materials) (e.g. an adjustable modulus of elasticity that can be specifically influenced by actuators attached to the surface of the component)?
- If mechanical functions are to be taken over by electrical or software functions, the type and number of components now required must be clarified (space requirement? Ease of assembly?). What is the energy requirement and where are

sensors, actuators and energy sources placed? Can the energy source be a standard solution or must a customised solution be used? Should the energy source be interchangeable?
- What are the mutual influences of the new partial solutions? Is the respective fulfilment of the attributes safety, reliability and quality still given?
- What should the user interface look like? Which interventions should be enabled and which should be prevented?
- Which operating modes should be provided for the expected operating conditions?
- What is the economic balance of the mechatronisation of a product?

The VDI Guideline 2206 'Design methodology for mechatronic systems' [VDI-2206] was created for the development of mechatronic products and systems, which claims to be an integrated development methodology, i.e. spanning all disciplines involved (i.e. mechanical engineering, electrical engineering/electronics, information technology), Fig. 23.4.

This process model is formally based on the V-model from Software Engineering [IABG-2013]. In terms of content, it is based on the approaches originating from mechanics and mechanical engineering (see Chap. 1), so that the core of development activities remains discipline-specific. Accordingly, the mechanical or mechanical engineering activities (including pneumatics and hydraulics), the development activities in the fields of electrical engineering and information and communication technology run in parallel, each of them individually and in series. A layer is superimposed on these, which on the one hand ensures the integration of the subsystems into a heterogeneous overall system, and on the other hand, ensures ongoing system

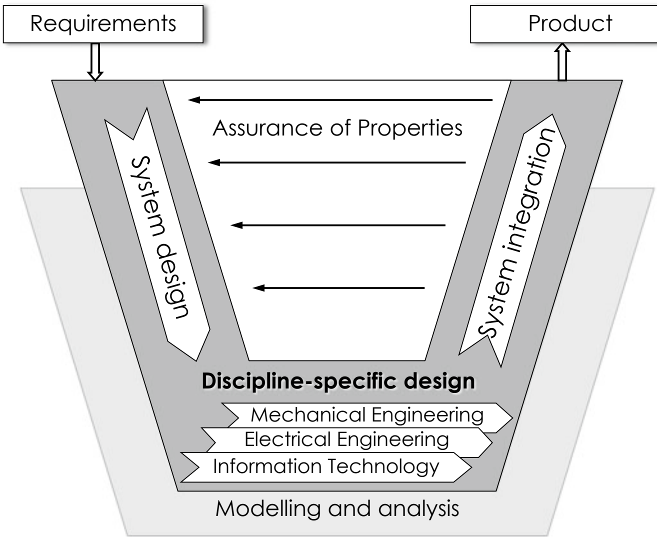

Fig. 23.4 Process model for the development of mechatronic products and systems according to [VDI-2206]

analysis (especially for the transient or dynamic behaviour). The system analysis also takes over the role of feedback in the development process and is, therefore, its decisive control mechanism (assurance of properties, performance checks, verification and validation).

The process model according to [VDI-2206] is more a framework concept than a directly applicable development method for mechatronic products and systems. However, the model provides indications of how the existing methods and tools can be used in the corresponding processes how they are interlinked with each other. Furthermore, it reflects the role of computer-based methods and tools in the development process, but here again without going into the questions of product modelling or product models in more detail (for more details see [VWZH-2018], Chap. 4 and Sect. 5.4).

Structures and procedures from the process model according to [VDI-2206] can be mapped without difficulty by the IDE procedure model (Chap. 16), consistently detailed and holistically realised.

- By describing the desired performance of the product (consisting of the performance of the product and its behaviour when providing this performance) via the six product attributes and their respective fulfilments (Chaps. 3 and 13), which do not prejudge any particular solution, the different mechatronic disciplines and their interaction are taken into account at a very early stage so that they no longer have to be processed separately (as in the V-Modell) during the actual genesis of the product.
- By means of the genesis of the attributes, the integration of possible subsystems into a heterogeneous overall system is also carried out at the earliest possible points in time.
- Comprehensive simulation and evaluation options in the activity group Evaluate/Compare/Select in the IDE procedure model (Chap. 16) ensure ongoing system analysis and necessary feedback during product development. This applies in particular to the assurance of properties as a control loop, which is carried out permanently in the IDE procedure model.

The serial structures implicit in the V-Modell (especially in the discipline-specific design) can be completely resolved with the IDE process model and arranged and designed according to requirements.

23.4 Mechatronisation of Processes

The mechatronisation of processes [ZeHS-2006] means the use of mechatronic concepts to improve the performance of industrial processes. These comprise, for example, manufacturing processes and their output, in order to minimise undesirable effects (such as environmental pollution through noise or pollutants) and to improve the utilisation of operating personnel and economic efficiency. A core element in this context is the targeted intervention with the aid of electronic control equipment for better control of the process, i.e. for its guidance and for the correction of control deviations if any are detected. This requires suitable sensor systems in order to detect control deviations at all, suitable actuators in order to intervene in the process in a targeted manner, and suitable control devices that dose the control intervention in such a way that the desired process result is ensured.

Mechatronisation of processes is understood as a mean of those mechatronic measures that have an effect on the process. There may, of course, be further ones, such as for maintenance, rapid and low-error commissioning, cost tracking, error detection and diagnosis, etc.

Rolling mill technology can serve as an example of machines and processes whose mechatronisation is already well advanced. However, mechatronisation has long since taken hold of many other applications (for example paper machines, combustion engines, agricultural machinery, cutting machine tools, spinning machines, storage and retrieval systems, parcel sorting systems), while some areas have hardly been touched at all (many manufacturing processes in construction technology). The reasons for these differences include the following: The various technical processes are differently suited for mechatronisation from a technical point of view (measurability of states, availability of technically and economically suitable sensors and actuators, sufficient understanding of the processes for successful automation). In many cases, however, the cost/benefit ratio plays a decisive role. While in some processes very high, monetary values are processed due to enormous throughput rates (material throughputs), and thus even small relative process improvements result in large benefits, in other processes the cost of mechatronisation far exceeds the economic benefit.

The benefit of mechatronisation of processes is achieved most quickly in those with the properties listed below, which is why mechatronisation is most advanced in these processes [ZeHS-2006]:

- Continuous processes with primarily high throughput, i.e. high monetary value of the material throughput, because even small relative improvements result in high benefits.
- Fast processes because there is a great potential for improvement in comparison to manual operation.
- Complex processes because their guidance and control often require non-linear multi-variable controls, which are, however, hardly controllable manually. Here, too, there is great potential for improvement through computer-aided process control in conjunction with fast control systems.

References

[AbHe-2016] Abramovici, M., Herzog, O. (Eds.): Engineering im Umfeld von Industrie 4.0: Einschätzungen und Handlungsbedarf, acatech STUDIE. Herbert Utz Verlag, München (2016)

[Desi-2005] De Silva, C.W.: Mechatronics—an integrated approach. CRC Press, Boca Raton, London, New York, Washington D.C. (2005)

[DGSC-2018] Dumitrescu, R., Gausemeier, J., Slusallek, P., Cieslik, S., Demme, G., Falkowski, T., Hoffmann, H., Kadner, S., Reinhart F., Westermann, T., Winter, J.: Studie “Autonome Systeme”; Studien zum deutschen Innovationssystem Nr. 13-2018. Expertenkommission Forschung und Innovation (EFI), Berlin (2018)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, Denkabläufe, Methodeneinsatz, Zusammenarbeit. 6. Völlig erweiterte Auflage Hanser, München, Wien (2017)

[Föll-1994] Föllinger, O.: Regelungstechnik, Einführung in die Methoden und ihre Anwendungen (8. Auflage). Hüthig GmbH, Heidelberg (1994)

[GeBr-2012] Geisberger, E., Broy, M. (Eds.): agendaCPS, Integrierte Forschungsagenda Cyber-Physical Systems, acatech STUDIE. acatech Deutsche Akademie der Technikwissenschaften (2012)

[GGSA-2004] Gausemeier, J., Giese, H., Schäfer, W., Axenath, B., Frank1, U., Henkler, S., Pook, S., Tichy, M.: Towards the design of self-optimizing mechatronic systems: consistency between domain-spanning and domain-specific models. In: Proceedings International Conference on Engineering Design. Paris, France (2007)

[HaTF-1996] Harashima, F., Tomizuka, M., Fukuda, T.: Mechatronics—“What is it, Why, and How?” An Editorial. IEEE/ASME Trans. Mech. **1**(1), 1–4 (1996)

[HeGP-2007] Heimann, B., Gerth, W., Popp, K.: Mechatronik, Komponenten - Methoden – Beispiele, 3rd edn. Carl Hanser, München, Wien (2007)

[Hubk-1984] Hubka, V.: Theorie Technischer Systeme. Springer, Berlin, Heidelberg, New York (1984)

[HuEd-1996] Hubka, V., Eder, W.E.: Design Science. Springer, Berlin, Heidelberg, New York (1996)

[IABG-2013] Leitseite der Industrieanlagen-Betriebsgesellschaft mbH Ottobrunn. http://v-modell.iabg.de. Zugriff am 23. Mai 2013

[Iser-2005] Isermann, R.: Mechatronic Systems. Springer, London (2005)

[Lee-2006] Lee, E.A.: Cyber-physical systems—are computing foundations adequate? Position Paper for NSF Workshop on Cyber-Physical Systems, Research Motivation, Techniques and Roadmap, 16–17 October, Austin, TX (2006)

[Lee-2008] Lee, E.: Cyber physical systems: design challenges. Technical Report No. UCB/EECS-2008-8. University of California, Berkeley (2008)

[Rodd-2006] Roddeck, W.: Einführung in die Mechatronik. B.G. Teubner, Stuttgart (2006)

[Tomi-2000] Tomizuka, M.: Mechatronics: from the 20th to 21st century. In: 1. IFAC Conference on Mechatronic Systems, Darmstadt, vol. I, pp. 1–10 (2000)

[VDI-2206] VDI Guideline 2206: Design methodology for mechatronic systems. VDI-Verlag, Düsseldorf (2004)

[VWZH-2018] Vajna, S., Weber, Ch., Zeman, K., Hehenberger, P., Wartzack, S, Gerhard, D.: CAx für Ingenieure, eine praxisbezogene Einführung (dritte völlig neu bearbeitete Auflage). Springer, Berlin, Heidelberg (2018)

[ZeHS-2006] Zeman, K., Hehenberger, P., Scheidl, R.: Perfekte Produkte durch Mechatronisierung von Prozessen. In: Proceedings International Forum Mechatronics, Linz, Österreich, Oktober 2006

Chapter 24
Value Creation and Business Planning

Matthias Raith

The development of a new product or service is part of a value creation process. The subject of this chapter is the conceptual design and practical implementation of this process. We show how the configuration of a firm's so-called business model is determined by the multiple value dimensions of the product or service and, conversely, which factors of the business model may affect the development of the product. We thereby highlight the economic significance of product development and, in particular, its strategic relevance for business planning.

24.1 Value Creation and Competitive Advantage

The conceptual design of a value creation process first of all requires a working definition of value creation, i.e., what it refers to and how it can be measured. According to Besanko et al., the value (V) added by a product or service is determined, on the one hand, by the perceived benefit of the product from the point of view of the customer for whom it is ultimately intended [BDSS-2007]. In the simplest case, this perceived benefit (B) can be valued in monetary terms, and the value expresses the customer's maximum willingness to pay for the product—B is then the amount of money the customer would bid for the product in an auction, for example. On the other hand, value-added expresses the increase in value realized by the provider of the product or service. The reference point for the increase in value is the unit cost (C) of creating the product or service, so that the total value-added results from the difference between the perceived benefit for the consumer and the unit cost for the producer:

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$$V = B - C.$$

Although the value, V, is provided by the producer, it can only be realized in combination with the consumer. The sales price (P) of the product or service thereby divides the value-added between the consumer and the producer:

$$V = (B - P) + (P - C).$$

The first term on the right-hand side represents the so-called consumer surplus—this is the value that the consumer experiences when buying the product. It is not the price alone that determines the purchase, but the consumer surplus made possible by a price, which is below the perceived benefit of the good or service. The second term on the right-hand side is the producer's surplus, which remains with the manufacturer after the sale of the product. In order to achieve a competitive advantage on the market in the long term, a company must be able to maintain its position on the market by means of a competitive producer's surplus, on the one hand, and on the other hand, it must attract customers with a competitive consumer surplus. Price setting is, therefore, of strategic importance, as it determines the distribution of value-added between the two surpluses. However, in order to be able to adequately secure both surpluses at the same time, the competitive advantage with regard to rival firms in the market requires a sufficiently high added value, V, overall.

PORTER [Port-2004] has identified two generic strategies to secure the competitive advantage, which are based on the two boundaries of value creation, B and C. At the upper end, the firm can strive for performance leadership by trying to distinguish itself from the competition by means of a differentiation strategy based on a higher product benefit B. At the lower end, the firm can try to lower C and strive for cost leadership through new production processes.

PORTER warns against pursuing both generic strategies at the same time, as firms may easily get stuck between both competitive goals and thereby miss the competitive edge. However, recent approaches, for example by KIM and MAUBORGNE, criticize this view and show how firms can simultaneously realize approaches for increasing B and decreasing C by taking a multidimensional perspective, thereby pursuing what they refer to as a *blue ocean strategy*[1] [KiMa-2005]. With the help of a customer utility matrix, as in Fig. 24.1, KIM and MAUBORGNE illustrate how multifaceted consumer benefits can be conceived.

The customer utility matrix distinguishes between six differentiable levels of customer utility and six different phases of buyer experience. As a consequence, 36 different approaches can be identified to generate customer benefit (B). The example in Fig. 24.1 illustrates how customer benefit can be addressed in 14 different ways with a single product.

[1] A strategy for discovering, creating and subsequently introducing products into previously untouched markets ("blue ocean"), where the firm can more easily become a market leader than in markets already occupied by competitors or even saturated and where competition is likely to be aggressive ("red ocean").

The six stages of the Buyer Experience Cycle

The six levels of Customer Utility	1. Purchase	2. Delivery	3. Use	4. Supplements	5. Maintenance	6. Disposal
Customer Productivity			✓	✓		
Simplicity	✓				✓	✓
Convenience		✓		✓		
Risk			✓			✓
Fun and Image	✓		✓			
Environmental friendliness			✓		✓	✓

Fig. 24.1 The customer utility matrix of KIM and MAUBORGNE [KiMa-2005]

For the development of the product, the definition of total value creation, *B*—*C*, highlights the potential of optimizing the linkage between customer orientation (*B*) and technical implementation (*C*), as value creation can only be expanded, if *B* and *C* can be pushed in opposite directions. The existential importance of a competitive advantage further emphasizes the relevance of strategic pricing, i.e., setting the price to divide created value optimally into a consumer and a producer surplus. In contrast. the simpler procedure of cost-plus pricing, which is often used in practice, focuses exclusively on the producer surplus, thereby neglecting all dimensions of customer utility and, hence, the potential of value creation.

24.2 Opportunities for Value Creation

Value creation is not realized merely by the provision of a product or service. A potential customer must also perceive added value and be willing to pay for it. According to DRUCKER, the opportunity to create value only exists, because an entrepreneur recognizes this possibility of creating such added value with a product or service [Druc-2006].

In a dynamic and interactive society, opportunities for value creation exist always and everywhere. DRUCKER distinguishes between seven distinct sources for innovative opportunities. Within an industry or branch, they arise by unexpected positive or negative events, by different perceptions of the market participants, by process requirements within a value creation process, or also by changes of the market structure. Outside individual industries, i.e., at the societal level, opportunities arise from demographic changes, changes in perception and, of course, new knowledge. These seven sources are continuously present and operating, i.e., they constantly provide new opportunities for value creation in a modern, changing society. Being able to recognize them systematically, not just by chance, characterizes the ability of an entrepreneur [Druc-2006].

This ability can be learned because it is primarily based on a certain perspective that can be acquired. Nalebuff and Ayres demonstrate how simple questioning techniques can be used to change one's perspective and reveal opportunities. Problems thereby become opportunities [NaAy-2003]. Crises, which are typically characterized by the general inability of the decision-makers to act, also offer opportunities for value creation, especially for proactive decision-makers such as entrepreneurs. In the more popular literature, the entrepreneurial way out of a crisis is often referred to as the "MacGyver effect." However, the same effect can also be observed in other cultures as well. In the modern Chinese language, for example, the ideogram for the word "crisis" consists of two signs, 危機, where the first stands for "danger" and the second for "opportunity."

In a dynamic society, opportunities are not available indefinitely. Since they depend on the value perceptions of customers, they may disappear just as quickly as they arise. Shane and Eckardt, therefore, speak of windows of opportunity that open and close again, depending on the elements the opportunities are composed of and the changing environment [ShEc-2005]. Entrepreneurial action, therefore, proceeds under time pressure, since the whole process of exploiting an opportunity for value creation with a new product or service must fit into the time window. Indeed, in his analysis of over 200 startups, Gross finds that for almost half of the businesses the "time to market" was the most important success factor [Gros-2017].

Recognizing opportunities at all is, however, only the first step towards exploitation. With the diversity of possible offers, it is also important to choose the right opportunity, because the implementation requires resources such as time, effort, and often money. For the choice between alternative opportunities, they must be assessable and comparable. This requires calculating the total benefit or return that the entrepreneur can achieve with their implementation. The opportunity analysis requires initial customer and market information, with which one can at least roughly estimate which opportunity is most suitable in order to be pursued further. In order to make quick decisions within a limited time frame, Weinstein recommends so-called Guesstimation techniques [Wein-2012], where calculated estimates are derived from plausible, arguable assumptions. These can also be learned and practiced, thereby giving the experienced entrepreneur a time advantage for implementation.

24.3 The Business Model

For a firm, the implementation of an opportunity for value creation is a multi-stage process, which comprises the creation, delivery, and capture of value. How this process is designed and how it takes place logically is described by the so-called business model. Osterwalder and Pigneur identify nine core components of a business model with which the logic of the value creation process in any industry can be characterized [OsPi-2010]. In their business model canvas, shown in Fig. 24.2., the nine components are arranged in an intuitive and memorable way, which not

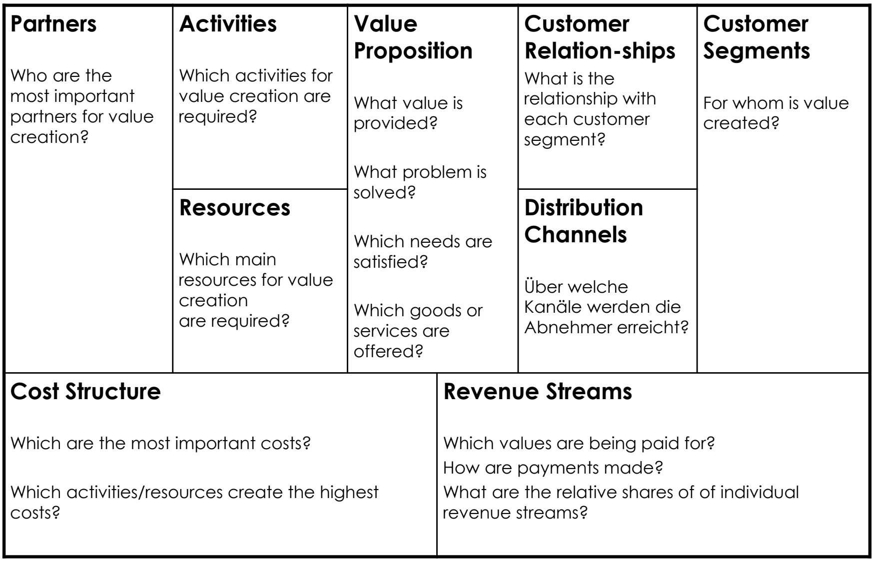

Fig. 24.2 The business model canvas of OSTERWALDER and PIGNEUR [OsPi-2010]

only supports business model design but also the communication with potential stakeholders of the venture.

Central to the business model is the firm's value proposition, which describes the needs that are satisfied and the values that are delivered by the offered product or service. The value proposition emphasizes that the products or services which a firm offers are only a means to an end, i.e., they serve to create value, but do not characterize value directly themselves. As we have argued above, their value is determined by the benefit that a customer attaches to them. For the acknowledgement of the value proposition, the relevant customer segments must, therefore, be identified, i.e., all customer segments, which in any way draw a consumer surplus from the proposed value. In order to ensure the delivery of value to the designated consumers, customer relationships must be established and distribution channels must be organized. The interaction of these components, shown on the right-hand side of Fig. 24.2, characterizes the "front stage" of the business model.

The left-hand side of Fig. 24.2 characterizes the corresponding "backstage" of the business model. The product or service, on which the value proposition is based, must be produced by the firm. This requires its own key resources, specific activities within the firm, and mostly also business relations with external partners such as suppliers. How well front- and backstage of the business model operate together determines the profitability of the venture, given by the difference between the revenues generated with the sold products and services and the costs incurred by their production. This is captured by the two boxes at the bottom of Fig. 24.2.

OSTERWALDER and PIGEUR'S nine core components of the business model, however, are only the building blocks of the business model. The logic of the value

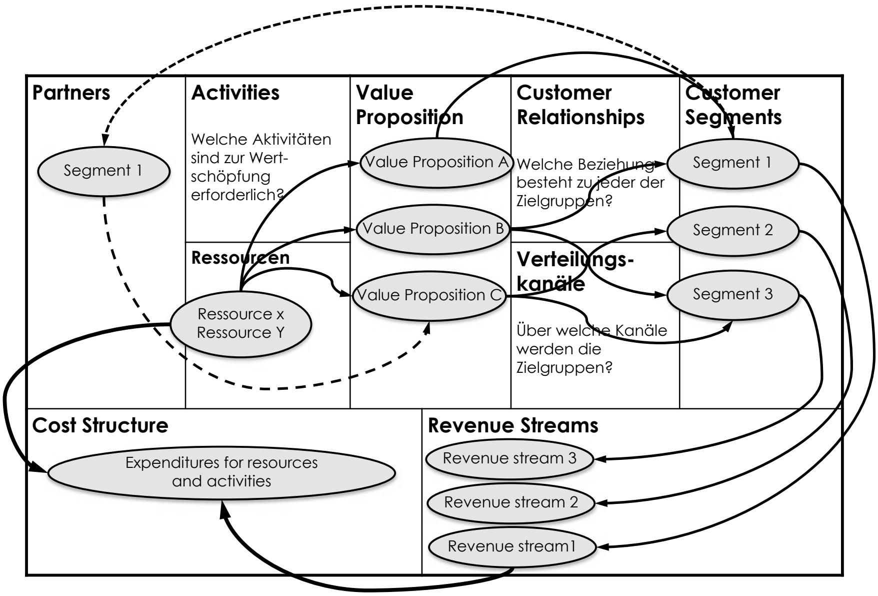

Fig. 24.3 The logic of the value creation process

creation process of a specific firm results from the way in which these components interact. For simple business models, the logic is evident simply from the arrangement of the components in Fig. 24.2. In contrast, for more complex models, with multiple value creation approaches or different target groups, the interaction of the components can be more demanding, as the example in Fig. 24.3 illustrates.

The center box of Fig. 24.3 shows three different value propositions, *A*, *B,* and *C*, which are provided by the firm by utilizing two key resources, *X* and *Y*, that the firm commands. The value propositions are directed towards different target groups. Specifically, value proposition *A* focuses only on target group 1, while value creation *B* addresses target groups 1 and 3, and value proposition *C* addresses target groups 2 and 3. Hence, target group 2 is addressed by value proposition *C* alone, while target groups 1 and 3 are each attracted by two different value propositions. These connections are essential for the entire value creation approach, because, as Fig. 24.3 shows, each target group generates a different revenue stream. A value proposition that does not reach a target group is meaningless for the business model, and a target group that is not addressed by any value proposition is irrelevant because it does not generate any revenue stream. The cumulated revenue streams can then be put in relation to the costs for the resources and activities used. In principle, revenues and expenditures can be of a monetary or non-monetary nature. This distinction is particularly relevant if the firm is not only geared to maximizing profits but also wants to generate social value. However, the business model can only be regarded as economically self-sustainable, if the total monetary revenues cover at least the expenditures for the creation and delivery of value.

An important insight from this business model representation in Fig. 24.3 with its distinct causal relations is that total revenues result as the sum of the individual revenue streams generated by different target groups with different value creation approaches. How new value propositions can be created, even with existing products, has already been discussed above in connection with the customer utility matrix in Fig. 24.1. New resources or activities may be required, but this is not necessarily always the case. For example, the internet trading company Amazon needs enormous computing capacities to cope, in particular, with its Christmas business, but these resources are not required for business during the rest of the year. In the middle of the 1990s, the company, therefore, began leasing storage and computing capacity to software development firms in order to generate new revenue streams. Amazon also markets its perfected logistic infrastructure to other sellers thereby allowing them access to the entire Amazon logistics without having to sell directly via Amazon [OsPi-2010].

The importance of an individual target group for the firm's business model cannot be assessed from its associated revenue stream alone. Suppose, for the example case illustrated in Fig. 24.3, that revenue stream 1, generated by target group 1 is so low that it cannot even cover the expenditures for value proposition A. For cost reasons, the firm could, therefore, be inclined to dispense with target group 1 and eliminate the associated expenditures. However, this would be fatal for the entire business model, because target group 1 not only serves as a customer segment but also, as Fig. 24.3 shows, as a partner for the provision of value proposition C, which may be crucial to attracting target groups 2 and 3. To dispense with target group 1 could, therefore, mean also losing target groups 2 and 3.

For more complex value creation processes with multiple value propositions and different target groups, the graphical representation within a single business model canvas as in Fig. 24.3 quickly becomes confusing. A clearer picture can be obtained by presenting the individual value creation approaches in separate modules. By then showing where and how the modules are connected, their interdependence can be highlighted more clearly. As an example, consider Fig. 24.4, where the three value propositions *A*, *B*, and *C* from Fig. 24.3 are characterized by two separate modules. The left module shows the value propositions *A* and *B*, directed towards target groups 1 and 3. The right module shows value proposition *C*, offered to target groups 2 and 3. Since the value creation process *C* on the right is dependent on target group 1 as a partner, it is logically behind value creation processes *A* and *B* on the left. This dependency is characterized by the upper dashed arrow, which indicates that target group 1 changes its role, becoming the firm's partner for the realization of value proposition *C*. This representation also reveals the importance of the customer relationship with target group 1, reflected in the expenditures in the module on the left. Finally, the lower dashed arrow indicates that revenue streams 2 and 3 in the module on the right subsidize the value creation processes of the module on the left, in order to ensure the economic self-sustainability of the complete business model.

The internet search engine Google, for example, offers web surfers internet searches free of charge. However, Google does not generate any revenue streams through this target group, which is now estimated at over one billion users. Instead,

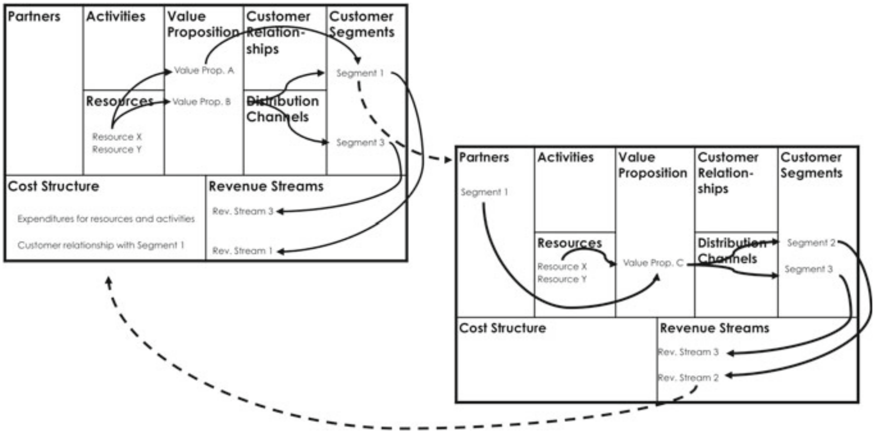

Fig. 24.4 The interaction of multiple value creation approaches

the company utilizes this target group as a valuable partner or resource for a second value proposition, i.e., targeted advertising, which is offered to commercial firms. Through this target group, Google generates enormous revenue streams, which easily subsidize the complete search platform. If Google were to neglect the value proposition of unlimited web search and thereby lose its attractiveness for web searchers, the value proposition for the advertising firms would collapse like a house of cards. It is therefore understandable that Google has expanded its range of value propositions and its target groups over the years with new business ideas.

The profitability of a firm is largely determined by the structure of its value creation processes—how many processes are pursued and how do they relate to one another? Do they stand side by side, i.e., with additive revenue streams, or do they interact with complementary revenue streams? Just as decisive is the selection of the target groups and the corresponding design of the value proposition. The contested market for video game consoles provides a vivid example of this. Sony and Microsoft pursued similar business models with their PSP and Xbox game consoles [OsPi-2010]. As their contested customer segment, both targeted young, mostly male players with preferences for technically sophisticated game consoles. With technological development as a significant cost driver in this value creation process, it became difficult for both companies to cover their costs with revenues from console sales. Indeed, the main profits were achieved with a further value proposition directed towards independent game developers. Since players are the target group for game developers, Sony and Microsoft utilized their console users as a resource for the value proposition offered to developers, with license revenues ultimately subsidizing their business of game consoles. Conversely, since the attractiveness of consoles depends on the games that can be played on them, game developers were also an important partner for the value proposition directed towards console buyers.

In 2006, the video game and console manufacturer Nintendo used the same business model for its new game console Wii but changed the components of the business model. Instead of the traditional customer segment of hard-core gamers, Nintendo focused on the significantly larger group of casual players of all age groups. Accordingly, the value proposition of the game console was also conceived for this group. Instead of costly technical perfection, a new and simple movement technology was introduced, whereby the Wii console with its new group games offered group fun and was moved from the basement into the living room. Through the new and larger target group, on the one hand, and the cheaper technology, on the other hand, Nintendo set itself apart from the competition and succeeded in implementing a so-called *Blue Ocean strategy* with its Wii [KiMa-2005].[2]

24.4 Business Planning

The business model is a didactically simple, but strategically very important design tool because it shows different starting points for designing and shaping the value creation process, from the creation over the delivery to the capture of value. The logic, with which the different components of the business model interact, shows clearly how the actual product is a central, integrative component of an entire economic process. The business model is thus the basic framework on which the entire operative economic business is based. The concrete design of this business is the subject of the so-called *business plan*.

For a potential financier, the most important components of the business plan can be inferred directly from the business model. The business model schema of Fig. 24.2 clearly shows the relationships. The product or service is the basis of the value proposition. The market and potential customers are captured in the customer segments. Marketing describes which distribution channels are to be used and how customer relationships are to be established. The founding team with all its core competencies makes up the key resources, and how value creation is achieved is determined by activity analysis, which also defines the role of partners (such as suppliers and intermediaries). Finally, the figures in the financial plan are derived from the detailed description of revenues and costs. During the entire design process—from the product idea to the business model and the business plan—the analytical approach remains the same, only the level of detail increases as the venture takes shape.

However, business planning is not only suitable as an economic design approach, but it is also a valuable evaluation tool. At the end of each design process, the comparison of expenditures and revenues reveals whether the business idea is economically viable at all. If it is not profitable, it should not be introduced to the market, at least not in its present form. A modified product or a modified business idea results in a new design approach, which must also be reevaluated, optimally with a new business

[2]Just as opportunity windows are open only for limited periods, blue oceans also turn red over time, i.e., when competitors enter the market to gain a share of the profits. With the other console manufacturers now also offering their own motion technologies, Nintendo discontinued the Wii console at the end of 2013.

plan. This, of course, requires additional effort and costs, but these are financially and often socially far less costly than a failed business idea. Moreover, the costs of business planning typically decline as the planner's experience rises.

The more qualified business planning becomes, the more reliable are its resulting signals regarding the success of a business idea. Within a decision-theoretical framework, CHWOLKA and RAITH show how the value of business planning is determined by the decision context of the planner, in particular the market potential of the business idea and the riskiness of the market [ChRa-2012]. However, in an uncertain environment, even the most carefully executed business planning cannot prevent failure. For very risky ventures, the probability of failure, even after business planning, can nevertheless be higher than the probability of success. As a consequence, even founders with business plans may more often fail than succeed on the market.

Relevant for the individual entrepreneur is only whether planning before market entry increases the likelihood of success. This is guaranteed, only if business planning as an evaluative process can also convey a signal for termination if the business idea is not good enough for the market. In a very uncertain environment, in which there may be more unsuccessful than successful business ideas, good evaluative business planning will also be more likely to signal termination rather than market entry. Indeed, the better the evaluation, the more likely the idea is to be abandoned. While creative business planning strategically prepares a business idea for the market, the value of good evaluative business planning lies in the fact that it keeps insufficiently good business ideas away from the market and thus protects the founder.

24.5 Implications for Product Development

The holistic perspective of business planning and the business model confronts the product developer with a particular challenge because the product to be created is the core of a usually more comprehensive value creation approach, aimed at a target group, which may possibly not yet be identified. The entire value creation process stands and falls with the product. Yet, to believe that the product alone constitutes the entire created value, is too short-sighted, because the product itself is only the core, around which the fruit with all its value dimensions is grown. Since the customer is interested in buying the complete fruit, this is what needs to be taken into account when developing the product.

In order to successfully develop a product, the developer must look at product development backward from the perspective of the customer or user. With the development of the iPhone, Apple was not the first to invent the smartphone. Yet, Apple understood like hardly any other cell-phone manufacturer before how to tailor the smartphone to customer needs that go far beyond the act of telephoning or texting. Technical elegance is an essential feature of all Apple products, but the technology alone does not drive their added value. Thinking product development forward and believing that a customer will always prefer a technically better product, often misses customer benefit. The example of the Wii console clearly shows that successful product development does not require technical perfection, but a rather successful target group orientation. In order to reach larger markets, standardization and simplification are often more successful than technical extensions.

With increasing societal pressures on firms to take on greater social responsibility (Corporate Social Responsibility), the necessity to consider social and environmental values beyond the traditional customer utility matrix of Fig. 24.1 not only increases the challenges but also the opportunities for product development. Toms Shoes, for example, a US-based shoemaker, donates a pair of shoes to people in need in Africa for every pair of shoes sold to customers in the US. This example of a buy-one-give-one business model illustrates the possibilities of adding social value to traditional products. This approach, however, can only be successful with the appropriate customer segment willing to pay a price premium on the purchased product. The same logic applies to bioproducts, where bio-customers are willing to pay a price premium on food products if they are manufactured in an environmentally responsible way. With customers increasingly sensitized to possibilities of hybrid, i.e., commercial and social or environmental value creation, the necessity arises for product developers to also acknowledge this multi-dimensional value orientation in conceiving a product or service that meets more sophisticated customer needs. Rather than simply tweaking traditional product development approaches, within profit-oriented business models, RAITH and Siebold show how business models can be strategically built around social and environmental missions with or without the objective of making profits [RaSi-2018].

The consideration of the business model thus crucially belongs to successful product development, because the business model provides the strategic framework for product development. A product idea originates in connection with a perceived opportunity. The criteria that the product needs to fulfil are, therefore, determined by the nature of the opportunity. With the marketability of the opportunity, further product specifications are required to position the product against possible rival alternatives, thereby making the value creation process competitive, in the sense that it is economically sustainable.

References

[BDSS-2007] Besanko, D., Dranove, D., Shanley, M., Schaefer, S.: Economics strategy, Wiley (2007)

[ChRa-2012] Chwolka, A., Raith, M.G.: The value of business planning before startup—a decision-theoretical perspective. J. Bus. Ventur. **27**, 385–399 (2012)

[Druc-2006] Drucker, P.F.: Innovation and entrepreneurship, Harper Business (2006)

[Gros-2017] Gross, B.: Youtube: https://www.ted.com/talks/bill_gross_the_single_biggest_reason_why_startups_succeed (accessed on 6th Sept 2018)

[KiMa-2005] Kim, W.C., Mauborgne, R.: Blue ocean strategy—how to create uncontested market space and make the competition irrelevant, Harvard Business School Press (2005)

[NaAy-2003] Nalebuff, B., Ayres I.: Why not? How to use everyday ingenuity to solve problems big and small, Harvard Business School Press (2003)

[OsPi-2010] Osterwalder, A., Pigneur, Y.: Business model generation, Self Published (2010)

[Port-2004] Porter, M.E.: Competitive strategy: techniques for analyzing competitors and industries, Free Press (2004)

[RaSi-2018] Raith, M.G., Siebold, N.: Building business models around sustainable development goals. J. Bus. Models **6**(2), 71–77 (2018)

[ShEc-2005] Shane, S., Eckhardt, J.: The individual-opporunity nexus, handbook of entrepreneurship research. Int. Handb. Ser. Entrepreneurship. **1**, S. 161–191 (2005)

[Wein-2012] Weinstein, L.: Guesstimation 2.0—solving today's problems on the back of a Napkin, Princeton University Press (2012)

Chapter 25
Economic Efficiency Aspects in IDE

Michael Schabacker and Sándor Vajna

As practical experience with comparable approaches has shown (an extensive collection of such experiences can, e.g., be found in [EhMe-2017]), the economic efficiency of IDE itself is given from the outset and therefore does not need to be considered further here, because

- the conversion of activities to the principles of IDE involves only non-recurring costs for setting up the project organisation and running costs for staff training.
- the benefits arise from the overall significantly higher quality of the work results due to integration and interdisciplinarity in comparison with procedures that tend to involve the division of labour, from the lower and more intelligent use of resources, and from shorter processing and testing times.

The contents of this chapter are therefore the descriptions of the different approaches and procedures for determining the economic efficiency[1] of any products (for the product term, see Sect. 2.1) that are created with IDE and used by the customer. On the one hand, the descriptions are given from the views of providers and customers of a product, and on the other hand from the views of the capital goods and consumer goods industries.

The economic efficiency E of a new product is defined as the quotient of the benefits or services to be provided or rendered (output) and the costs incurred or to be incurred for them (input):

[1]The issue of value creation related to economic efficiency is discussed in Chap. 24.

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$$\text{Economic effciency } E = \frac{\text{Output(benefits)}}{\text{Input(costs)}}$$

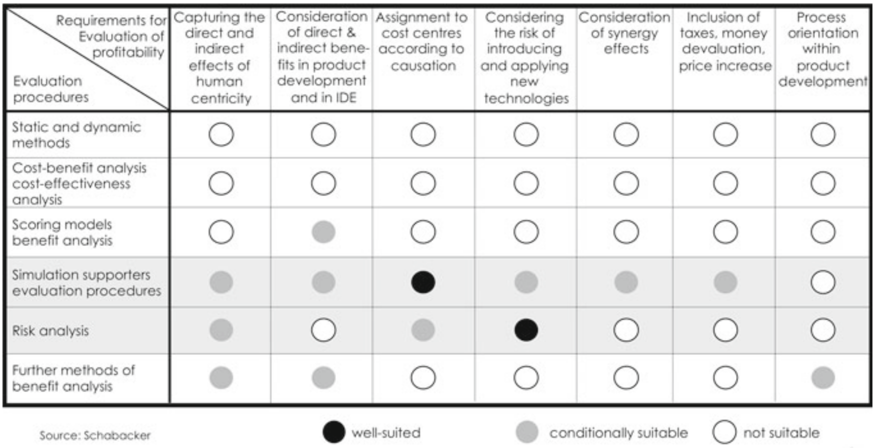
- The benefits are determined over a period of time from all services rendered that result in an investment. To this end, benefits must be recorded as completely as possible. Benefits are valued in monetary terms ("quantified") so that they are comparable with costs.
- The costs correspond to the value of all goods and services consumed in the same period (non-recurring or ongoing) that are required in connection with the creation or introduction and operation of the new product.
- If the quotient E is greater than 1, an absolute profitability is given.
- If the quotient E equals 1, then the product makes a contribution margin equal to zero for the provider. The achieved returns created by the product are the same as the cost of the product, since the revenue (sales) generated by the product is offset by the variable costs of the product in order to cover the fixed costs of the product (cost-covering profitability).
- If the quotient E is greater than zero but less than 1, then the product contributes a loss to the overall economic situation of the provider (inefficiency).

In IDE, economic efficiency is regarded from several viewpoints. If a company acts as a provider, it hopes that the product created with IDE will be attractively profitable. The customer expects a reasonable added value from the product, whereby it must be differentiated in IDE whether the customer is from the capital goods or from the consumer goods industry (see Chap. 2). Added value and profitability arise from both the performance and behaviour of the product, which are offered within a reasonable time and at a reasonable cost.

Chapter 3 shows that IDE is human-centred, integrated, interdisciplinary and networked in many ways, leading to a shift of activities and decisions to product development. This is made possible by predicting product and process characteristics (*predictive engineering*) and reinsurance in decisions through advance information and feedback (*reverse engineering*) (Fig. 1.1). This enables a provider to achieve an early or timely market entry, which today has become the decisive criterion for the market success of a product, primarily in the consumer goods industry. The "first provider" often secures market leadership over its competitors, especially in innovation-intensive areas, and thus the opportunity of rapid amortisation of investments through considerable profits (see also Sect. 24.1).

At the same time, work within IDE takes place within a dynamic framework in which both requirements and environments of an order can (and usually do) change at will. These properties of IDE result in the requirements for possible procedures for the evaluation of the economic efficiency. Therefore,

- evaluation procedures must first and foremost be focused on the human contribution and be able to capture it over the entire product life cycle,
- the results of this determination must be readily available with sufficient accuracy and detail,



Requirements for Evaluation of profitability / Evaluation procedures	Capturing the direct and indirect effects of human centricity	Consideration of direct & indirect benefits in product development and in IDE	Assignment to cost centres according to causation	Considering the risk of introducing and applying new technologies	Consideration of synergy effects	Inclusion of taxes, money devaluation, price increase	Process orientation within product development
Static and dynamic methods	○	○	○	○	○	○	○
Cost-benefit analysis cost-effectiveness analysis	○	○	○	○	○	○	○
Scoring models benefit analysis	○	◍	○	○	○	○	○
Simulation supporters evaluation procedures	◍	◍	●	◍	◍	◍	○
Risk analysis	◍	○	◍	●	○	○	○
Further methods of benefit analysis	◍	◍	○	○	○	○	◍

Source: Schabacker ● well-suited ◍ conditionally suitable ○ not suitable

Fig. 25.1 Comparison of evaluation methods for determining the economic efficiency within IDE [Scha-2001] (black circle: Well suited. Grey circle: Conditionally suitable. Empty circle: Not suitable)

- only those methods can be used which taken into account of the dynamics of the IDE environment.

Figure 25.1 shows the results of the comparison of evaluation methods and their suitability.

As shown in Fig. 25.1, only procedures that can simulate activities, decisions and tool use within IDE and that can record the associated risks can be considered for recording and evaluating the economic efficiency. These procedures include life cycle costing, the net present value method, and the benefit asset pricing model (BAPM®) with the balanced scorecard.

25.1 Determination of Costs

In determining costs, a distinction is made between non-recurring costs and operating costs. Costs can be estimated *prospectively* (in advance; for the provider during the offer phase of the product, for the customer during the decision phase as to whether he wants to procure the product) or during the use of the product and prepared *retrospectively* (afterwards). The general rule for the cost estimation in the prospective analysis is that the annual follow-up costs are about 30–40% of the respective investment.

25.1.1 Life Cycle Costing

An essential instrument for carrying out cost calculations at any time in the life cycle of a product is *life cycle costing* (LCC), which requires a continuous linking of the actual costs with the original requirements of the product. Life cycle costing is the calculation of all costs incurred by a product during its entire life cycle (among others [Harv-1976, ShKo-1981, PfWü-1983, Gabl-2013a, CoFG-2007]). Originally, LCC was used for the planning of large-scale projects, for example for the planning of power plants [Wübb-1986]. At the end of the 1990s, this term was extended to include the word "product" (product lifecycle costing, PLCC) in order to also analyse the economic efficiency of products or to decide on the selection of alternatives when purchasing large capital goods [CoFG-2007].

Related terms in life cycle costing are:

- Design to Cost: This process used in product development looks for the most cost-effective solution for individual components already in the development phase, which also includes (subsequent) follow-up costs, such as sales or service costs [Unte-2013].
- Total Cost of Ownership: In contrast to life cycle costing, only the costs incurred for the introduction as well as during and after use of a product are considered from an operational point of view [Kiel-2007].
- Lifecycle Costing Analysis: In addition to the life cycle cost calculation, which represents the sum of planning costs, development costs and follow-up costs, this includes the description of assumptions and limitations as well as the benefits (e.g. based on the sales price of the product) and risks of the product, which are also included in the investment decision [DIN-60300] (further details can be found in [DIN-60300]).

To calculate the life cycle costs of a product, it is recommended to include the processes of the product life cycle in Fig. 25.2, which can be carried out, for example, by using activity-based costing [Gabl-2013b]. In this case, the overhead costs are distributed according to the actual utilisation, so that the resources to be consumed can be allocated according to the process steps.

Another method for life cycle costing is target costing [CoFG-2007]. This procedure belongs to the backward costing procedures, since the target costs of the assemblies and components of a product are determined on the basis of the achievable sales price and these are to be adhered to. Of course, this procedure can also be applied in a similar way in other phases of the product life cycle. Further possibilities for predicting the cost elements occurring in the product life cycle are the other so-called progressive calculation methods (forward calculation methods) such as short calculation on the basis of cost growth laws or price calculation (among others [FFHP-2008, EhMe-2017]).

Figure 25.3 shows the cost types occurring in the life cycle of a product.

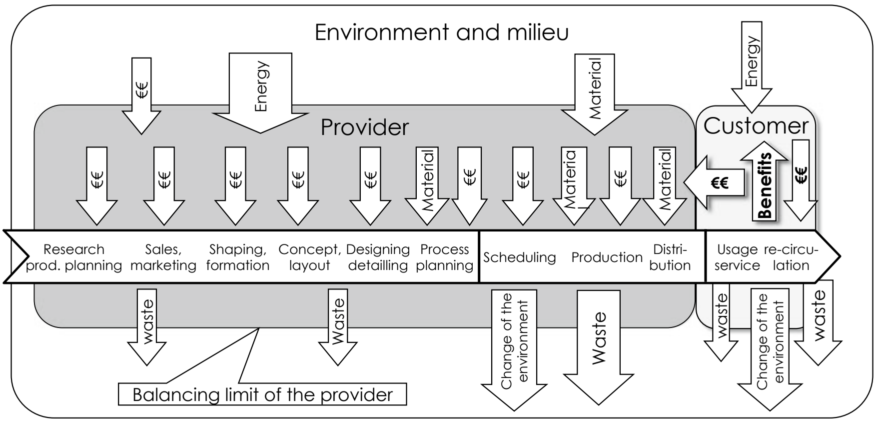


Fig. 25.2 Money, energy and material flows to and from the provider and between customer and provider

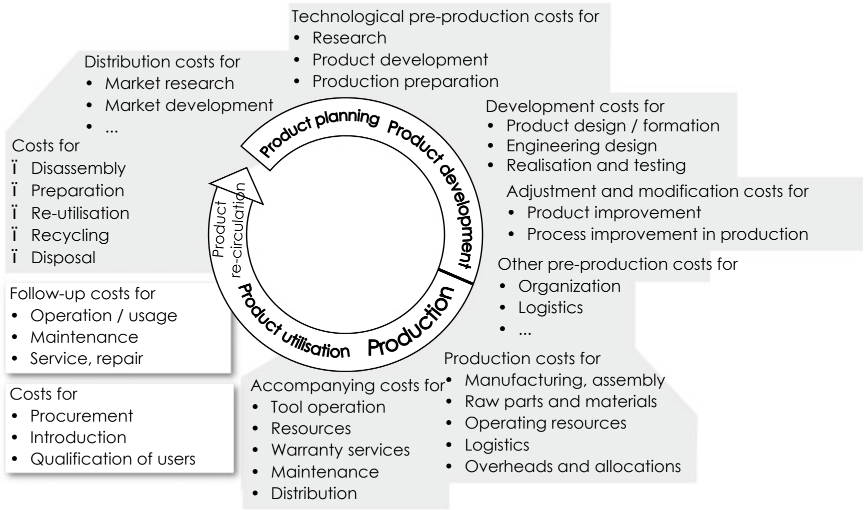


Fig. 25.3 Costs in the product life cycle (grey background: costs at the provider. white background: costs at the customer) on the basis of Fig. 2.2 and following [Scha-2011]

For "fast" life cycle costing analysis, the individual cost elements in the product life cycle phases are identified (see [VDMA-34160] for procedure). The calculation of the life cycle costs is then carried out by pure summation.

In Fig. 25.4, idealised cost curves for some of the costs within the product life cycle shown in Fig. 25.3 are presented.

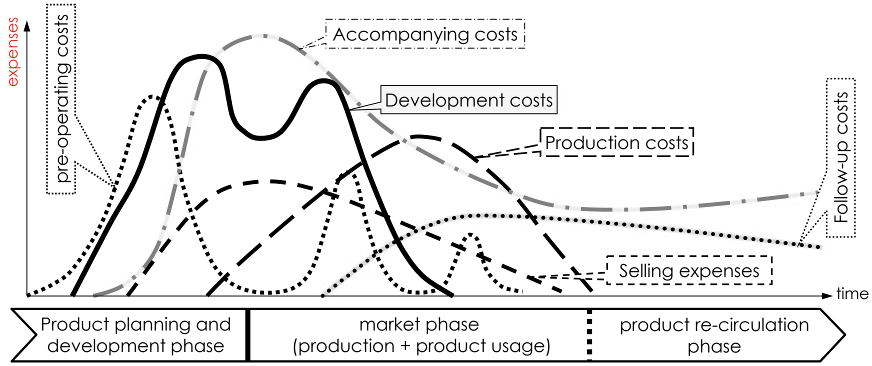


Fig. 25.4 Cost progressions in the (integrated) product life cycle based on [Back-1988]

The product life cycle is again is divided into three phases: product planning and development phase, market phase (in which the processes of production and product usage that take place almost simultaneously are combined) as well as product re-circulation phase. In the literature, this representation in three phases is also referred to as the integrated product life cycle (e.g. [Riez-1996, CoFG-2007]).

- The first costs incurred in this product lifecycle are the pre-production costs for research, product development and production preparation (dotted curve in Fig. 25.4). Since a product undergoes several product modifications (relaunch, face lifting, updates) in the course of its life, the incurring costs are wave-shaped, whereby the wave peaks are becoming smaller and smaller as more experience and knowledge about the product is available. Development costs (black curve) follow a similar course.
- Accompanying costs (dotted grey curve) rise sharply when a product is launched, fall flat during the market phase and rise again at the end due to product phase-out and product disposal costs.
- The sales costs (short dashed curve) start after planning the first marketing measures in the product development phase, the production costs (long-dashed curve) follow later towards the end of the product development phase. Both rise sharply and decline again at the end of the market phase.
- The follow-up costs for maintenance, servicing, etc. (grey-dotted curve) do not arise until the market phase, rise there and fall during the product re-circulation phase.

Although the cost trends can be described mathematically and thus most costs (e.g. for production or maintenance) can be predicted, it is difficult to determine the possible benefits and in particular the associated risks in monetary terms. The knowledge of these is indispensable for the selection of alternatives for technology projects with regard to their economic efficiency and life cycle cost analysis for the company management.

25.1.2 Costs of the Provider

The provider must (irrespective of whether he belongs to the capital goods or the consumer goods industry) record all costs for goods and services required for the creation, placing on the market and care of the product at the customer's (assumed that this care is taken over by the provider). Non-recurring costs (mainly in product development and production) are directly caused by a specific customer order. They can be predicted either by drawing on findings from earlier and similar projects or by pre-modelling the expected processes with dynamic process and project modelling (Sect. 15.7). Current costs include sales costs, pre-production costs and accompanying costs, for which it must be determined in each individual case to what extent they can be assigned to which order.

25.1.3 Costs of a Customer from the Capital Goods Industry

The cost of a product can be relatively easily captured, as the provider can accurately identify both the investment and maintenance costs, and the customer is aware of the time and effort required to do so in terms of personnel and production means.

Non-recurring costs incur for the introduction (year 0) and possible later expansion stages of the product, but not permanently. In the case of purchase, these are the investments, in the case of rent and leasing the first instalment as well as the costs for commissions and conclusion of the contract, etc., in the case of leasing the special payment at the beginning of the leasing contract. In addition, there are costs for application preparation and accompanying services, such as consulting or external training.

Non-recurring costs are included in depreciation. One can choose between a linear or a degressive form. Depending on the company and tax conditions, straight-line depreciation can be calculated over a period of five to six years[2]. In the case of products with a high proportion of IT, such as computer systems and mechatronic products, declining-balance depreciation with terms of no more than three years should be preferred (e.g. 50% depreciation in the first year, 30% in the second year, 20% in the third year) due to rapid technological progress. Typical non-recurring costs are (see also Fig. 25.3):

[2]The acquisition costs for depreciable items of the operational fixed assets (e.g. passenger car, machine, equipment, tools) are to be distributed over the normal useful life of the item (§ 7 Paragraph 1 Sentence 1 Income Tax Act). However, in bad economic times (i.e. in recessions) this is deviated from and depreciation periods are shortened so that companies can procure new fixed assets to stimulate the economy in order to reduce their tax burdens. Tax advice for investment decisions should be included in all cases, because, in Germany, taxes can have the effect that an unfavourable investment before tax becomes an advantageous investment after tax (or vice versa due to the German tax paradox), the ranking changes when comparing investment alternatives and the economically optimal useful life of investment projects shifts.

- Preparatory work (feasibility studies, weak point analyses, internal planning, external consulting, product selection, adaptation of processes and information flows, etc.),
- Procurement of the product,
- Installation costs, introductory costs, training of the employees who will work with the product (course fees, personnel costs, travel expenses),
- Projectable follow-up and expansion investments as well as
- Constructional measures (e.g. increased fire protection and disaster control).

Current costs (e.g. maintenance costs, operating costs, training costs, rental instalments and leasing fees) do not occur until the first year. For subsequent years, they are allocated as cash outflows to the respective accounting period in which they occur. Typical current costs are (see also Fig. 25.3) the costs for the operation of the product and the necessary support staff, maintenance and repair costs and (if required) further training and support for product users.

25.1.4 Costs of a Customer in the Consumer Goods Industry

For customers in the consumer goods industry, in addition to the non-recurring procurement costs, the follow-up costs for maintenance and care are of particular importance. Here in particular, the rule applies that the annual follow-up costs are about 30–40% of the procurement costs, especially as more and more products are offered on the market that has low procurement costs but cause high follow-up costs[3].

25.2 Determination of Benefits

In the capital goods industry, the benefits of a product can be seen, for example, in the form of shorter throughput times[4] and better use of resources, e.g. evaluated time advantages, material savings, quality improvement, cost reduction with the same performance, increased performance with the same use of resources, better image in the market, whereby the distinction between these individual types of benefits is fluid.

[3] With inkjet printers and mobile phones, for example, the actual device is offered at a very low price, but the consumables of the inkjet printer or the monthly costs of the mobile phone contract within the period of use of the device exceed the procurement costs many times over, because the provider generates its revenues primarily from these follow-up costs.

[4] According to [DIN-1996], the throughput time is made up of processing time, transport time, waiting time and idle time, whereby only the processing time contributes to the added value. It is interesting to note that the percentage of processing time in the throughput time in German industry is less than 10%.

If the benefits are captured with the well-known Controlling procedures, then this is only possible by a comparison of procedures, by setting the initial state (state before procurement and introduction of the product into the regarded range of the enterprise) in relation to the final state (product in application) in order that the use can be quantified monetarily. The following possibilities for the emergence of benefits result from process comparison:

- Cost reduction with unchanged performance of the considered area of the company through (a) replacement of rigid procedures by more flexible procedures and (b) replacement of low-value procedures by higher-value/more efficient procedures.
- Performance increase with the same use of resources by (a) replacing isolated by integrated procedures and (b) replacing serial by parallel procedures (e.g. Simultaneous Engineering, Sect. 15.1).

However, these possibilities do not capture every benefit. There may also be benefits that are often difficult or impossible to quantify in monetary terms, so-called qualitative benefits. The main reasons for this are:

- Working in IDE leads to a relocation of activities from downstream areas to product development (*Front Loading*, Fig. 1.1). Since these activities previously took place in a different area than after the conversion to IDE, a direct benefit assessment from a before-and-after comparison is not possible. Such activities, however, generate most of the IDE benefits.
- Missing or incomplete reference values for the assessment of benefits, because, for example, the processes in the area in which the customer launches the product were insufficiently documented. Therefore, the comparison of the state before with the state after cannot or only insufficiently take place.
- The positive effects of applying a product often become apparent only in the subsequent areas (e.g. CAx applications within product development often generate significant benefits mainly in the areas of process planning, production control, manufacturing and assembly, which are significantly higher than the benefits that arise in product development itself). However, due to the different cost centres in these areas, the direct allocation of the product application costs at one cost centre with the resulting benefits that arise at another cost centres is neither possible nor usual[5].

In the case of a product for the use of which employees must first be trained or which must be gradually brought up to operating condition (e.g. a complex plant), the benefits are subject to a ramp-up behaviour that depends not only on the suitability of the product but also on the quality and coordination of the introduction measures (in particular the appropriate qualification of the product users).

The total benefit of a product is then created by adding up the individual benefit shares and by their mutual reinforcement (synergy effect).

[5]However, a simpler and better allocation of costs to the respective originators would be possible with cost object accounting.

The value benefit analysis according to ZANGENMEISTER [Zang-1976] (as well as its derivatives scoring model and ranking model [Gabl-1995]) can be used to determine the monetary quantifiable and monetary non-quantifiable benefits, as they arise in IDE in particular from the evaluation of benefits from human centricity. Applying the benefit analysis, it is possible to consider technical, psychological and social evaluation criteria[6], which orient themselves to quantitative and qualitative characteristics (multi-attributive benefit analysis) and which are evaluated with a points system. The benefit analysis enables the evaluators to evaluate the system taking into account both a multidimensional target system and specific target preferences by weighting criteria according to the pairwise comparison method [LoWi-2012] or according to the method of BREIING and KNOSALA [BrKn-1997].

Advantages are the direct comparability of the individual criteria and the possibility of their flexible adaptation to special requirements. A disadvantage is the weighting of target criteria based on subjective judgements and the determination of part benefits. The determined benefit value contains a high degree of subjectivity due to the weightings and point assignments by different persons. Since this can have a decisive influence on the outcome, conflicts often arise when multiple people make decisions on the same issue.

The benefit analysis is to be regarded as a heuristic method for systematic decision-making because of its comprehensible and verifiable process, thus leading to an advantageous supplement of other methods that serve the structure of the decision problem in the evaluation of complex products.

25.3 Determination of Economic Efficiency

The procedures for calculating the economic efficiency in development and production of a product (provider and the resulting profitability) or the procurement and use of the product (customer or user and the resulting added value) can be divided into prospective and retrospective on the one hand, and static and dynamic investment processes on the other hand.

- In the prospective or ex-ante view, the costs to be incurred for the creation of the product (provider) or for its introduction and application (customer) and the expected benefits are estimated or taken from empirical values.
- In the retrospective or ex-post analysis, actual values for costs and benefits are included in the calculation of economic efficiency.

Since IDE takes place within a dynamic framework and requirements and boundary conditions can change at will, only the dynamic investment procedures, which are particularly suitable for performance reviews, are suitable here for determining

[6] While a benefit analysis records and evaluates subjective desires that cannot be evaluated in monetary terms (or with difficulties only), it is possible to determine time and cost criteria as well as other financial criteria precisely by calculating savings in time and resources.

economic efficiency. With these procedures, the length of a period for which the economic efficiency is to be determined can be defined and subdivided as finely as required. Costs and benefits are available as correspondingly detailed cash outflow and cash inflow series. In addition, the influence of ramp-up behaviour (initially low-cost savings which increase later) is taken into account. The same applies to fluctuations in cash inflows that occur later.

By discounting cost savings, it is noted that savings in later periods (i.e. with a longer time lag to the time of the investment, resulting in a more costly debt service) are less valuable than in earlier periods. Cash outflows in earlier periods are more significant than in later periods. It should be noted that costs (cash outflow series) and benefits (cash inflow series) are incurred in different sizes over a longer period of time. It is therefore necessary to take into account the time value of the investment in a product by discounting it.

- The time value describes the fact that the amount of an investment made at the beginning of a use (“year 0”) will not have the same value as an investment of the same nominal amount made in future years. The following example illustrates this: If 100.00 Euros are invested for five years with a fixed interest rate of 1.5%, then, by this interest rate, the 100.00 Euros increases to 101.50 Euros after one year and to 107.72 Euros after five years; i.e. the initial value has risen by 7.72 Euros over the five years. Cash outflows at the beginning of the period of use are thus “more expensive” than such in the meantime or at the end of the period of use. Cash inflows at the beginning of the usage period are thus all the more “valuable”. This changed time value must therefore be taken into account in the calculation of economic efficiency.
- Discounting means that all future values (investments, current costs, benefits) are reduced to their present value (usually to the year 0 of a project, immediately before the investment [Woeh-1986]). By discounting, one obtains the amount that one would have had to invest in year 0 in order to reach a certain final capital T years later. Accordingly, discounted values are determined by multiplying the final capital by the discount factor $1/(1 + p)^T$. Here p is the company-specific interest rate for the minimum return on the capital employed, T is the term in years. So if in the above example 100.00 Euros are to be invested only in five years time, then today only 92.83 Euros have to be invested (assuming a constant interest rate of 1.5%), which will grow to 100.00 Euros in five years.

The procedure described above can be used analogously for other periods (e.g. months). The appropriate interest rate must be determined from the respective annual interest rate. This also allows future inflation to be taken into account.

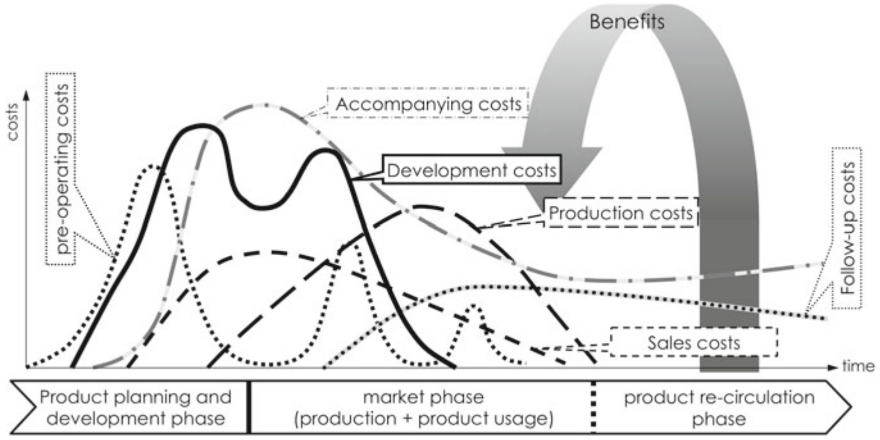


Fig. 25.5 Costs and benefits in the product life cycle

25.3.1 Provider

The provider hopes that the product created with IDE will be sufficiently profitable. Profitability is the ratio of profit earned to capital employed in a given accounting period.

The different cost trends (see Sect. 25.1.1 and Fig. 25.4) are used to determine profitability (also called return on investment). The benefit to offset the costs results from the sales proceeds of the product. In the case of products that are rented or leased to customers or products that are subject to a high level of preventive maintenance (e.g. computer hardware and software), in addition to the proceeds from the sale, the customer makes not inconsiderable payments of licence and usage fees, which are also included in the determination of profitability, Fig. 25.5.

25.3.2 Customer from the Capital Goods Industry

The added value in the case of a customer from the capital goods industry results from the efficiency and performance (demanded by the customer and realised by the provider) in the daily use of the product, so that the effort for procurement, introduction, operation and re-circulation of the product is perceived as reasonable compared to its performance.

When a product is purchased, the *net present value method* and its variants *internal rate of return method* and *dynamic amortisation calculation* are among the most widely used methods for determining the added value. They are based on the following net present value (NPV) formula for life cycle cost analysis:

$$\mathrm{NPV} = -\mathrm{I} + \sum_{T=1}^{T^*} \frac{(\mathrm{CI}_T - \mathrm{CO}_T)}{(1 + \mathrm{IR})^T}$$

In this formula

NPV	Net present value at the time of the investment I ($T = 0$)
I	Investment (purchase) or special payment (leasing), both in year 0
T	Period (e.g. months or other time units).
T^*	Amortisation period or economic lifetime (upper limit: end of depreciation period)
IR	Interest rate (enterprise-specific internal rate)
CI_T	Money-weighted, time-related benefit from payments received/savings (cash inflow), based on a period T at the end of this period
CO_T	Current costs from disbursements (cash outflow), based on a period T at the end of this period
$\mathrm{CI}_T - \mathrm{CO}_T$	Time-related resulting "profit", based on a period T at the end of this period
$1/(1 + \mathrm{IR})^T$	Discount factor at the end of a period T.

Figure 25.6 shows, on a year-by-year basis, the time-related relationship between

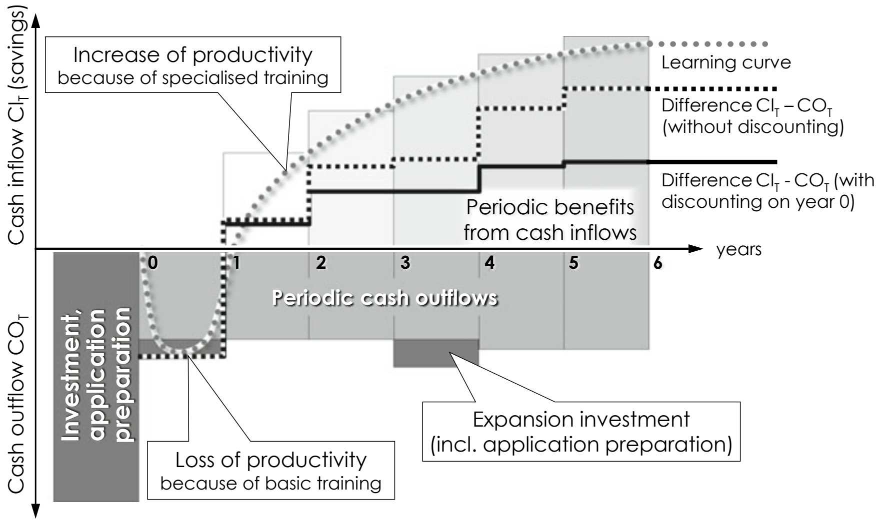


Fig. 25.6 Relationship between cash inflow and cash outflow on the basis of the learning curve (The learning curve is used when employees need to learn new or changed organisations, structures, rules, procedures, technologies and/or tools. The first phase of the learning curve includes basic training. Here the employee is not (or only hardly) productive and there are additional expenses for the training itself and possibly for an additional employee as a replacement during the training. There is a loss of productivity. In the second phase, the learning curve and learning success and thus productivity increase until the expected threshold value is reached.)

cash inflows and cash outflows and the effect of discounting when a customer in the capital goods industry is suing this product.

- There are no cash inflows in year 0. From year 1 onwards, cash inflows are generally continuous rather than erratic. When introducing a product for which employees have to be trained, the payments are essentially analogous to the learning curve (dotted curve). Thus, personnel influences are also included in the payments. Further courses are also possible (see [Scha-2001]).
- Cash outflows cover the investment when the product is purchased, the first instalment for rental and the associated initial costs and the special payment for leasing. In all cases, the costs for the investment and application preparation are added. No interest is due in year 0. The cash outflows include current costs from the first year onwards. These may increase if expansion investments are made (in Fig. 25.6 in the fourth year), which are to be considered at the time of their occurrence. Cash outflows do not include depreciation and interest costs, as from year 0 the investment (at purchase) or the regular instalments (at rent and leasing) are fully included in the calculation. Nevertheless, they are also discounted.

The time value of the cost savings is taken into account by discounting to year 0. This is clearly shown in the difference between the curves of the cost-saving curves in Fig. 25.6.

- In the *NPV method,* the NPV is calculated for fixed enterprise-specific values for interest rate IR and depreciation period T^*. An investment is economic if the net present value is greater than zero, where the degree of economic efficiency is directly proportional to the amount of the net present value.
- With the *internal interest rate metho*d, the system searches for the interest rate IR* where the net present value equals 0 for a fixed depreciation period T^*. IR* is the actual return on the capital employed. If the interest rate is above the (specified) company-specific interest rate IR_{min} (minimum return), the investment is economical. This method is particularly useful if the interest rates of several competing projects are to be compared.
- The *dynamic payback period* T^* is calculated with a fixed interest rate IR at the time when $NPV = 0$. For an economic investment, it must be below the company's target value (e.g. three years) or at least under the usual depreciation period typical for this company.

The dynamic methods are suitable for both prospective (introductory and ramp-up phase) and retrospective economic considerations (within an ongoing operation). In the prospective case, estimated or calculated values are used for the series of cash inflows and cash outflows; in the retrospective case, the actual benefits and costs incurred are used. However, the net present value formula has two serious disadvantages: On the one hand, in the forecast of cash inflows, i.e. future repayments (net cash flows), and on the other hand, in the estimation of the expected return on the product's benefits. Both can be calculated using the benefit asset pricing model (see Sect. 25.4).

25.3.3 Customer of the Consumer Goods Industry

In the case of a customer in the consumer goods industry, the financial added value by ownership of the product can in principle be determined using the same procedures as for a customer in the capital goods industry, preferably using the net present value method, whereas the internal rate of return method and the dynamic payback period for consumers only play a role in exceptional cases.

However, an important and often misunderstood component of added value arises from the customer's feeling that the product meets his primary needs and expectations in a particularly pleasant way in relation to the purchase and operating costs. The customer may feel an added value from product ownership if it provides him with an additional (and unanticipated) benefit. This can manifest itself, for example, in increased well-being through previously unimagined possibilities of use (affordances, see Sect. 2.1) and in a change in its social status (desired distinctive feature, "admission ticket" to certain circles, yielding to or resisting public pressure, additional prestige, envy factor). Not to be underestimated is also a good conscience towards the environment, fellow human beings and institutions through ownership and use of the product.

25.4 Benefit Asset Pricing Model (BAPM®)

Difficulties may arise in recording the detailed benefits and their conversion into monetary values (quantification and evaluation) for the profitability calculation, since, for example, productivity increases in product development often only become visible in subsequent areas. The question of the compensation of costs occurring at one cost centre and the resulting benefits arising at another cost centre has not yet been clearly clarified in controlling. In addition, new activities and procedures emerge within IDE for which there is no model in the conventional process. Thus, a direct comparability before–after is not given and a benefit determination is only with difficulty possible.

In this section, the Benefit Asset Pricing Model (BAPM[7]) according to SCHABACKER [Scha-2001] is described as a powerful method for the valuation of such

[7] "BAPM" is a registered trademark. This also applies if this term is used in this text without the trademark.

benefits[8], which are very different and can originate from different areas. BAPM says the return on investment of a product (provider) or a product application (customer) uniformly and with a reliability of approximately 90% ahead. Of course, this method can also be used to predict the future benefits of the product or its use.

In BAPM, the different benefits must first be categorised. This is based on the balanced scorecard [KaNo-1997] approach developed by KAPLAN and NORTON. The basic idea of the balanced scorecard is based on four perspectives:

- The *financial perspective of* a company is traditionally presented in annual or quarterly financial statements. It contains information on the net assets, financial position and results of operations of a company.
- The *customer perspective* provides the provider with information about the positioning of the company in certain market segments, about customer satisfaction or customer loyalty.
- In the internal *process perspective, the* description of the company is based on the individual processes and activities implemented in the company.
- The *learning and development perspective* includes the so-called soft success factors that result from human centricity within IDE. These are the motivation and level of training of employees, access to relevant external sources of information and the organisation of the company.

This results in six benefit categories in BAPM for the economic evaluation of a product:

- Service quality and product quality (from the customer perspective),
- Process performance and project performance[9] (from the process perspective) and
- Employee environment and use of tools (from a learning and development perspective).

In Fig. 25.7, examples from these six benefit categories are presented.

In the individual benefit categories, both monetary quantifiable and monetary hardly quantifiable benefits and any number of intermediate stages can occur. SCHABACKER grouped these for their uniform evaluation in benefit classes according to [VDI-2216], which he extended by internal and external synergy effects[10]. The BAPM portfolio [Scha-2001] was created from these (technical) benefit classes.

The determination of the resulting benefit is made with the help of analogies to benefit classes in other domains, because there is an astonishing analogy in the

[8]This method has been successfully used so far in the evaluation of different applications, see, for example, [Scha-2002, ScVa-2002, ScWo-2002, Scha-2004]. Further information can be found at www.bapm.de.

[9]A process describes a working instruction on how something is done. If an order is started, the process becomes a concrete project with defined targets for the result, start and end dates as well as the use of resources (see also Chap. 15).

[10]Synergy effects are those benefits that arise from the interaction of several procedures or systems, without it being possible to directly assign the cause or the trigger for a benefit to a specific procedure or system.

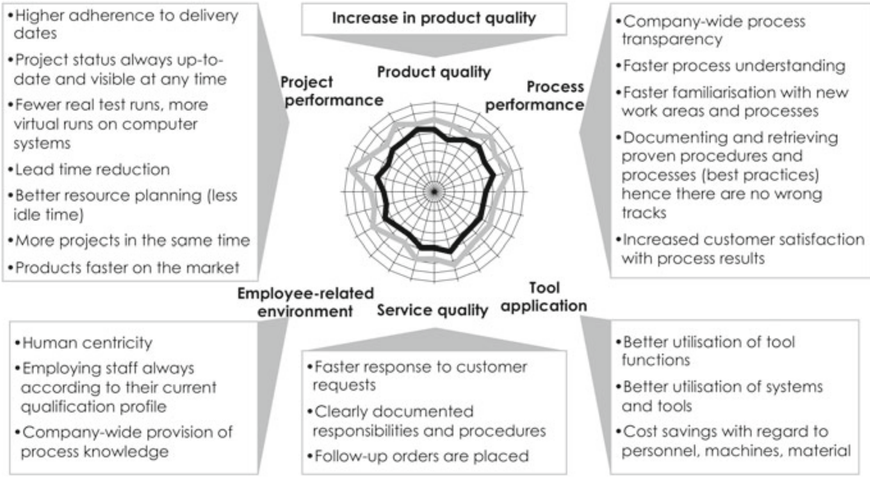


Fig. 25.7 Examples from the six benefit categories in BAPM

behaviour of (financial) objects from the capital market and the behaviour of benefit objects from the (technical) environment of product development. The analogy was derived from the very similar conflicts of objectives in the manufacturing industry on the one hand and in banks and insurance companies on the other [Scha-2001]. It has been demonstrated by the following observations:

- There are financial objects in the capital market whose behaviour is mathematically similar to that of benefit classes in technology due to their risk/return profile, which are evaluated according to a risk/benefit profile.
- A certain financial object from the capital market can be uniquely mapped to a benefit class in technology on the basis of the same behaviour (these are opposite each other in Fig. 25.8). For example, in the case of directly quantifiable benefits, its size and the time until the benefit occurs are known. The benefit is achieved in any case, so there is no risk. An investment in time deposits or fixed-term deposits behaves in the same way in the capital market. In contrast, in the case of a synergy effect, no concrete statement can be made as to the magnitude of its benefit and the time until which it will occur; therefore, there is a multiple risk. The same applies to a foreign bond, which is subject to the risk of the bond itself and the currency risk.
- For the prediction of yield and risk of financial objects in the capital market,[11] there are efficient methods (e.g. portfolio theory of Markowitz [Mark-1952], option

[11] Bonds are long-term and fixed interest obligations (i.e. a claim of the creditor with a fixed interest rate). Zero bonds are bonds that do not carry a current interest rate. They are issued at the discounted issue price and redeemed at the nominal price (redemption price on the due date). The difference between the issue price and the redemption price is the yield.

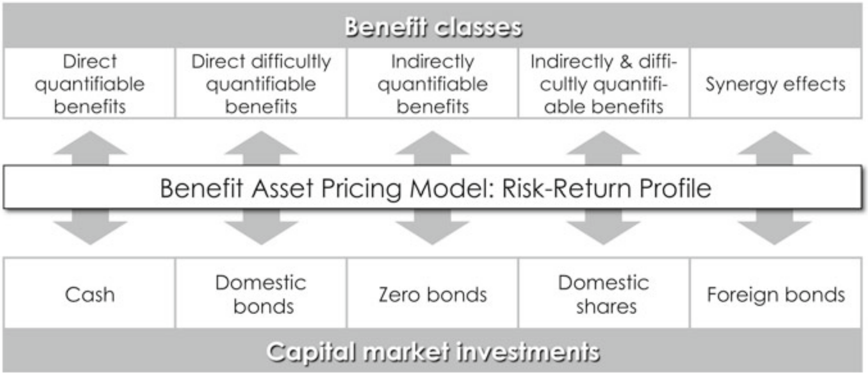


Fig. 25.8 Benefit assignment in BAPM®

price theory (e.g. [Irle-1998])), which consider the speculative[12] character of the objects, which can lead to abrupt price developments in the capital market.

- The corresponding objects in technology behave much more reliably, as experience to date has shown that there are no abrupt changes in direction, as is the case with share prices, but rather continuous development of organisations and technologies (e.g. investments have to be written off over a fixed period of time). During this period, there is usually no change of direction, because otherwise the investment would become uneconomical).

Therefore, certain prediction methods can be transferred from the capital market with sufficient accuracy and reliability to the technique for predicting the benefits of IDE.

BAPM evaluates the efficiency of a procedure or a process or a technology in the broadest sense on the basis of the respective application in a concrete task for a specified period of time. On the one hand, this provides an insight into which functions and components of the procedure or technology occur where and at what frequency. On the other hand, the dynamic behaviour of costs and benefits is captured. The valuation can be carried out both prospectively and retrospectively.

On the basis of extensive test series, it was established in [Scha-2001] that the behaviour of benefits can be modelled with a limited number of so-called yield curves. Each component of an approach or each individual functionality of a technology can be unambiguously assigned to a specific yield curve. The beginning and end of the yield, its course as well as its minimum and maximum values can be set according to the problem from rules and empirical values stored in BAPM (a list of the individual monetary values for the yields is available, for example, in [ScEn-2005]). Figure 25.9 shows this using the known learning curve (see also Fig. 25.6).

BAPM allows to evaluate either all components of a procedure (or functions of a technology) or subsets of them. The appropriate selection must be made and the

[12]In 1880, the Stock Exchange Committee of Enquiry defined in its 75th report: "Speculation is the intellectual activity which draws a conclusion about the future from the experience of the past and the observation of the present" (quoted after [NeBr-1928 and Hahn-1954]).

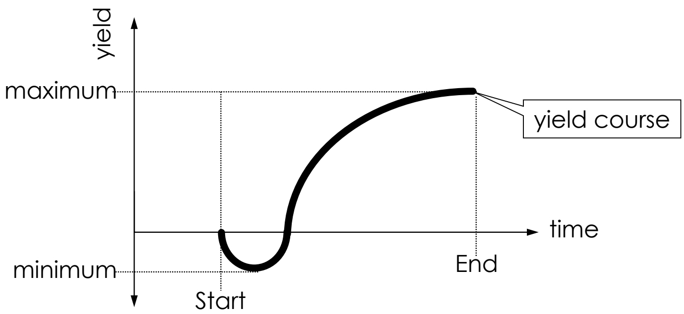


Fig. 25.9 Adjustable parameters of a yield curve using the example of the learning curve

yield curves belonging to the respective functions or components can be configured from tables or on the basis of experience.

Now the assignment to the considered work process takes place. For this purpose, the work process is divided into individual process elements and each element is assigned the respective function or component. For this purpose, process modelling systems can be used (see Sect. 15.7) with which the work process can be modelled. This means that not only the benefit resulting from the isolated application of a procedure or technology can be recorded, but also the benefit from the interaction of the individual functions or components in the entire work process, for example via process-specific key figures (e.g. an improvement in the quality of a manufacturing process leads to a reduction in processing times and costs). Then the simulation run of the process of interest takes place in the period determined by the user, in which the application of a certain function or component is also recorded both according to its frequency and according to the location of its occurrence.

The result of this (multidimensional) assessment is a portfolio of expected benefits and the respective risk of achieving each component of expected benefits. These benefit components form the expected payments for the dynamic investment processes. The expected disbursements (costs) result from the required investments in procedures and technologies and their current costs (such as for training, application, care and maintenance). Finally, the economic efficiency of the application can be determined with the respective dynamic investment procedure.

In general, the following tasks can be processed with BAPM:

- Assessment of result data and optimisation of processes and projects in a dynamic environment. While a process navigator (see Chap. 15) identifies possible process alternatives, BAPM evaluates the individual alternatives on the basis of the current situation and thus provides the decision-making aid for their selection.
- Estimating the possible results of using a product.
- Determining the return on investment of a technology (e.g. CAx, PDM, ERP).
- Comparison of different technology alternatives.
- Assessing the risks of technology projects.
- Managing product portfolios.

Overall, BAPM delivers amazingly precise results, especially in cases where the benefits are difficult to quantify, as the retrospective investigations of numerous use cases by the authors have shown, in which it was usually possible to achieve accuracies in the prediction of over 90%. In the following, different possible applications for a provider and a customer from the capital goods industry are described. For a customer from the consumer goods industry, the use of BAPM does not seem to make sense at present, as the primary focus for this customer is on the (hardly quantifiable) added value of a product.

25.4.1 Provider

A provider can use BAPM to calculate the cost of goods manufactured for a product using its creation processes and the tools used to do this—both prospectively in the quotation phase and retrospectively for final costing. Another possibility is the improvement of work processes. To illustrate a possible use of BAPM, Fig. 25.10 shows the procedure for improving a work process and its possible support by various tools available at the provider.

- In the first step, the work process of interest consisting of process elements is configured exactly as it is currently carried out. Each of these process elements contains information about which tools can be used with which functions for which process element (Sect. 15.7). Exactly the tools with the corresponding

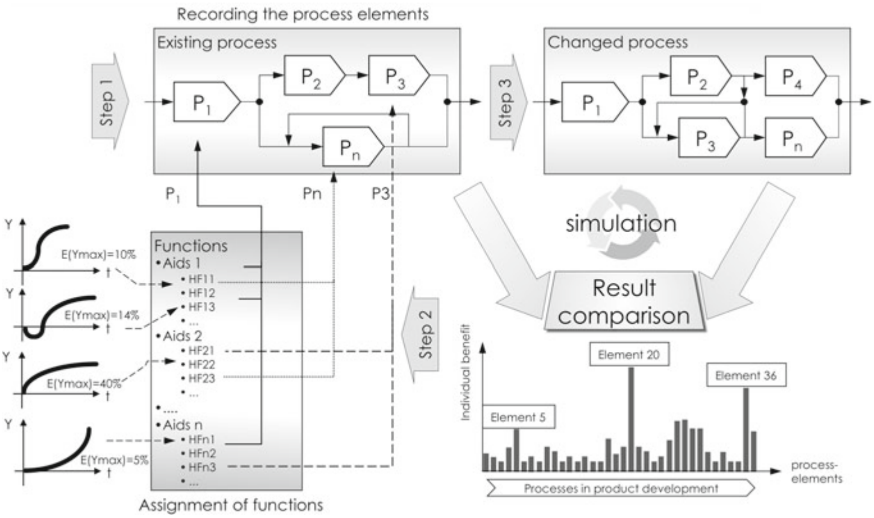


Fig. 25.10 Benefit analysis in process improvement (E(Ymax): Expected maximum yield after 5 years)

functions that are currently used are selected. In this way, the portfolio of tools used with the respective functions is created parallel to the process modelling.

- If they are not yet stored in the process elements, the second step is to select the tools and combine their respective functions with preconfigured yield curves.
- In the third step, the work process is changed by different configuration and combinations of process elements. This also leads to a change in the portfolio, which now becomes a portfolio of the tools that can be used in the changed process with their respective basically usable functions.
- In the last step, the existing and the changed process are simulated. In both processes, the results are not only the processing times and costs that are achieved in the selection of procedures and tools, but also the overall benefit ("return") of the changed work process in relation to the existing process in the specified period under consideration. At the same time, the risk of achieving these benefits is determined. The benefit classes from which the total benefit is determined are shown. Finally, the total benefits can be divided among the individual process elements so that those elements with the highest part benefits can be easily identified (lower right corner in Fig. 25.10).

This approach has two advantages. The results have a prediction accuracy of over 90%, so that the provider can prepare an offer well-founded enough and in a short time. All processes are modelled so that they can be used immediately and navigated dynamically after order acceptance or selection.

25.4.2 Customer from the Capital Goods Industry

A customer from the capital goods industry will usually procure a product for a specific application. Since the application case is known, the corresponding processes can be modelled before the actual procurement. It does not matter whether it is a question of workflow processes or technological processes that are to be enabled and/or supported by the product. Figure 25.11 shows a basic procedure for determining the return and risk of product use with BAPM (according to [ScWo-2002]).

- In the first step, the attributes of the product to be procured that are of interest for use are selected with their degree of fulfilment and quality and linked to the corresponding yield curves.
- In the second step, the work process to be supported by the product is configured from suitable process elements.
- In the third step, the attributes are assigned to the individual process elements.
- In the last step, the process to be supported is simulated. The result is first of all the total benefit ("return") of the use of the product in relation to the investment sum and for the specified observation period. At the same time, the risk of achieving this benefit is determined. The benefit classes from which the total benefit is determined are shown. BAPM can also divide the total benefit between

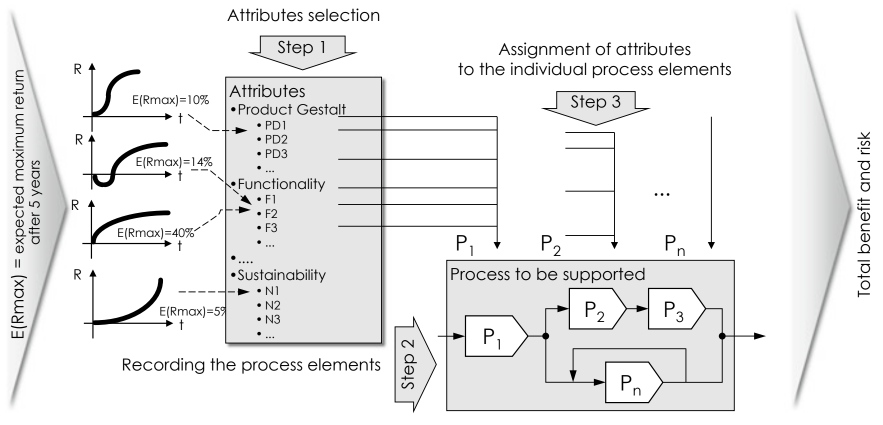


Fig. 25.11 Benefit assessment at product launch (based on [ScWo-2002])

the individual process elements so that those elements where the highest partial benefit will occur can be easily identified.

Here, too, the results have a prediction accuracy of over 90%, so that the customer can make a much more informed choice for a product. All processes for using the product are modelled so that they can be used immediately and navigated dynamically once the product has been procured and delivered.

References

[Back-1988] Back-Hock, A.: Lebenszyklusorientiertes Produktcontrolling, Ansätze zur computergestützten Realisierung mit einer Rechnungswesen-Daten- und -Methodenbank, Dissertation Erlangen-Nürnberg (1988)

[BrKn-1997] Breiing, A., Knosala, R.: Bewerten technischer Systeme: theoretische und methodische crundlagen bewertungstechnischer entscheidungshilfen. Springer, Berlin Heidelberg (1997)

[CoFG-2007] Coenenberg, A.G., Fischer, Th. M., Günther, Th.: Kostenrechnung und Kostenanalyse. 6., überarbeitete und erweiterte Auflage. Schäffer-Poeschel Verlag Stuttgart (2007)

[DIN-1996] DIN-Fachbericht 50: DIN Deutsches Institut für Normung e.V. (Eds.): Geschäftsprozessmodellierung und Workflow-Management, Forschungs- und Entwicklungsbedarf im Rahmen der Entwicklungsbegleitenden Normung (EBN) 1st edition, Beuth Berlin (1996)

[DIN-60300] DIN EN 60300-3-3:2005-03: Zuverlässigkeitsmanagement - part 3-3: Anwendungsleitfaden - Lebenszykluskosten (IEC 60300-3-3:2004); German version of EN 60300-3-3:2004. Beuth Berlin (2005)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, 6th edition. Hanser München (2017)

[FFHP-2008] Fandel, G., Fey, A. Heuft, B., Pitz, Th.: Kostenrechnung, 3rd edition. Springer, Berlin Heidelberg (2008)

[Gabl-1995] Gabler-Wirtschafts-Lexikon: Volume 1–8, 13th edition, Gabler Verlag Wiesbaden (1995)

[Gabl-2013a] Gabler Wirtschaftslexikon: http://wirtschaftslexikon.gabler.de/Definition/life-cycle-costing.html, accessed on 5 Sept 2013

[Gabl-2013b] Gabler Wirtschaftslexikon: http://wirtschaftslexikon.gabler.de/Definition/prozesskostenrech-nung.html, accessed on 5 Sept 2013

[Hahn-1954] Hahn, A.: Wirtschaftswissenschaft des gesunden Menschenverstandes, Knapp Verlag Frankfurt/Main (1954)

[Harv-1976] Harvey, G.: Life-cycle-costing: a review of the technique. Manage. Account. **57**, S.344 (1976)

[Irle-1998] Irle, A.: Finanzmathematik: Die Bewertung von Derivaten, B. G. Teubner Stuttgart, (1998)

[KaNo-1997] Kaplan, R.S., Norton, D.P.: Balanced scorecard—Strategien erfolgreich umsetzen, Schäffer-Poeschel Verlag Stuttgart (1997)

[Kiel-2007] Kiel, E. (Hrsg.).: Antriebslösungen, Springer, Berlin Heidelberg (2007)

[LoWi-2012] Lotter, B., Wiendahl, H.: Montage in der industriellen Produktion—Ein Handbuch für die Praxis, 2nd edn. Springer, Berlin Heidelberg (2012)

[Mark-1952] Markowitz, H.M.: Portfolio selection. J. Finance, S.77–91 (1952)

[NeBr-1928] von Nell-Breuning, O.: Grundzüge der Börsenmoral. Dissertation Universität Freiburg 1928. Reprint als Band 4 in Keller, F. (Hrsg): Studien zur Katholischen Sozial- und Wirtschaftsethik. Topos Verlag Ruggell (Liechtenstein)

[PfWü-1983] Pfohl, H.-C., Wübbenhorst, K.: Lebenszykluskosten. Ursprung, Begriff und Gestaltungsvariablen. J. für Betriebswirtschaft **33**, 142–155 (1983)

[Riez-1996] Riezler, St.: Lebenszyklusrechnung, Instrument des Controlling strategischer Projekte, Verlag Dr. Th. Gabler Wiesbaden (1996)

[Scha-2001] Schabacker, M.: Bewertung der Nutzen neuer Technologien in der Produktentwicklung. Book series 'Integrierte Produktentwicklung' edition 1, Otto von Guericke university Magdeburg Germany (2001)

[Scha-2002] Schabacker, M.: Benefit evaluation of new technologies. In: Proceedings of 2002 ASME: Design Engineering Technical Conferences, Montreal, Canada, DAC-34133 (2002)

[Scha-2004] Schabacker, M.: PDM im Produktentwicklungsprozess - Sprungbrett für den Mittelstand. AUTOCAD Mag. **10**(6), S. 16–18 (2004)

[Scha-2011] Schabacker, M.: Software-Einsatz im Produktlebenszyklus – Kosten und Nutzen im Blick. IT&Production PLM Wissen Kompakt **12**, S. 40–43 (2011)

[ScVa-2002] Schabacker, M., Vajna, S.: Nutzen- und Kostenbewertung von Prozessen und Technologien. CAD-CAM Report **21**(12), S. 46–49 (2002)

[ScEn-2005] Schabacker, M., Engel, T.: Immer voll akzeptiert. AUTOCAD Mag. **11**(2), S. 52–54, (2005) [ScWo-2002] Schabacker, M., Wohlbold, L.: Benefit evaluation of EDM/PDM systems. In: Proceedings of the 8th International Conference on Concurrent Enterprising Rom 2002, S. 413–420 (2002)

[ShKo-1981] Sherif, Y.S., Kolarik, W.: Life cycle costing: concepts and practice. Omega **9**(3), S. 287–296 (1981)

[Unte-2013] Unternehmerinfo Lexikon: http://www.unternehmerinfo.de/Lexikon/D/Design_to_cost.htm. Accessed on 5 Sept 2013

[VDMA-34160] VDMA-Einheitsblatt 34160: Prognosemodell für die Lebenszykluskosten von Maschinen und Anlagen, VDMA Frankfurt (2006)

[VDI-2216] VDI-Richtlinie 2216, Einführungsstrategien und Wirtschaftlichkeit von CAD-Systemen. Beuth-Verlag, Berlin (1990)

[Woeh-1986] Wöhe, G.: Einführung in die Allgemeine Betriebswirtschaftslehre, 16th edition. Vahlen (1986)

[Wübb-1986] Wübbenhorst, K.: Life cycle costing for construction projects. Long Range Plan. **19**4, S. 87–97 (1986)

[Zang-1976] Zangenmeister, C.: Nutzwertanalyse in der Systemtechnik. Wittemann, München (1976)

Correction to: Integration of Processes and Organizations

S. Vajna, S. Ottosson, S. Rothkötter, J. Stal-Le Cardinal, and J. C. Briede-Westermeyer

Correction to:
Chapter 15 in: S. Vajna, *Integrated Design Engineering*, https://doi.org/10.1007/978-3-030-19357-7_15

In the original version of the book, the following belated correction has been incorporated: In Chapter 15, the affiliation of author S. Ottosson has been changed to Department of Manufacturing and Civil Engineering, Faculty of Engineering, NTNU—Norwegian University of Science and Technology, Gjøvik, Norway.

The chapter and book have been updated with the change.

The updated version of this chapter can be found at
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Professor h.c. Dipl.-Ing., Dipl.-Formgestalter Thomas Gatzky studied Mechanical Engineering/Design at the University of Technology Magdeburg (UTM) from 1967 to 1971. Until 1979, he worked as Scientific Assistant at UTM and as a Development Engineer in industry. Then he started a second course of study at the University of Applied Sciences for Industrial Design, Halle-Burg Giebichenstein, which he completed in 1984 with a degree in Industrial Design. From 1984, he built up the field of Industrial Design for engineering and computer science studies at UTM. He was co-initiator of the main study specialization "Integrated Product Development" and of the master's course "Integrated Design Engineering" in the Faculty of Mechanical Engineering at Otto-von-Guericke University (OvGU). This was followed by a deputy professorship for capital goods design at the University of Applied Sciences Magdeburg/Stendal and teaching positions at the University of Fine Arts Braunschweig and the University of Stuttgart. In 2001 he was appointed university lecturer for Industrial Design at OvGU. A large number of design commissions for industry linked him to design practice. In 2014, the University of Miskolc (Hungary) awarded him the title of honorary professor.

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Glossary

The contents of the glossary was provided by the authors of the individual chapters.

3D model See *Geometry model.*

Action regulation Describes the psychological regulation of an individual's goal-directed behaviour.

Action regulation theory A theory developed by Winfried HACKER and Walter VOLPERT in the 1980s. Work is seen as a conscious and purposeful activity aimed at the realization of a goal. The theory explains how workers regulate their behaviour through cognitive processes.

Action system Action systems contain structured activities that are necessary, for example, to fulfil the objectives of a system of facts to be created. These include people, methods, procedures, material resources, etc.

Activity-based costing Approach that helps to better plan and control the costs of indirect divisions (or the costs of a service provider) or to allocate them to products or services. In this context, an orientation towards the value chain is achieved by referring to the individual business processes. The tasks processed in the cost centres of the enterprise are broken down into process-related activities. The costs are assigned to these activities depending on so-called cost drivers and process cost rates are determined from these. The process cost rates are used to calculate the process-related overhead costs for the products or activities.

Adaptation development/Adaptation design The adaptation of an initial solution (model) to new requirements. The basic properties of the model do not change.

Added value In the view of a customer or user, the increase in value is through the usage of the product. The added value is the difference between the profile of the product attributes, which exist in different fulfilments, and the procurement and maintenance costs for the product. In addition, the added value can contain emotional components such as prestige and status, attitude to life and preferences, first economic attribute in IDE. Company view: *Profitability.*

Additive manufacturing (AF) The transformation of a digital 3D model (at least one spatial solid model) that is stored in the CAx system into a physical object. For this purpose, the solid model is converted into a triangulated surface model

S. Vajna (ed.), *Integrated Design Engineering*,
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(STL format). This surface model is broken down into slices of defined thickness, which are converted into physical objects using various methods. Most important procedures: stereo-lithography, laminated object manufacturing (LOM), 3D printing, Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), deposition welding, electronic beam melting.

Additive repair is an additive manufacturing process for reconstructions and modifications of already manufactured components [Zgha-2016]. Such processes take place in the usage phase, and the main field of application is the repair of high-quality capital goods.

Aesthetics of action Sensual and meaningful component of user-oriented design. In the sense of a perception-oriented design, it deals with the management, inclusion and development of action situations of objective action. Designable and evaluable criteria are in particular action competence and control. See also *design aesthetics.*

Aesthetics The aesthetics always refers to people. It is not to be understood as "pleasing aesthetics", but describes the way in which a product is sensual and/or meaningful. Connected with this are all questions of perception, action, experience and behaviour of the user of a product.

Affective design A design approach with the goal to design interfaces that are capable of eliciting a certain emotional experience from users.

Affective response A psychological state of an individual referring to an underlying affective experience of feeling, emotion or mood.

Affordance The term "affordance", sometimes also referred to as "offer character", originates from cognitive psychology. An affordance is a possibility of interaction directly linked to objects, which was not intended when the object was developed, but which results from the characteristics of the object in interaction with the (subjective) abilities of the actor (e.g. the actually not intended but nevertheless possible usage of the glass surface of a tray for cutting vegetables). The perceivability of affordances depends on both experience and knowledge of the user.

Animation Generation of image sequences for the representation of sequences or processes. For this purpose, the position of each affected element of the product model (e.g. in the form of a DMU) in space is continuously recalculated and displayed at such short intervals that the impression of flowing motion is created. Main fields of application are the presentation of calculation results (e.g. crash behaviour of a car body) and kinematic investigations (e.g. assembly simulation).

Application integration Networked use of modern IT systems for continuous computer support in product development. This ensures that the appropriate IT application system is available for each task and at any time.

Archive The entirety of all the information stocks (documents and generation systems) required for a process or order and generated for it on appropriate media. A digital archive is characterized by the entirety of the production systems and information stocks available in an IT system on corresponding media.

Archiving Backup of data stocks (multiple redundant), their constant maintenance as well as the guarantee of a fast and exact access to searched information with the corresponding producer systems, regardless of where they are stored and when they were generated.

Attributes are used for the neutral (i.e. detached from possible forms of realization) description of characteristics and properties of a product, the interaction of which determines the performance of this product and its behaviour in delivering its performance. Basically, all attributes for a product have the same meaning, importance and value. Attributes are divided into three equal groups, namely six product attributes (product design, functionality, usability, availability (customer view) or producibility (supplier view), maintainability and sustainability), three fulfilment attributes (safety, reliability and quality) and two profitability attributes (added value from the customer view and profitability from the supplier view). The attributes are linked to a profile in which each attribute group is represented. From the customer's point of view, they form the target profile, and from the provider's point of view, they form the actual profile. There is no prioritization of the attributes. However, in the target profile, it can happen that a customer only uses individual attributes that are important to him or her, since he or she assumes that the other attributes will be adequately fulfilled anyway.

Autogenetic Design Theory The basic approach here is the procedures, methods and processes of development, and adaptation of products can be described and designed in analogy to the procedures, methods and processes of biological evolution to create or adapt individuals. Since evolution represents a multi-criteria and stochastic optimization under changing initial and boundary conditions, product development can thus also be considered as a multi-criteria optimization task.

Auxiliary material Substance or material to eliminate or reduce undesirable side effects in a process. Auxiliary materials are used, for example, when joining at the joining point to keep environmental influences away.

Auxotonic The auxotonic muscle contraction is accompanied by a change in muscle length as well as the currently applied muscle strength.

Availability From the customer's point of view, on the one hand, the ability of a manufacturer to keep a product available for the market or to deliver it within the agreed time frame, on the other hand, the ability of the product to be used according to the requirements during the product's lifetime (see also *reliability*), fourth product attribute in IDE. From the manufacturer's perspective: *producibility.*

BAD See *Brain-aided Design.*

Basic population The quantity of all parts of a produced product.

Benchmark Comparison of products, results and processes with defined target values (specifications as an abbreviation for contract specification).

Benefit Sum of the (prospective)/performed (retrospective) services to be provided, which the introduction of an investment brings about.

Biodiversity Biodiversity refers to three interrelated areas: diversity of ecosystems, diversity of species and genetic diversity within species.

Boomerang effect The effect of an action or communication achieves exactly the opposite of what it was originally intended to achieve. The reasons for this lie, on the one hand, in unexpected or unnoticed influences and effects during the action, and on the other hand, in a communication that the statement transported by it is perceived as untrustworthy and thus leads to a different reaction than expected. For example, The supposedly “paperless office” as the place of the greatest paper consumption of all times due to extensive computer support and automation—more resource consumption as a result of improved resource productivity and the resulting falling prices for the respective resources.

Brain-aided design Procedures and methods that take place on abstract levels in the brain and serve to round off possible solutions at an early stage.

Business process Sequence of functions or activities in business operations that contributes to the realization and maintenance of business tasks and on-going business, whereby a function/activity is started by one or more events and ends in one or more events. The individual activities are logically related to one another and are completed in terms of content. Synonyms: process chain, process chain, company process. In German: Geschäftsprozess.

Capital goods industry Manufacture of such products in which other industries invest in order to manufacture further products for different markets or, in turn, industries.

CAx systems Summarizing designation for CAD, CAM, CAE, EDA, FEM, CAQ, CAP systems, etc. Synonym: *(Data) generator systems.*

CFD Abbreviation for Computational Fluid Dynamics—systems for calculating and simulating the fluidic behaviour of a medium on the basis of finite elements. CFD systems take their reference data from a CAD model.

Characteristic Publication type of a product in various forms. These are geometric shape, dimensions, material, weight, surface finish and colour, and structure if the product consists of several components.

Client (external) External client for product development from the capital goods and consumer goods industry.

Client-server principle In a bus network, computer workstations (customers, clients) are connected to a powerful computer that, as a service provider (server), provides central services such as programs and data, control of peripheral devices and connection to other networks. The advantages of this configuration are central data storage, central updating of applications and effective data backup.

Cognition Mental processes that lead to knowledge and which can often be described by the generic term “thinking”.

Collaborative engineering A variant of *Simultaneous Engineering* and *Concurrent Engineering*, in which all parties involved in a process make decisions together at the earliest possible point in time to enable extreme parallelization of the processes.

Competence A combination of *knowledge* and corresponding *experience* about the content, meaning and links of action knowledge (meta-knowledge) as well as the actual action knowledge for implementing and applying experience and knowledge.

Concurrent engineering Splitting and overlapping processing of a single activity. For example, an automobile body is designed in many places simultaneously. The consistency of this parallel processing is ensured by defining installation spaces, design zones and the associated interfaces and references.

Configuration management The management of the temporal changes of product structures (effectiveness) in the form of configurations and versions as well as the management of product variants.

Configurator A generator system that combines existing elements of a building set into a meaningful object on the basis of rules (decision table), rules and/or knowledge. Elements can be products or processes (or their respective components).

Consistency The adaptation of natural cycles for the design of processes in the technosphere. Materials that are created in the production process and do not correspond to the purpose of the production do not become waste but remain resources in the sense of the Cycle Economy or the *Cradle to Cradle* approach.

Constraint A condition or relationship. In 3D modelling, elements of an object are related to each other, and this relationship must be maintained under all circumstances (i.e. every time the object is changed). Constraints can be divided into line elements (e.g. parallel, perpendicular, horizontal), which is mainly used in sketching, and relationships between area elements (of modelling elements, of parts or assemblies). As long as constraints do not contradict each other, they contribute to the consistency of the modelled object.

Consumer goods industry The manufacture and distribution of products directly to the person who ultimately uses the product (consumer, end-user, user).

Continuous engineering Continuous, uninterrupted work, both around the clock and around the globe (in the course of the sun). Not economically feasible without the use of information and communication systems (Internet with groupware applications). Can be used for work organizations of *simultaneous engineering* or *concurrent engineering*.

Contribution margin A contribution from sales of a product to cover costs incurred or to be incurred, but which is not sufficient to establish *profitability*.

Copy strategy The term "Copy Strategy" has been adopted from American to German terminology and is therefore interpreted differently. The copy strategy is divided into the creative strategy and the creative implementation of the advertising strategy. The *creative strategy* contains the definition of the advertising content according to the needs of the target groups and the desired positioning. A prerequisite is the planning of the advertising objective. The *creative implementation of the advertising strategy essentially* consists of (1) an appropriate (image) motif, (2) the product promise (formulation of the product benefit), (3) the justification of the promise for the target group through credible and understandable argumentation and (4) the definition of the style and charisma of the advertisement [GaCS-2018].

Costs The activity-based valuated consumption of goods (e.g. tangible assets) in an accounting period.

Cradle to cradle An approach to *sustainability in* which the substances and materials used to develop, manufacture and use a product can be used in unchanged quality for a next product.

Customer (internal) Customer from the company for product development who defines product ideas, for example, marketing, sales or product management.

Customer According to Schumpeter, a person who purchases a product and/or uses a product.

Customer, external An external client for product development from the capital goods and the consumer goods industry.

Customer, internal The internal client for product development defining product ideas, e.g. marketing, sales or product management.

Data Units that, from an information technology point of view, may be numeric in numerical form, alphabetic in alphabetical form or, in a mixture, alphanumeric in character form The characters have a specific sequence and structure, the syntax. The syntax gives data a meaning (semantics). Data can be summarized (aggregation) and divided (decomposition).

Data model Data models are used at the conceptual and external level to formally describe all data contained in a database and their relationships to each other. Each individual object (entity), its properties (attributes) and its relationships to other objects (relationship) are listed. This leads to the so-called entity relationship model, which is independent of a concrete application. The majority of databases are based on one of the following three models: hierarchical data model, network data model or relational data model.

Data subject A person who may be directly or indirectly affected by activities or impacts related to the product at all stages of the product life cycle, without being the purchaser or user of the product.

Decreasing/Downgrading Simplifying the shape, surfaces, structures and materials of components without compromising the performance of the resulting product too much (in the sense of the *Pareto rule*).

Default-free time A time interval in which failures do not occur, i.e. in which the probability of failure is 0%.

Design composition The interaction of all design aesthetic elements. The degree of coupling relationships between these elements determines the perceptual impression.

Design parameters These are parameters (see *Parameters*) which can be freely selected within certain limits within the product development process and which are to be determined by suitable selection (e.g. by defining dimensions, number of holes, thermal boundary conditions, by material selection, selection of subsystems (components), (system–) elements, links between elements). The properties of the product are quantified by their selection or definition. Design parameters (design parameters) determine, in connection with the selected solution concept, the extent to which the requirements of the product are quantitatively fulfilled.

Design zone A design zone represents a subset of an installation space in which certain functional complexes are to be implemented in the form of assemblies and/or individual parts. It can also be used to divide a single part into areas to be modelled in parallel. Sketches in sketching technology can also be divided into individual design zones.

Design-to-cost A Method of product development, in which the most cost-effective solution is consequently sought for individual components, right from the development stage. In particular, the costs that are incurred subsequently (follow-up costs) are also taken into consideration (e.g. sales costs, service costs).

Development contract Documentation between the development team and internal or external contractor on the scope of the design and the mandate of the team.

DfX In Design for X, the solution, which becomes increasingly concrete during product development, is adapted step by step to the possibilities of the downstream areas in the product lifecycle by continuously taking into account specifications (e.g. available production technologies) from the downstream areas in the solution, whereby these specifications can lead to limitations of the solution quality.

Digital twin is a 3D product model, which accompanies the product throughout its entire product life and which digitally depicts the current state of the product at all times. On the one hand, any information or documents can be (partially) automatically derived from it at any time, and on the other hand, possible changes to the product can be calculated and simulated in advance on the digital image.

Direct manufacturing refers to the additive production of end products [VDI-3405]. Direct manufacturing is the only way to exploit the design freedom of additive manufacturing.

Discounting All future values (investments, current costs or benefits) are reduced to their current value in the present (usually to the year 0 of a project). Discounted values are determined by multiplying the final capital by the discount factor $1/(1+p)^{T.}$ Where p is the interest rate for the minimum return on capital employed and T is the term of the project in years.

Dissolution A separation of spatial, temporal and factual boundaries and orders of an activity, for example, permanent accessibility and availability of an employee even outside working hours.

Divisional integration This integrates employees from all departments directly involved in the design of the product lifecycle, as well as customers, partners and suppliers if required.

DMU Digital mock-up, construction of a virtual prototype of a component in the CAD system to perform various simulations, animations and tests, such as kinetic and kinematic simulations, installation tests, virtual crash tests, checking the appearance of the component, etc.

Document A document is a collection of information treated as a unit and stored non-volatilely on an information carrier/media.

Documentation A documentation is the sum of the documents completely compiled for a specific purpose.

Document management General management (administration) of product data and the associated documents such as CAD models and drawings includes the various file types and the link to the respective generator systems. This includes version or status management, the management of folders and the management of metadata for objects, such as classification data.

E-collaboration An Internet-based, networked collaboration of several people using web-based information and communication solutions.

EAD See *Evaluation-aided design.*

Eco-social market economy An approach to the synergetic linking of (classical) market economy and sustainable development.

Ecological footprint The compilation of all resources needed for everyday life. From this demand, the part of the earth's surface is determined in order to make these resources available. This land consumption is then extrapolated to the world population and compared with the areas actually available on earth.

Economic efficiency Ratio of the benefits to be provided or services rendered to the costs incurred or to be incurred.

Effectiveness and efficiency While effectiveness ("Doing the right things") is a measure of the achievement of objectives and the associated effectiveness and quality and does not focus on the effort required to achieve them, efficiency ("Doing things right") measures the ratio of benefits to the effort required to achieve a specific result. Thus, efficiency is a measure of resource efficiency. Since even the wrong things can be done efficiently, efficiency can be regarded as a subgoal of effectiveness.

Emotional design A design approach with the aim of developing human-machine interfaces that give the user a specific emotional experience.

Ergonomics The optimization of the holistically considered work system of people, organization and technology. In general, the aim is to reduce the work load on people, to avoid physical and psychological (consequential) damage and to increase work performance.

ERP Abbreviation for enterprise resource planning, planning of all resources of a company, (currently understood as employees, machinery, material, financial resources and information). The ERP approach is developed from the PPS concept. The uncritical transfer of such approaches to product development must be viewed with scepticism, since the basis of the PPS approach is fixed, reproducible organizations and processes (as they must be present in production to ensure production quality), which do not occur in this form in product development. Rather, the processes in product development in particular are often chaotic due to the creative part and therefore not reproducible. To support them efficiently, different approaches than those currently used in ERP are therefore required (e.g. dynamic process management).

Evaluation-aided design Measures for verification and evaluation of (intermediate) results in the IDE process model.

Experience This arises from personal experience in the application of knowledge and as a quintessence of successes and mistakes. An experience is always individual and related to a specific situation. It can serve as a basis for analogies.

Failure-free time Represents the time interval in which no failures occur, i.e. the probability of failure is 0%.

Feature A feature is an information technology element that represents areas of special (technical) interest (not exclusively geometry) of individual products. It is described by the sum of properties of a product. The description contains relevant properties themselves, their values and their relationships (relations and constraints). A feature represents a specific view of the product description that is related to certain property classes and certain phases of the product life cycle. The feature can contain properties from different property classes. Especially the geometry property class is important in almost all phases of the product life cycle. For this reason, and because the representation of geometric properties dominates in today's CAx systems, a somewhat more specific definition is also common for the term feature. A feature is seen as the aggregation of geometric elements and/or semantics. In this particular case, "syntax" means the (geometric) structure of the feature, "semantics" means its meaning.

FEM Abbreviation for finite element method. This is used to calculate the physical structure and behaviour of an object (continuum, component geometry, solid bodies or fluids). The object is broken down into finitely large, mechanically and mathematically determinable elements (finite elements), so that even bodies with complex geometry can be approximated with practically any degree of accuracy. The elements are coupled with each other at their corner points (nodes). Properties are assigned to the elements in the form of parameters for the analysis. The behaviour of the object under load is calculated by stepwise transfer of the state variables via the nodes by approximation methods. In addition to the actual calculation programs, FEM systems also contain modules with which the finite elements for the component to be calculated can be computer generated (mesh generator) and the results (the deformed structure) can be graphically displayed together with the initial situation.

File Unit of electronically stored data or designation for a quantity of *data* compiled according to certain criteria.

Follow-up costs Costs are from the usage of a product, for example, costs for operating resources and consumables, maintenance costs, insurance costs, financing costs, savings for follow-up products. It can be roughly assumed that an annual investment in a product will result in about 30% of this investment as follow-up costs.

Form A form is understood as a self-contained individual phenomenon. The contour encloses a plane surface, the surface course describes a spatial form. Formation or shape design means the design of contour or surface. Contours and surfaces determine the perception of a shape. See also *Shape.*

Front loading Shifting activities and decisions from the phases after the product has been released for production into product planning and product development, provided that sufficient decision security can be guaranteed by calculation and simulation procedures. See also *Predictive Engineering* and *Reverse Engineering.*

Fulfilment The realization of requirements that results from the interplay between the type of fulfilment (the way in *which* requirements are realized), the degree of fulfilment (the relationship between requirements and their proportionate realization, that is, *how much* has been realized), and the quality of fulfilment (*how well* something has been realized).

Functional design Shape-forming criteria are technical-functional and economic requirements that are implemented in the design process. See also *functional design* and *product design.*

Functional requirements Describe how the product should behave and address higher levels of abstraction of the solution concept as opposed to requirements on the physical form of the product.

Functionality The ability of a product to meet certain requirements by summing up and combining the direct and indirect functions realized in the product. It does not matter whether functions are realized as mechanical, electrical, electronic, hydraulic, optical or software functions or combinations thereof. Functionality is the second product attribute of IDE.

Generation system Systems that primarily generate data (such as CAx systems), whereby the data is (must be) managed by other systems.

Geometry model Geometry models are used to describe and analyse geometry and kinematics. In solid modelling, one essentially differentiates between generative (procedural), accumulative (descriptive) and hybrid geometry models. In the case of generative geometry models, the model information is contained in a generation specification, so the solution path is stored. The most important representatives are the CSG models. In contrast to the accumulative geometry models, the generation rule is stored separately from the model information and the solution result is stored. The most important representatives among the accumulative geometry models are the B-Rep models. Hybrid geometry models use a combination of generative (mostly CSG) and accumulative (mostly B-Rep) geometry models.

Gestalt aesthetics Perceptual design, which always aims at finding a design in its unity of form, colour, material and surface. Finding and designing a perceptual shape takes up a large part of the design process. See also *Aesthetics of Action.*

Global governance The cross-national social governance of societies. According to current understanding, this is done in the sense of *sustainability.*

Good design High design quality in the context of the overall quality of a product. Good design represents an economic and cultural value and is an expression of a social and individual awareness of values in a given time.

Green growth A growth with consistent environmental and resource protection.

Gross domestic product The monetary value of all goods and services created in a country in a period of time.

Hawthorn studies Studies conducted on workers at the Hawthorne plant (Illinois) by Elten Mayo and others in the 1920s.

Holistic thinking The ability to look beyond one's area of responsibility, to understand and to handle the complex interrelationships to other disciplines and within an organization.

Human centricity The employee is (in contrast to the view that people are production factors just as much as machines, material or financial resources) in the focus of interest of entrepreneurial action, because only the human is able to find and develop creative solutions. An investment in the qualification and competence of employees is therefore the investment that pays off most sustainably for a company.

Human factor (human influencing variable). In socio-technical systems, this term summarizes the psychological, cognitive and social factors influencing the interaction of a person with a product or systems.

Human relations movement A movement motivated by the outcomes of the Hawthorne studies focusing on the link between employee satisfaction/wellbeing and workplace productivity.

Human-product relationship The interrelation between perception and behaviour. It represents the basic aesthetic problem in product design.

Improvement All activities to increase the safety, reliability, availability and maintainability of a product.

Incoterms International trade clauses concerning the terms of delivery in foreign trade (e.g. freight costs, terms of payment, transfer of risk).

Individual part In the context of product modelling, an individual part (component) means a coherent, non-demountable body, the geometry of which and, where applicable, other properties are described in the product model. For the purposes of manufacturing, it is understood to be geometrically defined technical structures that have been created by processing a material without joining several components (e.g. crankshafts, housings, pistons).

Industrial design An outline and shaping discipline that is effective in the division of labour in the product development process for the design of serial and/or industrial goods. The focus of the activity of an industrial designer is the design of human-product relationships, which mainly take place in the process of usage. The drafting of future action sequences and the creation of form are the core tasks in the design process.

Industrial product design This approach gives objects culture, identity, aura and presence. Product design describes form, appearance, impression and aesthetics of a product, in short the visual and emotional "charisma" of a product as the most important interface to the user. It describes the perception prerequisites (stimuli) to be created for all (!) senses in order to enable the usage of the product to be developed by an individual user or by a user group, to design it sensibly and to make it an individual sensual experience. Product design is the first product attribute in IDE. See also *Functional Design* and *Utility Design.*

Information Date that has a purpose and that is targeted.

Information integration Uniform, complete, consistent and continuous information basis for redundancy-free storage of product data and for largely avoiding interfaces between data stocks.

Innovation A new idea or a new process that has become an invention and that has been (economically) successfully introduced to the market.

Input See *System.*

Inspection Collective term for all measures taken to determine and assess the actual condition of an installation or system and to initiate appropriate countermeasures.

Installation space An installation space is the limiting space in which the currently modelled component is to be fitted. With the concept of installation space it is possible to model complex products (such as a vehicle) in (time) parallel (in the sense of *concurrent engineering)*. Each installation space therefore has interfaces to its neighbouring installation spaces.

Integrated Design Enginering Further development of *Integrated product development* into a human-centred and interdisciplinary model for holistic product development, taking into account all influences of impacts on the life cycle of the resulting product.

Integrated product and process model A consistently modelled, process- and product-specific model. It is created from a product model and a process model, which are closely linked at the schema and instance level.

Integrated product development The integrated application of holistic and multidisciplinary methods, procedures, forms of organization as well as manual and computer-aided tools with minimized and sustainable use of production factors and resources. IPD comprises all steps from the idea to the series release/market launch of a product or service. It is human-centred and serves to develop products or services of high quality at a reasonable price and in a reasonable time.

Integration or coupling Integration is a close connection of several systems designed for the long term, which are perceived as a unit by a user. Integration is mainly carried out using a uniform user interface and/or common data sets. A coupling is a connection between several systems that can be separated at any time and that can be identified as independent at any time.

Isometric An isometric muscle contraction describes the tensing of a muscle without changing its length.

Isotonic During an isotonic muscle contraction, the muscle length changes with constantly applied muscle power.

Job characteristics model A theory based on the idea that the task itself is the key to the employee's motivation. Specific job characteristics such as skill variety, task identity, task significance, autonomy and feedback are predicted to benefit an employee's psychological state and job performance.

Job characteristics theory A theory with the approach that employee motivation depends on the design of the work task. The theory assumes that specific characteristics of the work activity such as requirement diversity, task identity, task interpretation, autonomy and feedback have an influence on work motivation, job satisfaction and performance quality.

Job enlargement Expanding the range of activities by taking on more extensive tasks beyond one's own area of responsibility, usually coupled with a higher grouping in terms of remuneration.

Job enrichment The enrichment of work through more responsible and higher quality activities up to the delegation of responsibility to the executing agencies.

Knowledge (declarative) Description of objects and the relationships between the objects. This includes arbitrary documents, such as reports (e.g. on trade fair visits, conferences, etc.), analyses, specialist books and component catalogues, rules (instructions for usage, assembly instructions, etc.), rules of thumb and standards. Structured minutes of meetings and the documentation of decisions (including the reasons that led to the rejection of alternatives) play a special role. Declarative knowledge (including factual knowledge) can be called up and made available to others at any time.

Knowledge (implicit, explicit, obsolete) *Implicit* (or latent) knowledge is not readily available. It is "stored" within individuals in the form of diverse experience and competence. Storage on external media is difficult because the knowledge carriers are only very rarely able to describe the underlying (essentially fuzzy) rules and the manifold interconnections of information in a reproducible way. *Explicit* (or active and applicable) knowledge is knowledge that everyone can formulate, pronounce, explain to others in a comprehensible way, that they can talk about: "He knows that he knows". Such knowledge can easily be stored in external media. *Obsolete* knowledge is currently outdated and/or no longer in use, but it can be reactivated if required (with more or less effort).

Knowledge (procedural) Places the objects of declarative knowledge in a problem-specific context. It can only be represented in formulas and/or rules. With the storage of processes and their documentation, the knowledge is preserved of how a problem has been processed and solved and what difficulties have been encountered. In many cases, procedural or process knowledge is more valuable than pure factual knowledge, because in the former the know-how of the company is stored.

Knowledge A person's knowledge and experience, consisting of self-made discoveries and experiences as well as acquired knowledge and experience of third parties. Knowledge exists only in the mind of a person. Outside (e.g. on data carriers) it is represented in the form of interlinked data, information and rules. It arises both from the induction of experiences and the continuous preoccupation with a topic, as well as from intuition, spontaneous findings (heuristics), random observations and indirect conclusions.

Knowledge integration This consists of the provision of complete *knowledge* about the product in a holistic knowledge base, in which the knowledge is stored in the form of interlinked data, information and rules.

Knowledge management It comprises the provision, storage, administration and maintenance of knowledge in an external repository to realize the life cycle of the knowledge under consideration of strategic knowledge goals set by the respective company or user (groups).

Level of compliance A certain percentage ("level") of compliance with requirements. Different levels of fulfilment are required for the fulfilment attributes Safety, Reliability and Quality.

Life cycle costing Calculation of all costs (types) that a product causes during its entire life from the very first idea to its disposal.

Load capacity The load capacity represents the load which the product can bear after a defined time.

Load The load characterizes the damage caused by the usage of the product.

Long-term archiving Procedure for the most loss-free possible storage of data and generation systems on suitable media in a computer system using standard formats, since archive contents usually exist considerably longer than the systems with which they were created. With these procedures, the conversion of data can be avoided with every release upgrade or migration.

MAD See *Model-aided Design.*

Maintainability Ability of the product to be restored to at least the condition before the fault without restrictions after a fault. The term qualitatively describes the ease with which maintenance work (e.g. repairs) can be carried out on a plant or system. Quantitatively, maintainability describes the probability that the time required for a maintenance task is less than a specified interval if the maintenance is performed under defined material or personnel conditions. Maintainability is the fifth product attribute in IDE.

Maintenance All measures to maintain the desired condition of a product, a plant or a system. Maintenance can also be performed as a preventive measure. If, for example, a critical component fails in one system, it is usually replaced in all other systems of the same type as a precautionary measure to prevent possible damage to the systems.

Mandate for the development team Nature and scope of the development team's interpretation options and freedom of decision that may be used in solving the problem, defined subgoals or partial solutions.

Marketing All tasks of the consistently aligning the entire company with the needs of the market and of recording and interpreting these needs.

MDA Machine data acquisition, with which interesting data of a production machine and its technical or logistical periphery are automatically collected and processed by ERP, controlling or other systems.

Mechatronics The term, which originated from the combination of the terms "mechanics" and "electronics", refers to the synergetic integration of the disciplines of mechanical engineering, electrical engineering/electronics, control engineering and information technology (the so-called disciplines of mechatronics) for the development, manufacture and operation of innovative products and processes. It is thus an interdisciplinary field of engineering sciences. In addition, a distinction is made between two forms of integration. The first concerns the material components (hardware) from the different disciplines of mechatronics and means a physical, material and therefore also spatial integration. The second type refers to the functions that are increasingly information-driven (mainly by software). It is therefore called functional integration and has an immaterial character.

Method Integration This includes the combination of all flexible and powerful problem-solving methods as well as creativity and learning techniques with context sensitive delivery.

Method The description of a procedure, procedure or action (prescriptive part) structured with rules, planned and consistent to achieve one or more goals (intentional part).

Model The image or the replica of an *original*, where the model does not have all the characteristics of the original (if it had all the characteristics, it would be an identical copy or clone). Models are abstract, tangible or intangible entities created to represent an original for a specific purpose (model purpose). The original itself can be a model. Thus, a model is a simplified representation of a part of past, present or future reality, whereby the model can refer either to an actual state or to an ideal state. The model abstracts reality, i.e. characteristics and characteristics that are not essential for the observation or the task are omitted. A distinction is made between mental, gestalt, pictorial and formal models. Mental models (thought models) are mental ideas about an original (e.g. the model idea of phases in thermodynamics or of state variables or parameters). Shaped models are reduced or enlarged images (e.g. physical models), whereby only certain characteristics of the original are pronounced (e.g. the clay model for a new vehicle that is optimized in a wind tunnel). Pictorial models are graphic representations of the original (e.g. technical drawings, photographs). Formal models are data sets for the digital capture of certain characteristics of the original (e.g. the computer-internal product model).

Model-aided design (MAD) Creation of real and virtual models to get a quick first functional and aesthetic impression of the resulting solution.

Modelling The definition of the shape of a component using the modelling elements available in the CAx system and the possible description methods.

Navigation See *Project Navigation.*

Net present value method A method used in investment appraisal to determine the advantageousness of investment projects. The net present value is calculated by discounting all incoming and outgoing payments associated with the investment to time $T = 0$.

New development Product development without direct model. The solution is created by new development of all components, by a new arrangement of known components or by combinations of these.

Non-functional requirements The requirements on lower levels of abstraction than functional requirements, addressing the physical form of the product, usually additional dependencies on external conditions or between system parameters considered.

Object A real or conceptual object with a fixed, known set of properties (attributes). An object is also called an entity. Similar objects are instances of an object type. They are described by values of the attributes of the corresponding object type.

Object systems In technology, functional systems are the structures created by engineers, which can be both material (e.g. machines, machine parts, devices, apparatus) and immaterial (e.g. ideas, concepts, software, assembly plans, schedules). Material systems are the objects of action systems and thus represent subsystems of action systems (see the term System in [EhMe-2017]).

Organization A system of rules that defines the competencies, responsibilities, authorizations and roles (tasks, functions) of related persons.

Organizational and process integration This comprises all measures that are necessary to describe, combine and improve organizational forms as well as business and development processes.

Organizational structure This represents the linking of basic organizational elements to a structure and the regulation of relationships between these elements in a company.

Original See *model.*

PAD See *Pencil-aided Design.*

Parameter A symbolic quantity with which a property of a system can be quantified. When running a program or a creation rule, a parameter can take on certain values either as the results of a calculation or by reading it from files. These values can be used for dimensioning or for changing the product topology (see also *System Property*).

Pareto rule An empirical rule formulated by Vilfredo PARETO (1848–1923) at the beginning of the twentieth century stating that 80% of the output can be achieved with 20% of the effort. For the remaining 20% of the output, 80% of the effort is needed.

PDM system A technical information system for the storage, management and provision of all product-describing data, information and documents as well as their respective versions and relationships with each other throughout the company (PDM: product data management). In product development, the PDM system supports all activities for creating, changing, versioning, revising and archiving a product structure. It manages the documents and data required for this or created in the process. The elements of the product structure (assemblies, individual parts, etc.) are provided by CAx systems. If one of the versions is to be produced, the PDM system transfers the relevant technical and planning data to the ERP system.

Pencil-aided design (PAD) The quick visualization of solution concepts through simple sketches.

Percentile A percentile is a value on a scale from zero to one hundred that indicates the percentage of record values that are equal to or lower than itself.

Perceptual suitability The degree of fulfilment of a human-product relationship always depends on the interrelation of perception and behaviour. Perceptual fairness as a design goal means taking into account requirements that arise from the physiology and psychology of the human perception process and the individual experiences of the individual or those influenced by the respective environment and that are used to design products in terms of their design appearance. Perceptual suitability as a design requirement and objective means designing products in a way that is appropriate to their meaning, i.e. according to aesthetic criteria.

Person concerned Any person that might be directly or indirectly affected by activities or effects in context with a product across all the stages of the product life cycle.

Population The quantity of all parts of a produced product.

Postal growth society An economy that leads to a high quality of life within ecological limits even without growth.

PPS A system for production planning and control. PPS refers to the application of computer-aided systems for the organizational planning, control and monitoring of production processes from quotation processing to dispatch, taking into account quantity, deadline and capacity aspects. PPS's area of responsibility includes the subtasks of production program planning, materials and time management, quantity planning, scheduling, capacity planning, order planning, production data acquisition and administration of the (mainly dispositive) data generated by these activities. For example, production processes, the usage of materials and operating resources as well as the stock, order and order backlog are controlled and monitored. Today, the term ERP is more commonly used in this context.

Predictive engineering The usage of simulation and evaluation systems to predict the later product behaviour in the phases of the product life after product development.

Principle design A design strategy in which only dimensional variants of an initial solution are generated. This means that only the dimensions of the product or its components vary, while the shape and topology (the arrangement of the elements relative to each other) remain the same.

Probability of failure The probability that the system will fail at a certain point in time.

Procedure model A guideline that proposes a sensible (and usually proven) sequence of organizational, methodological and technically meaningful activities and processes (with the use of the associated methods, procedures and tools) for a specific task/problem (e.g. developing products), but does not necessarily prescribe it.

Process A structure consisting of process elements and/or subprocesses, each of which describes a respective task with functions, actions and their supporting tools and procedures that can be put into a logical context (e.g. serial and parallel activities) so that the completion of a task can take place. A process contains defined inputs and outputs and always describes desired procedures that serve to create value. The process is triggered by one or more events and ends in one or more events. If a concrete order is given for execution, the process changes to an (individual) *project.*

Process management The design and layout of processes with the aim of simplifying and improving them, not controlling them.

Process organization This represents work, time and space relationships in their respective contexts and thus ensures the processes of task handling, taking into account factual-logical, personal and spatio-temporal aspects.

Producibility From a manufacturer's/provider's point of view, this provides information on whether, how and under what conditions of a technical, organizational and financial nature a product can be produced (manufactured, assembled, tested, etc.) with the available possibilities or externally. Producibility is the fourth product attribute in IDE. From the customer's perspective: *Availability.*

Product classification The structure of the assemblies and components of a product or article.

Product design The design of consumer and investment goods according to aesthetic and ergonomic requirements for users/user groups of serial and industrially producible products.

Product development Phase in which all relevant properties and data of a product are defined for all other areas of the company and for later usage and exploitation.

Product development process Sequence of activities required to develop a product from the initial idea to release for production.

Product integration This includes all properties of a product that can be represented by the IDE attributes.

Product life cycle Sequence of the life phases of a product, beginning with *product planning* and *product development*, in which the product is predominantly available in virtual form, followed by its materialization in *production*, the transfer to the user in sales, product usage with product support and service, and ending with product re-circulation.

Product lifecycle costing See *Lifecycle Costing.*

Product model This model includes all data as well as usage rules and links that are necessary for a complete production of a product. It is a formal description of all information about a product throughout all phases of the product life cycle in one model. Quantities of information in a product model are function and shape of the component, results from calculation, simulation and test, product structures (e.g. parts list), representations (e.g. technical drawing, exploded drawings), specifications for production (e.g. work plans), forms of object representations (e.g. 2D or 3D, geometric model or voxel model), regulations for archiving.

Product planning This is used to structure a company's product range depending on the target markets and the profitability and market leadership achievable there. It consists of the phases of research, creation of the product portfolio and marketing.

Product recycling Components, substances and materials of a product are recycled as completely as possible. Substances and materials can be reused in the same (recycling or up-cycling) or in a lower quality (down-cycling).

Product structure The product structure (also called product outline or product structure) describes the subelements of a product (components/assemblies) and relates them to each other. The elements are assigned to each other, for example, by means of interfaces or higher-level product characteristics.

Production control Transfer of the defined work sequence and the specification of certain machine tools from the work plans as well as the dispositive data of the current order (order quantity and lot sizes, time and cost frame) between other orders and, on the basis of current quantity data (capacities, dates), into a running production.

Production Phase of the materialization of the product created during product development on the basis of its documents on production, use and recycling.

Profitability The ratio of achieved profit to invested capital in an accounting period that leads to a return on the company's invested capital, second profitability attribute in IDE. View of the customer: *added value.*

Project A one-off undertaking with a task definition and fixed specifications for resources, time and cost frames. The repetition of this task is not foreseeable at the time of the task definition.

Project management Direct, multidisciplinary planning, coordination, regulation and management of activities, dependencies and schedules (planning, control and decision processes) and the necessary information such as project-specific roles, access rights and milestones.

Project navigation An approach to model and to integrate a process by rule-based combinations and configurations of process elements to form a dynamic network. During the project, a continuous evaluation of the running activities with all active connections, rules, resource situation and boundary conditions takes place. In case of malfunctions, the system reacts dynamically as follows: Immediate reactivity of the process by stopping, modelling an appropriate reaction and continuing at the same point, automatic strategies for parallelizing, combining and splitting processes as well as relocating or expanding resources, and manual modification of the process configuration by the project manager.

Property The behaviour of a product resulting from the interaction of the *features,* as required by the customer of the product. See also *System Properties.*

Prototype Any type of physical or non-physical product model that can be used to demonstrate the functionality and/or design of the product under development (in a tangible as well as a virtual format).

Provider On the one hand, all persons involved in planning, development, production and reuse of a product, on the other hand, the institution in which these persons work.

Quality assurance The continuous recording of the current quality in all phases of the product life cycle and immediate reaction if the quality deviates from specifications.

Quality describes the level and excellence of fulfilment in product performance and behaviour in relation to the (subjective) expectations and assumptions a customer has of the product. In IDE also the current quality, i.e. condition, usability and value level of the combinations of the *fulfilments of* the product requirements, third fulfilment attribute in IDE.

RAID system Abbreviation for redundant array of independent discs. Here, several data carriers (usually magnetic hard discs) are combined into a virtual disc as a logical unit. Redundancy results in higher data security, large amounts of data can be managed more easily and defective discs can be replaced during operation.

Random sample Randomly withdrawn number of test specimens from the population.

Rapid prototyping Added manufacturing of components applying different technologies of fabrication of a variety of materials. Results usually are limited in functionality and capacity but the intended specific characteristics are sufficiently well developed to allow model investigations [VDI-3405]. Specific characteristics can be, for example, the geometry and haptics of the component, whereas the materials of the prototypes do not necessarily have to be identical to those of the series parts.

Rapid tooling The application of additive methods and processes to the realization of end products that are used as tools, moulds or mould inserts [VDI-3405]. A distinction is made between direct and indirect rapid tooling. In direct rapid tooling, the tool inserts are manufactured and reworked using additive manufacturing. In the process chain of indirect rapid tooling, only a first process step—usually the manufacture of a mould—is carried out by additive manufacturing. For example, the negative moulds of casting tools can be produced by additive manufacturing and the subsequent manufacture of the tools can be carried out using conventional manufacturing processes. Rapid tooling promises a time reduction of 50–80% compared to traditional tool making [Gebh-2016].

Rebound effect "In energy economics, the term rebound effect refers to several effects that lead to the savings potential of efficiency increases not being realized or only partially realized. The efficiency increase ensures that the consumer has less expenditure and can therefore purchase additional products". [Wiki-2020].

Reference A relation to coordinates, surfaces or components. A typical reference system is the coordinate system in which the position or movement of an object is described.

Relationship See *Parametrics* and *System.*

Reliability The probability with which a system is in a functional state up to a certain point in time. Within IDE, the combination of the fulfilments ensures the intended, fault-tolerant and reliable as well as reproducible usage of a product over its lifetime. Reliability is the second of the three fulfilment attributes in IDE.

Repair Collective term for all measures to restore the target state) of a plant or system (also referred to as repairs.

Repository The complete directory of all objects occurring in an information model. It consists of a data dictionary as well as directories of other information, such as data model, function and process model, possibly also with the associated masks.

Requirement and specification process The process between customer and contractor translating the requirements sheet (customer view) into the system specifications (contractor view) of the product.

Requirement base (initial) Consists of all requirements relevant for a product development, development starts with initial requirements base, requirements base must be updated and aligned with objectives along the entire product lifecycle.

Requirements (functional) Description of the behaviour of the product and consideration of higher levels of abstraction of the solution concept in contrast to the requirements for the physical form of the product.

Requirements (non-functional) Requirements at lower levels of abstraction than the functional requirements, which relate to the physical form of the product, usually taking into account additional dependencies on external conditions or between the system parameters considered.

Requirements and specification process A process between customer and contractor that translates the requirements sheet (customer view) into the system specifications (contractor view) of the product.

Requirements development Identification and structuring of the requirements for the product to be developed, whereby the requirements are collected from various participants and life cycle phases.

Requirements engineering Identification of all requirements relevant for product development. Result is a requirements base.

Requirements management Working with an existing requirements base, documenting and tracking changes.

Requirements sheet Document containing requirements from the customer/client on what to develop and for what purpose, ideally solution-neutral.

Resilience Ability of a system to absorb and to compensate for disturbances and changes in order to maintain essentially the same function, structure, identity and feedback (see also *robustness*).

Restriction system A system with inherent constraints, without which the system is not workable or viable.

Retrograde costing Type of costing that, in contrast to progressive costing, assumes a known price (market price, achievable price). From this price, a previous value, such as the cost price, the lower price limit, the upper price limit, or the net result is calculated retroactively. A well-known retrograde costing method is target costing.

Reverse engineering On the one hand, advance information and feedback into product development about existing technologies and processes and from decisions made in advance, so that well-founded forecasts and decisions are possible, and on the other hand, the backward tracking of the individual parts, components, materials and activity steps that were necessary to develop and manufacture a product. From this, product documentation can be created, especially if access to the original product documentation is not (or no longer) possible.

Robustness The ability of a system to compensate for imprecise or erroneous inputs and uses with a certain tolerance (varying according to user group) (see also *resilience*).

Rule Prescribed guidelines, methods or regulations, usually confirmed by experience. Rules serve to describe contexts, meanings, purposes, actions, etc.

Safety Combination of the *fulfilment levels of* a product to ensure that no harm is done to the user when the product is used as intended (including a certain robustness against misuse and abuse), because the safety of the product must always and under all circumstances be guaranteed. Safety is the first fulfilment attribute in IDE.

Safety inventory An inventory that is build up to hedge against variability in production and demand with the objective to ensure the availability of the product on the market.

Safety stocks These are built up with the aim of balancing out fluctuations in production and demand and thus ensuring the availability of the product on the market.

Sales tools A collection of tools to support sales (e.g. software for sales management, market entry, advertising).

Semi-finished product Individual parts that require several manufacturing steps before they are finished. Semi-finished products are manufactured as ingots or strands primarily by ingot or continuous casting and then further processed by other methods, such as forming and cutting processes.

Service level A logistic performance measure that quantifies the ability of a firm to supply a product and hence is suitable to measure the availability on the market.

Shape Perceptible overall appearance of a product. A shape (or gestalt) is not only a geometric group of forms but the entirety of the aesthetic elements form, colour, material and surface as well as their individual characteristics, such as the constellation of the design elements in relation to each other. See also *Form.*

Simulation A model-like reproduction of the properties and behaviour of an object in a computer system by means of a model (simulation model). The results of the simulation should correspond to those of the original. In product modelling, the focus is on the model-like imitation of the behaviour of an object, which cannot be exactly predicted mathematically and usually follows the rules of probability calculation. Preferably, kinematic, thermal, dynamic, mechanical processes or digital or analogue electrical circuits are simulated in their sequence functions.

Simultaneous engineering The overlapped (parallel) processing of different tasks with continuous coordination of progress. For example, the planning of manufacturing processes in process planning can be carried out almost parallel to design, whereby a certain amount of advance design work is required so that data is available that can be accessed by process planning. The decisive question for the parallelization of tasks is: When are the results of the preceding task stable enough that the statistical probability of a change and the associated costs of change are lower than the costs caused by continuing work too late?

Sketch technique Procedure in which the defining contour for a profile or a part of rotation on a construction plane (work plane) is constructed from edge elements (line, circle/circle arc, freehand line). The dimensions of these edge elements can be described using parameters and constraints (e.g. perpendicular to, parallel to) can be assigned to them. Only after entering the current values is the volume created by sweeping.

Socio-technical system An organizational approach that refers to the interrelatedness of social and technical aspects in organizations. Goal of socio-technical systems is the joint optimization of social aspects (people and society) and technical aspects (procedures, knowledge, technical structure) of an organization.

Soil degradation Soil degradation is the deterioration of soil quality up to the complete loss of soil fertility. The process leads to conditions of desertification and even desertification.

State Totality of the values of all properties of the system at a given time. The totality of all properties of a system is quantified by the given parameters (for the given properties) and the state variables (for the variable properties) (see also parameter). If both the state variables and the predefined parameters take on fixed values at a certain point in time, the state of the system is fixed.

State change A change in the system state, which means a change in the state variable and thus a change in the properties of the system assumed to be variable. If the state variables of a system change, then its properties change as well, and the system undergoes a change of state. The *system behaviour* is closely linked to the change of state variables (state changes). A system interacts with its environment via its input and output variables, whereby the system is influenced from the outside only via the input variables. If energy or matter is supplied to the system beyond its limits (e.g. compression of a gas volume in a piston or filling of a container), its state changes. Similarly, a change of state can be caused by information that is transmitted beyond the system limits (e.g. by switching operations, signal flow). As a result of external influences, the system goes through a process (procedure), which thus represents something dynamic and with which the state of the system changes. The *transition from one state to another state* can be either differential (continuous transition) or discrete (discontinuous transition, e.g. switching) [Baeh-1996, Hubk-1984].

State variables or state values can be understood as those excellent parameters that should be considered as variable in an adequate model of the system under investigation in order to describe the possible change (variability) of the properties of the system quantified by these variables. The model should thus enable the investigation of the properties of the system (and thus the system behaviour) that are considered variable. Which properties these are is depending on the purpose of the model and must be determined in the course of the model development. The *variable state variables* adjust themselves freely[1] in their temporal or local course, following certain laws (e.g. laws of nature, rules, algorithms), they are thus exposed to the free play of these forces. Exactly in this sense the terms variable and state variable shall be understood[2]. The *remaining parameters* quantify all other properties of the system, namely those which are considered in the model as predetermined (e.g. as constant or periodically variable) in their temporal course and local distribution. They thus quantify (specify) certain predetermined properties of the system that are actually to be predetermined in the model, which is why they are referred to here as predetermined parameters or, for the sake of simplicity, simply as parameters. The *entirety of all properties of a system* considered in the model is thus captured by state variables and predefined parameters, whereby state variables quantify the properties considered as variable[3], while parameters quantify the properties assumed to be predefined (not necessarily constant).

Steady-state economy Economic development at an optimal physical level.

Strength The strength represents the stress that the product can withstand after a defined period of time.

Stress (1) The stress characterizes the damage caused by the use of the product.

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[1]They depend on the initial state and the input variables, but otherwise are free.

[2]One could just as usefully call the state variables released parameters of the system.

[3]Variable, freely adjustable according to certain laws (e.g. laws of nature, rules, algorithms).

Stress (2) Any reaction caused by an external factor. This can affect the entire body, an organ system, a single body organ or an isolated function of an organ. Nevertheless, the strain on the human body must be seen as a reaction of the whole body and always as a consequence of the strain from all areas of life.

Structural material A solid material manufactured with the intention of a technical usage, which can be used for structural applications.

Sufficiency The appropriately limited use of resources (e.g. food, housing, energy) to lead an adequate life, supplemented by aspects of deceleration of life, intelligent self-limitation and sensible renunciation of consumption.

Suitability A system of rules that ensures that requirements, characteristics and limitations of one area are considered in other areas. For example, assembly-compliant development ensures that only those products are created that can be assembled in the company with the available operating resources. A typical application is Design for X, where X is a placeholder for certain industrial applications or situations.

Sustainability Within IDE, the equal consideration of ecological, technical, social and economic aspects, the guiding principle of a strategy for the mutual interlocking of society, ecology and economy with the aim of promoting such a development that meets the needs of the present generation without restricting the possibilities of future generations (in the broadest sense). Ensuring sustainability demonstrates the high level of responsibility of product development, because in its phases it creates the conditions for a sustainable product. Sustainability is the sixth product attribute in IDE and the only one that needs to be observed and realized in all phases of the product life cycle.

SWOT analysis The analysis of strengths and weaknesses in the form of a portfolio as a tool for strategy development in a company. S = Strengths, W = Weaknesses, O = Opportunities, T = Threats.

System A system consists of a set of system elements and their relationships to each other (mutual influence). A system is separated or delimited from the environment (from the surrounding system) by a system boundary (enveloping surface). An *open system* also has relationships with its environment through entrances and exits that penetrate the system boundary. By purposeful selection (consideration of certain aspects, aspect-oriented consideration) of the quantity and properties of the system elements and relations as well as by appropriate definition of the system boundary, a delimited, ordered whole is created which serves a certain purpose. This definition also allows the interpretation that a (mathematical) model of an original can in turn be understood as a system. However, the terms "element" and "system" are relative: The system elements can themselves be regarded as systems consisting of elements and relationships. On the other hand, a system can be an element of a higher-level system.

System analysis The systematic examination of a system with regard to all system elements and their effects on each other. With its help, the complexity of a system is resolved in accordance with the investigation goals by a logical division into system elements. The aim of the system analysis is to determine the input/output behaviour of the system in order to understand its mode of operation and to evaluate it with regard to the target system (requirements).

System behaviour The special characteristics of a system, consisting of its ability to do or cause something specific. The behaviour of a system can be understood as a transmission process between the inputs and outputs of the system and thus as the set of successive states of a system. The behaviour of a system (input/output behaviour) can be specified by descriptions of the relevant input and output variables. The system behaviour is determined by the structure. A system can be understood as a carrier of very specific properties.

System boarder see *System.*

System characteristic Each system (object, system element) including its elements and relationships has a number of specific properties that are inherent to the system and characterize or define (specify) it more precisely. *Properties of systems, system elements or (sub)systems* are, for example, length, weight, clock rate, memory size, etc., but also their suitability for certain purposes (e.g. for production, assembly, operation, operation, maintenance, disposal, etc.). *Properties of relationships* are, for example, is parallel to, is part of, acts on, has the same value as, is given to, is input from. Particularly important properties are structure and behaviour of a system ([Hubk-1984]). Systems are characterized by their properties, which form the basis for any evaluation of systems and therefore represent criteria for the evaluation of systems. This results in the need to quantify properties (in the sense of measuring), which requires appropriate measures (in the sense of metrics). Parameters are those quantities with which the properties of a system are quantified (see also Parameters).

System elements (objects, subsystems, subsystems, modules, components, etc.) can be tangible objects such as parts, assemblies, machines, devices, apparatus or microprocessors, but also intangible entities such as ideas, methods of thought, procedures, algorithms, analyses, concepts, software or schedules. First, the *relationships* (relations, interactions, cause-effect relationships, interactions, flow relationships, connections, interconnections, couplings, hierarchical order relationships, etc.) arise when certain outputs of a (part of) a system simultaneously serve as inputs of the same or another (part of) a system. Energy, matter (substances) and information (e.g. through signals) can be transmitted via the (internal and external) relationships. The relationships (interactions) with the environment can be distinguished into influences from outside (inputs) and influences to outside (outputs). Secondly, the *inputs* (effects, causes, inputs, input variables, input objects and their properties) represent the external relations from the environment to the system, they are not influenced by the system itself. At least in the context of mechatronic systems, input variables with which a (sub) system or a process running in it is to be influenced in a targeted manner (controlled, closed-loop control) by the effects of actuators are referred to as manipulated variables, while disturbance variables represent uncontrolled input variables. Finally, the *outputs* (effects, results, outputs, output variables, output objects and their properties) represent the relations of the system to the environment, these can be, for example, measured variables, observations about the system or work results (e.g. of action systems).

System function A system function is the desired (according to the purpose) conversion of the inputs into the outputs, it therefore corresponds to the desired behaviour of the system. The system can also behave differently than desired (wrong), which is why the term system behaviour has a more general character than the function, which always refers to the desired mode of action (see System behaviour, [EhMe-2017], [Gips-1999], [Hubk-1984]).

System purpose Every artificial system serves a very specific purpose (system purpose) according to the requirements set and therefore has to fulfil a specific function. The purpose can be described by a specific target system. It is achieved when the conversion of the inputs into the outputs meets the requirements.

System specification The specification from contractor view on how the product to be developed, derived from requirements sheet and aligned with customer/client view.

System structure A system structure is the inner structure (order), the building or construction of a system. The system structure comprises the set of system elements including their properties as well as the set of relations between them and with the surrounding system including their properties (system topology). Depending on the point of view (system aspect), different systems and thus also structures can be defined on one and the same object (e.g. drive system, heating and ventilation system, hydraulic system, automation system). The system structure is one of the most important properties of a system, since it determines the system behaviour. Especially in complex systems, it makes sense to develop different views of a system (system aspects such as geometry, position, forces, material flow, energy flow) and to treat them largely separately from each other, which may then quite naturally result in different, overlapping structures for one and the same object. This aspect-oriented approach facilitates the handling of complexity.

Target costing The retrograde cost estimation, in which the costs for subcomponents and assemblies are calculated by backward calculation starting from the price that the customer is prepared to pay.

Target function In the Autogenetic Design Theory, the synthesis of the optimization objectives derived from the requirements that must be met under certain conditions and in certain environments, even if these requirements may contradict or exclude each other. The objective function can also change during an autogenetic product development, for example, due to changed requirements of the customer.

Target system In a target system (system of targets), the requirements for an artificial system (e.g. new product) are structured hierarchically according to their importance. The results of this are (structured) requirements lists and functional or requirement specifications, which form the basis for any assessment of the resulting system (e.g. new product as a functional system) and the associated action process (e.g. the development process or the entire product creation process). For the creation of technical systems, a very specific behaviour (the function) is the overall goal, to which other goals (subgoals) must be subordinate.

Technical documentation A documentation of the type and completeness required for a specific technical purpose.

Template Electronic template tailored to a specific application with definitions and initial values in a *generator system.*

Time value Time-based value of an investment, since an investment made at the beginning of a usage ("year 0") will not have the same value as an investment of nominally the same amount made in future years due to interest and inflation.

Tipping point In the context of Earth system research, a sudden and strong reaction of a system element, although the changes in external influences are small. The irreversibility of this reaction and feedbacks to other subsystems are also problematic.

Total cost of ownership Sum of all costs incurred for the acquisition of a product, its usage and, if applicable, its disposal. Total costs of ownership are a design aspect during the product development phase, they are used to try to understand and influence the determinants of the customer's purchase decision.

TOTE scheme Abbreviation for test-operate-test-exit, both a strategy of action and a control loop consisting of operation and evaluation, which is run through until a solution adequate to the goal is found.

Traceability of requirements Follow up on requirements origin, interdependency and hierarchy among each other, specifically relevant to follow up on requirements changes.

Universal design The design of products or environments to make them accessible, understood, and used to the greatest extent possible by all people regardless of age, size, ability or disability.

Usability The ability of a product to adequately meet the requirements in a given environment according to the user's ideas through its attributes as well as performance, utility and quality of the interfaces between user and product. This interface must be intuitive, reasonable, understandable, and have a certain tolerance for operating errors (robustness). Usability is composed of the product attributes product design, functionality, serviceability and maintainability. Usability is the third product attribute in IDE.

Usage scenario The usage scenario is determined by the entirety of the aesthetic requirements for action and design. Developing a usage scenario for a product is one of the core tasks in *product design.*

User An active agent who deals with a product autonomously, on his own responsibility, self-determined, appropriately and independently.

User experience (UX) It describes all perspectives and impressions of a user during product or system interaction. An important aspect of the UX view is the question of how the product or system fulfils the user's expectations.

Utility design A design criteria that results mainly from the consideration of future usage processes of a user or user group. The focus is on aesthetic and ergonomic product requirements. See also *functional design* and *product design.*

Validation Check for sufficient agreement between the model and the original to be examined. It must be ensured that the model reflects the behaviour of the original with regard to the objectives of the investigation accurately enough and without errors (Was the right thing done? Does the developed product meet the customer's needs?). Of particular importance are the first simulation runs, which serve to validate the simulation model. The validation can be carried out, for example, by sensitivity analyses, plausibility checks or comparison with measurements on the real object or on a prototype.

Value chain A sequence of processes that contribute to the creation of value through the use of human and operating resources (the productive process). A value chain can also extend across several companies.

Variable A variable is a symbol (name, variable name, placeholder) for a certain variable quantity (e.g. p for pressure, v for speed, A for the memory area in a computer program) for which elements of[4] a basic set[5] can be used. The variable associated with the symbol can have different values (elements of the associated basic set).

Variant design The sequential determination of variable sizes. Both dimensions and shape of the component can vary within limits defined at the beginning. A subsequent change of the limits is not possible. The result is a (static) model with fixed values (variant). Differentiation from parametric construction: In a parametric construction, an instance is created with sizes that can remain variable and that can also take on values that have not been defined in advance (as in a variant construction).

Verification Track the implementation of each specified requirement and demonstrate its fulfilment. This process of verification checks, for example, whether the simulation has been correctly implemented in the computer. (Was this all done correctly?). Verification is usually carried out by means of desk tests based on own or third-party experience [VDI-2206].

VR Virtual reality for the representation of reality and its physical properties in a real-time computer-generated (today usually three-dimensional) environment in which the user can immerse himself. The main areas of application are currently the aircraft and automotive industries. Virtual Reality can also be used to represent unrealistic worlds.

Workflow A firmly linked sequence of work steps/processes which are not changed at all or only very rarely and which can be managed, organized and controlled with computer support. Examples in product development: release processes and change processes.

Working memory A temporary human memory with limited capacity for processing information.

XfD In this approach, the departments of the company that are outside product development provide their various capabilities and possibilities as a *service offer* in different ways and formats in order to support the product realization within

[4]The term element is to be understood here in the sense of set theory and not as a system element.
[5]By basic quantity is meant the possible range of values for the variable in question.

product development. Product development can also provide specifications for other types of realization, which are either implemented by the other departments or which may lead to a transfer of realization to third parties.

Bibliography

[Baeh-1996] Baehr, H. D.: Thermodynamik (9. Auflage). Springer, Berlin Heidelberg (1996)

[EhMe-2017] Ehrlenspiel, K., Meerkamm, H.: Integrierte Produktentwicklung, 6th edition. Carl Hanser Verlag München (2017)

[GaCS-2018] https://wirtschaftslexikon.gabler.de/definition/copy-strategie-28920/version-252542. Accessed 24 Nov 2018

[Gebh-2016] Gebhardt, A.: Additive Manufacturing Processes: Additive Manufacturing and 3D Printing for Prototyping—Tooling—Production. 5th edition, Hanser Munich (2016)

[Gips-1999] Gipser, M.: Systemdynamik und Simulation. Teubner Verlag, Stuttgart (1999)

[Hubk-1984] Hubka, V.: Theorie technischer Systeme 2nd edition. Springer, Berlin-Heidelberg (1984)

[VDI-2206] VDI-Richtlinie 2206: Design Methodology for Mechatronic Systems. VDI, Düsseldorf, 2004

[VDI-3405] VDI Guideline 3405: Additive manufacturing processes—Basic principles, terms, process descriptions. Beuth Berlin 2014

[Wiki-2020] Quote from https://de.wikipedia.org/wiki/Rebound-Effekt_(Economics). Accessed on 08 Feb 2020

[Zgha-2016] Zghair, Y.: Rapid repair of high-value capital goods. In: Lachmayer, R., Lippert, R. B., Fahlbusch, T. (eds.) 3D Print Illuminated: Additive Manufacturing On the Way to Application, pp. 57–69. Springer, Berlin (2016)

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