3 Life cycle evaluation

The previous chapter presented the various approaches in the field of life cycle modelling. This chapter is concerned with the economical and ecological acquisition and assessment of product life cycles (see Figure 3.1). As life cycle costs are especially relevant in industrial practice, particular attention has been paid to this aspect. By recording, analysing and optimising these costs, significant potential economic benefits can be tapped during the product life cycle.

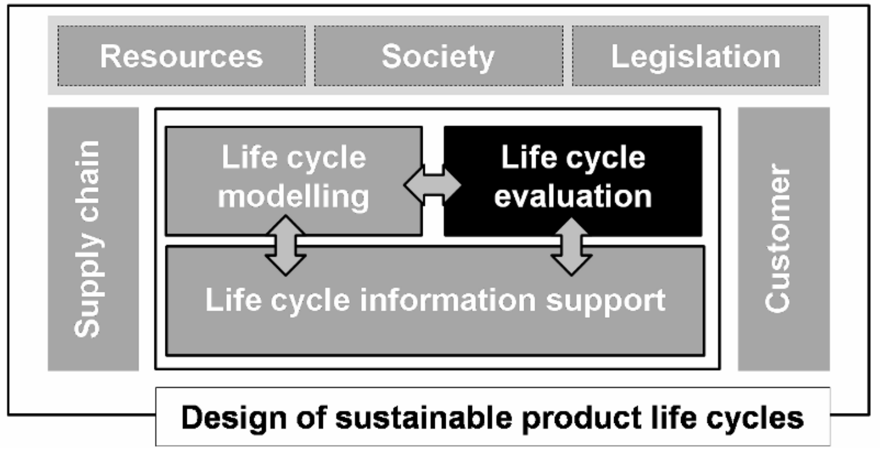


Fig. 3.1: Structure of chapter 3.

It is not just due to rising energy prices, the tightening of statutory regulations and increasing consumer awareness that products in the future will be more and more carefully examined and assessed with regard to their potentials for improvement and ecological impact. It is essential that the design sustainable of product life cycles considers and optimises both ecological and economical effects. As a result, the following chapter presents standards and innovative concepts from research and practice.

3.1 Economical assessment of product life cycles

The following graph (Figure 3.2) represents the principal course of a product's value over its lifetime. During the comparatively short production phase, product value rises to sale price. Subsequent to wear and increasing failure rates, a drop in value occurs which can be partially compensated through maintenance, repair and upgrading. Once no further measures are possible, recycling at least enables the material value to be retained. Higher values can only be achieved through reuse and re-manufacturing.

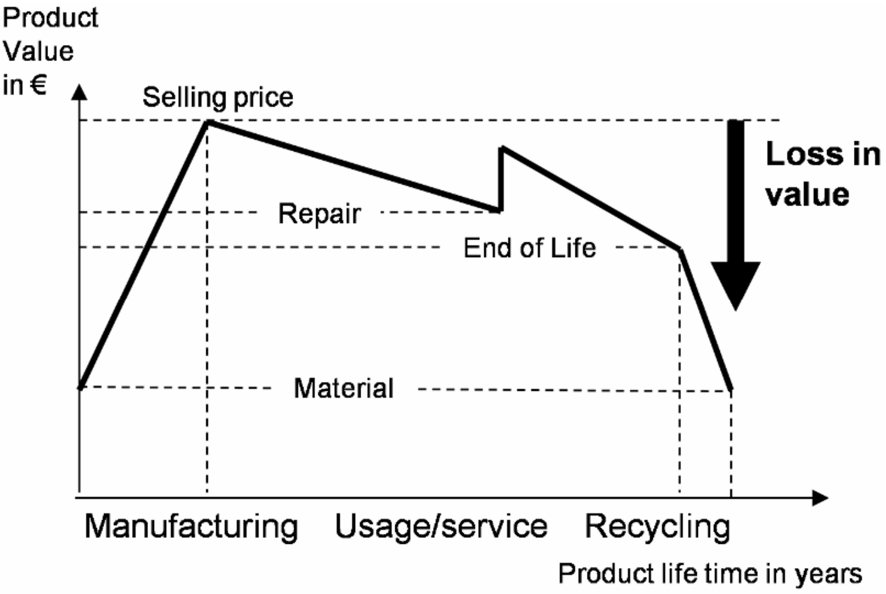


Fig. 3.2: Product value during its life cycle.

The deterioration of product value does necessarily mean that the overall value of all modules and components belonging to the product is lost. The utilisation of reusable components offers high utilisation efficiency as a whole. As a result, a *new life* with conservation of the material and (at least a part of) the economic value of a product can begin once again.

The economical feasibility of measures to maintain value and to recuperate remaining values at the end of a product's life is a function of product value at that particular point in the product's life cycle. Life cycle cost (LCC) methods can be used to calculate the product value and to pro-actively assess future developments. LCC can be defined as a systematic analytical process for evaluating various designs or alternative courses of action with the objective of choosing the best way to employ scarce resources. (Kumaran et al. 2003)

Pro-active assessment of future cost developments requires the in-depth knowledge of possible developments. Costs (Blanchard 1978) measured over an entire life cycle possess the structure of an iceberg (Figure 3.3).

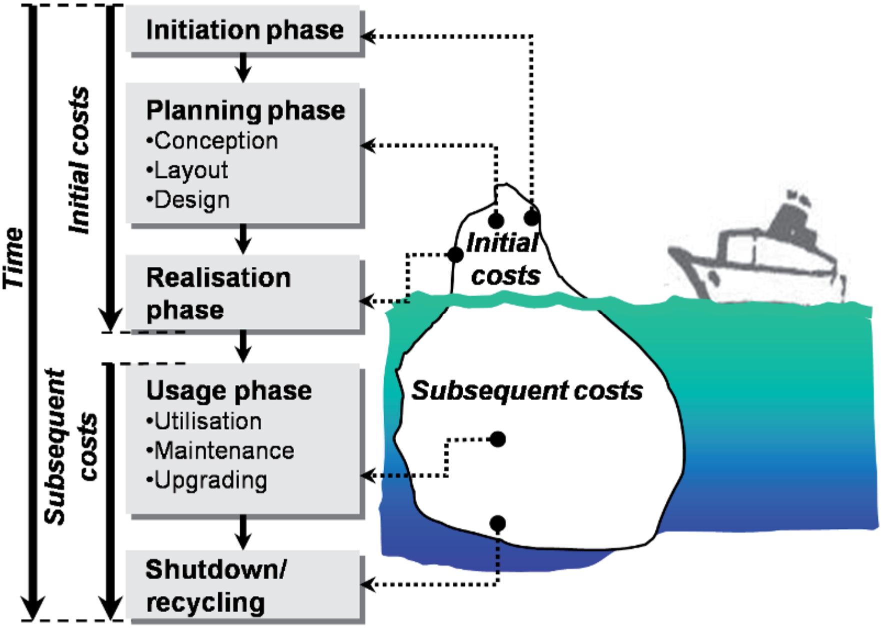


Fig. 3.3: The iceberg effect (Blanchard 1978), (Wübbenhorst 1992).

Arising costs can be divided into initial costs and subsequent costs over the lifetime. As with an iceberg, only a small part of the entire (cost) block is visible to start with. The main part is (initially) hidden but must be taken into account in order to avoid “shipwreck”. By assigning the various costs to specific life cycle phases, it becomes clear that the initial costs occur during the phases of initiation, planning and realisation. The product is manufactured in this period. Subsequent costs mainly arise in the usage phase of a product. Due to the fact that most of the financial transactions are performed during this phase, an estimation of costs and revenues is essential. Studies have shown that a focus on minimised initial costs by ignoring (later) subsequent costs does not result in minimised total life cycle costs (Wübbenhorst 1992). Nevertheless, subsequent costs are essentially determined in the early phases of product design. One way of evaluating and analysing these economic correlations is to apply the method of life cycle costing.

3.1.1 Life cycle costing

The main objective of a life cycle cost analysis (LCC analysis) is to maximise the difference between life cycle costs and benefits (finally evaluated as profits).

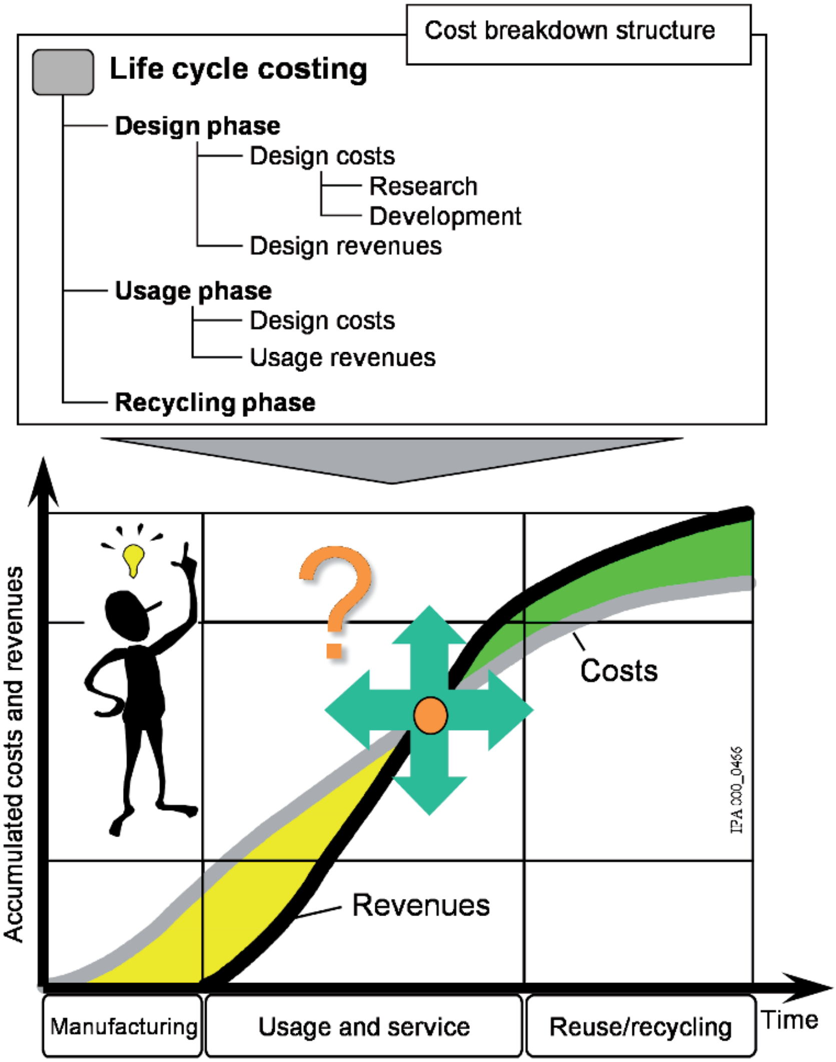


Fig. 3.4: Method of life cycle costing.

In the process, life cycle costs can be roughly divided into the three segments of development costs, utility /service costs and recycling/ reprocessing costs. Figure 3.4 shows an example of such a cost breakdown structure.

The passing through of these three phases is as important as the technical product life cycle itself. Analogous to costs, life cycle revenues can also be allocated to the individual phases in a similar way. Firstly, relevant cost and revenues blocks are recorded; the type of the individual positions varies depending on the investment goods investigated. To assess total success in the life cycle, the positions are aggregated separately according to expenditure and revenue spread out over all the phases. If only marginally-different functional solution options exist for a certain system design, a life cycle cost analysis may be of assistance in finding the best economical variant. If – in later phases – the results of the life cycle cost analysis carried out are critically assessed from time to time and are used to optimise the design within an improvement cycle, a technically and economically optimised product is the final result. The method can be applied both to plan and identify profit potentials over the entire product life cycle:

- Calculation of total costs for products (initial and subsequent costs)
- Identification of cost and revenue drivers
- Impact of outsourcing decisions
- Cash-flow analyses, return on investment (ROI)
- Analysis of "what if" scenarios (prognosis)
- Optimal due-date for machine replacement
- Holistic investment budgeting
- Analysis of trade-offs between initial and subsequent costs
- Analysis of customer lifetime value (evaluating the value/profitability of each business relation)

By looking at the situation in the long-term, LCC analyses uncover hidden cost drivers as well as profit potentials during the entire life cycle. In this way, the analysis also supplies parameters for outsourcing strategies right up to calculations for modern full-service concepts and complete outsourcing. LCC is also consistent with "Design for X" approaches, where the perception that decisions made in the earliest design step have important and irreversible effects upon the whole life cycle of the designed product.

For these reasons, LCC helps companies to pursue PLM objectives and can be considered as part of the initial phases making up a PLM approach. LCC can form part of the portfolio evaluation of new concepts and new ideas before starting the functional design (see also chapter 6.7). Adopting a LCC approach for assessing and evaluating innovations also requires the adoption of a set of procedures and tools which allow data to be systematically collected and stored.

Exact estimation of such financial figures accumulated during the entire product life cycle inevitably requires information about the behaviour of products and the actors involved in the life cycle (i.e. users, producers and service providers). To obtain this information, life cycle simulation techniques based on digital data are necessary.

3.1.2 Strategic portfolio for optimising life cycle costs

On analysing the life cycles of various products, it becomes obvious that the life span is of different duration. The products also differ in their degree of complexity and product value. A strategy to master and optimise product life cycles has to take this into account. This implies that no one universally-valid optimisation strategy exists. Also, a differentiated approach is required in order to identify the key cost drivers. To achieve this, the cost breakdown structure of a product life cycle can be divided into the general categories of investment and running costs. The ratio of these two cost drivers helps to identify the variables for optimisation.

The investment costs cover all costs which occur only once, e.g. cost of design, installation, training and recycling. Running costs comprise all the operational costs (including maintenance, service, unplanned downtimes, etc.) incurred during the usage of a product throughout its entire life cycle. It is essential that both types of costs are recorded (or at least forecast) over the total life cycle. The cause of specific cost origins may be anchored in various points within the life cycle and it is often a highly time-consuming and problematic process to identify them. A detailed analysis of trade-offs may be of assistance here (Figure 3.5).

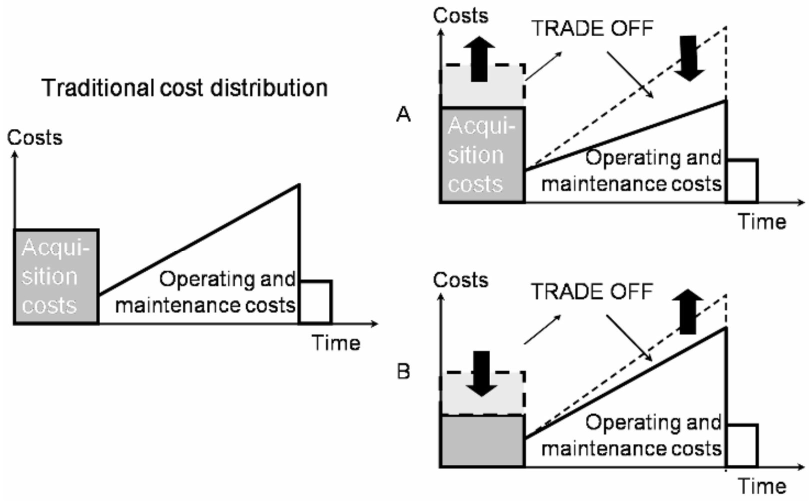


Fig. 3.5: Strategic courses of action to optimise a life cycle. (extending according to Wübbenhorst, K. 1984)

On considering the trade-offs and methods of coordinating the entire life cycle, it can be seen that the phases are not independent of one another. The product realisation phase plays a particularly important role in life cycle costing. As ascertained previously, this is because a large part of the costs are fixed in the early phases of a product's life cycle which cannot be influenced later on in the cycle.

Therefore, decisions need to be made at an early stage which take interrelationships between the various quality, time, profit and cost aims into account. The impact of these decisions on product success can be accurately analysed using the instrument of life cycle costing.

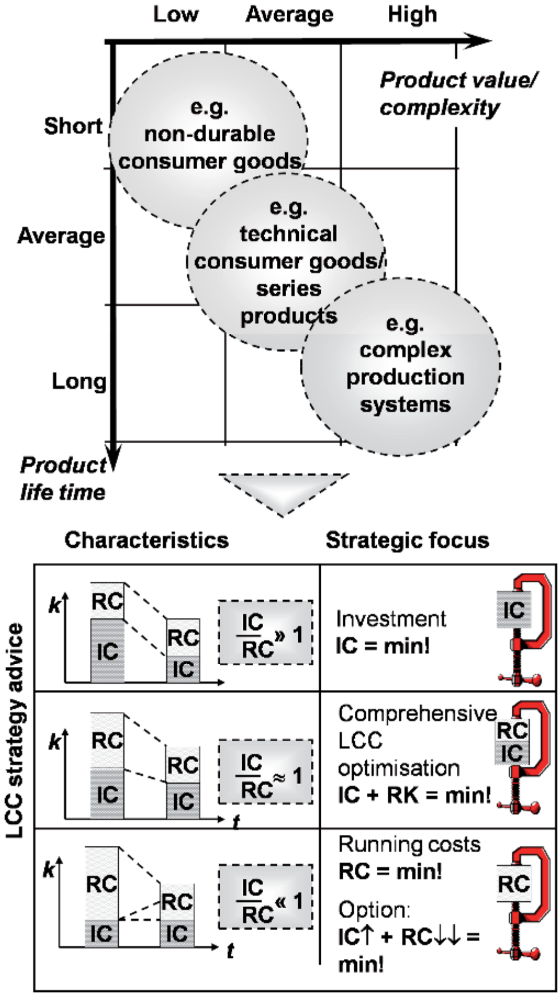


Fig. 3.6: Strategic options for product life cycle optimization. (Niemann 2003)

In order to make informed decisions, integrating and long-term viewpoints are required and the individual aspects of each aim have to be made quantifiable. In a second step, the strategy advice is assigned to specific product functions to enable concrete actions to be executed at the base of cost origins.

As Figure 3.6 shows, three categories with varying time scales and strategies may thus be defined. The first group is characterised by a short lifetime and low product value or complexity. Such non-durable technical consumer goods are usually mass-produced and manufactured in large series. The main emphasis of life cycle management is placed on the rational organisation of services, marketing and product recycling techniques. Robust techniques can be used for recycling due to the fact that the added value profit is low in relation to the value of the product. The second category is assigned to series products with a limited number of variants. Life cycle management of these products includes services and maintenance as well as industrial recycling and the partial reuse of parts and components. High-quality capital goods are assigned to the third category. The main emphases here are on maximum utilisation strategies, the maintenance of performance and additional added value in the field of after-sales. Industrial recycling only plays a minor economic role in this category of products. (Brussel and Valckenaers 1999)

3.1.3 Standardised worksheet for evaluating life cycle costs

More and more customers are asking their manufacturers about the total cost of ownership for investment goods. As a result, the total costs become a focus and have to be determined and made transparent by the manufacturer at the point of sale.

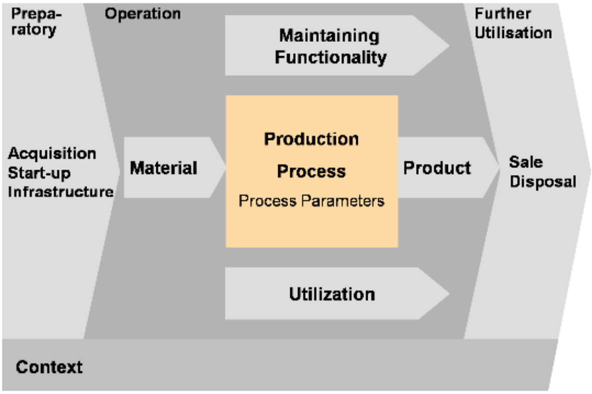


Fig. 3.7: Life cycle cost functions.

To do this, a standardised cost sheet is necessary which covers all relevant cost positions over the life cycle. The general framework for this is shown in Figure 3.7. The cost sheet is structured according to system theory and uses a functional approach to generate a consistent cost breakdown structure over the product life cycle. The Federal Association of Engineering (VDMA, Germany) started up a working group to create an industrial standard in this field. With its extensive knowledge and experience, the working group within KCiP has contributed to the development of such a standardised sheet. A catalogue of over 60 parameters covering all life cycle phases has been compiled and integrated into the scheme and includes all the necessary arithmetic operations. A screenshot of this structure is shown in Figure 3.8.

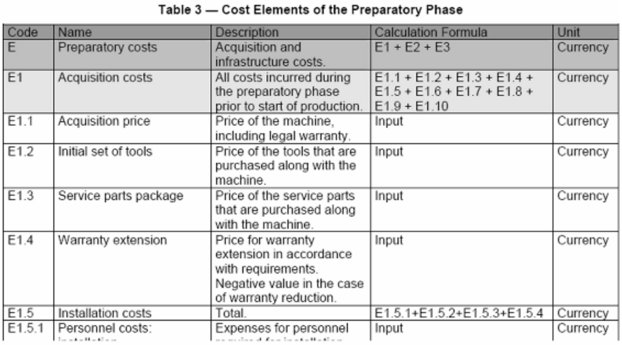


Table 3 — Cost Elements of the Preparatory Phase

Code	Name	Description	Calculation Formula	Unit
E	Preparatory costs	Acquisition and infrastructure costs.	E1 + E2 + E3	Currency
E1	Acquisition costs	All costs incurred during the preparatory phase prior to start of production.	E1.1 + E1.2 + E1.3 + E1.4 + E1.5 + E1.6 + E1.7 + E1.8 + E1.9 + E1.10	Currency
E1.1	Acquisition price	Price of the machine, including legal warranty.	Input	Currency
E1.2	Initial set of tools	Price of the tools that are purchased along with the machine.	Input	Currency
E1.3	Service parts package	Price of the service parts that are purchased along with the machine.	Input	Currency
E1.4	Warranty extension	Price for warranty extension in accordance with requirements. Negative value in the case of warranty reduction.	Input	Currency
E1.5	Installation costs	Total.	E1.5.1+E1.5.2+E1.5.3+E1.5.4	Currency
E1.5.1	Personnel costs:	Expenses for personnel	Input	Currency

Fig. 3.8: Screenshot of the cost breakdown structure (VDMA 2006).

The scheme will now serve as a standardised basis for the calculation of life cycle costs among European manufactures (see also Chapter 6.7.1).

3.1.4 Case study of a life cycle cost calculation for a machine tool

The following paragraphs describe the case of a machine tool builder - here a transfer machine tool constructor - who is requested by an important client to calculate and include the life cost of a particular machine in the offer. Transfer machines are utilised to manufacture a particular part (or a particular family of parts). The manufacturer has to demonstrate that his machine can produce a certain part at a requested production rate and quality level demanded by the buyer. These quality and production levels have to be maintained during the entire life of the machine tool which is estimated to be 10 years. LCC calculations are usually based on this figure for the total duration of machine life.

These machines need to be available as much as possible during their lifetime. Breakdowns are directly related to loss of production. The client belongs to the automotive sector and is particularly worried about the issue of machine availability. The client is well aware of the importance of knowing the life cycle cost and does not want to acquire machine tools, or equipment in general, based only on production capacity and price. Customers want a guarantee of machine availability. Even beyond availability, they want a machine which is relatively cheap to use in order to compensate for high acquisition costs. This is also a crucial issue for European machine tool builders if they want to keep their position in the market.

If they succeed in producing reliable machines which consume less, it would be possible to convince purchasers to make a higher investment when buying machines. To achieve this, manufacturers have to be able to prove to the buyer that the life cycle cost of their machines is lower and has been calculated based on objective data, i.e. real machine performance.

Buyers may soon start requesting contractual commitment to life cycle cost. For certain products such as trains, for example, it is not unusual for the purchaser to buy products and services such as maintenance at the same time. Therefore, it is essential the manufacturer is precisely informed about the performance of his products throughout their entire life cycle. The product life cycle model used by the manufacturer is one as simple as the one shown in Figure 3.9 below:

Fig. 3.9: Life cycle cost model.

The cost corresponding to the construction phase is called the *acquisition cost* and comprises the following parts:

- Purchase price
- Administration costs
- Installation
- Training
- Shipping cost
- Warranty
- Support equipment

This is what the buyer has to spend when he acquires and installs the machine tool. The manufacturer may provide some of these services (such as training). It is a matter of negotiation between the manufacturer and customer as to who will bear the remaining costs (e.g. shipping costs). In any case, these are costs which do not require any special calculations but are fixed at the time of purchase of the machine tool. Operating costs are those incurred when using the machine in normal working conditions and include the following:

- Tooling
- Direct labour
- Changeover labour
- Consumables
- Utilities
- Waste handling
- Floor space

Tooling costs are calculated based on tool wear. As the operations to be carried out are well known, the manufacturer has to provide the number of parts which can be produced by each tool. As the production rate is known, it is possible to deduce the number of tools which will be required during the life of the machine tool (usually set at 10 years). The cost would therefore be the cost of each individual tool times the number of tools used. Using this method, the total number of tools is calculated assuming the machine will be working the total number of hours allocated to it., However, as machines do not have 100 % availability in reality, the operational availability of the machine tool therefore has to be calculated.

Availability is the ratio between the uptime and the total allocated working time for the machine. Downtime is the addition of the times when the machine is stopped due either to a machine breakdown or because the machine user is simply not using it for organisational reasons (e.g. lack of input parts). Inherent availability is then obtained from the ratio between machine downtime and the total time. Finally, operational downtime is the ratio between the total downtime and the total time. The manufacturer should be able to estimate the inherent availability of his machines from the historical data of breakdowns of his machines. Thus, the actual number of working hours is obtained by multiplying the operational availability by the total number of hours.

Similarly, in order to calculate labour costs, information from both the user (hourly labour cost, number of working hours/year) and the manufacturer (number of operators per machine) is required. Consumables and utilities refer to costs of materials and fluids required by the machine to function normally. They are grouped as follows. Consumables:

- Coolant
- Filters
- Lubrication
- Utilities:
- Compressed air
- Electricity
- Gas
- Steam
- Water

A consumption rate is proposed for all these cost concepts which is then multiplied by the number of hours which the machine is actually available. Costs also have to be calculated for waste handling and the amount of floor space occupied by the machine. Waste handling comprises:

- Coolant dumping
- Filter
- Sludge

Costs of coolant and sludge are given per litre. Costs of disposing of filters is expressed per metre. No other environmental impact costs are foreseen (except disposal costs, if they can be considered as such). The second large group of usage costs is those termed maintenance costs. Here, three types of costs are considered:

- Preventive maintenance costs
- Unscheduled maintenance costs
- Spare parts costs

PM costs are a function of planned preventive maintenance tasks and their duration. Corrective or unscheduled maintenance is a function of the number of stops due to breakdowns and the time required to repair. The manufacturer has to provide the MTBF (Mean Time Between Failures) and the MTTR (Mean Time To Repair) of the equipment. These need to be derived from historical data of equipment already installed which is equal or “similar” to that being analysed. These parameters can be calculated by adjusting failure and repair distributions using a Weibull function.

Spare part costs are also dependent on the failure rate, the latter also having to be derived from historical data. Finally, the cost of disposal or retrofitting has to be taken into account in order to complete the life cycle cost.

In transfer lines such as that mentioned in this case, it is quite usual that acquisition costs, operation costs and maintenance costs each represent 1/3 of the total costs (without the consideration of disposal costs).

3.1.5 Continuous life cycle cost controlling

Today, manufacturing companies in the field of high-variant series productions operate in markets which are extremely dynamic and turbulent. Here especially, changing customer demands create a challenge for companies to manufacture high-quality products and variants within shorter and shorter innovation cycles and to launch them onto the market. (Spath 2003), (Westkämper 2004), (Hummel and Westkämper 2006)

According to calculations made by the Federal Statistical Office, technical investment goods with a (new) value of almost 12 billion Euros were utilised for industrial manufacturing in Germany in 2007 (Federal Statistical Office 2007). In the field of series productions, these investments were mainly made in direct relation to the product being manufactured. This shows that the economic calculation of a capital investment needs to be orientated towards the planned turnover curve of manufactured products. The expected life cycle (market cycle) of products over time thus essentially determines the type and amount of investment made. However, as far as manufacturing companies are concerned, the presence of market change drivers means that the inflow of future orders is affected by increasing planning uncertainty with regard to the type (product mix) and number of products being manufactured.

In the process, the main objectives of a company with regard to efficiency are defined by a *magical triangle* formed by cost reduction, time reduction and quality improvement. Series manufacturers work under high cost pressures with the result that the efficiency of manufacturing systems is usually expressed in piece costs. The aims of reducing times and improving quality are forced to accept a subordinate role here and thus be converted to piece cost values. Consequently, companies are constantly being challenged to manufacture product units at the lowest possible piece costs in order to keep up with the competition. As far as the effective usage of operating manufacturing systems is concerned, this results in the problem of having to constantly absorb external adaptation pressures by making continuous internal adjustments. In this context, a manufacturing system is seen as being an independent unit in which all resources required for manufacturing a specific product are united. (Niemann 2007), (Westkämper 2003, 2006)

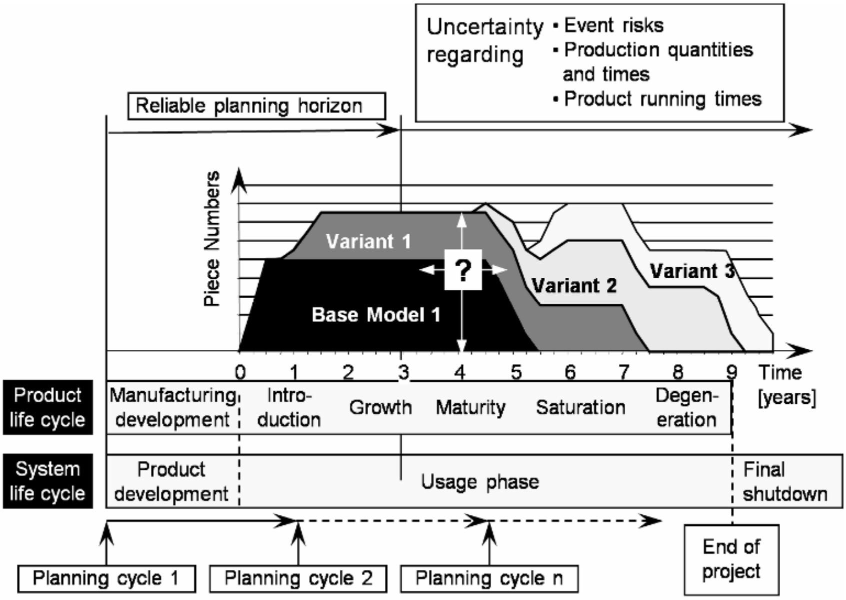
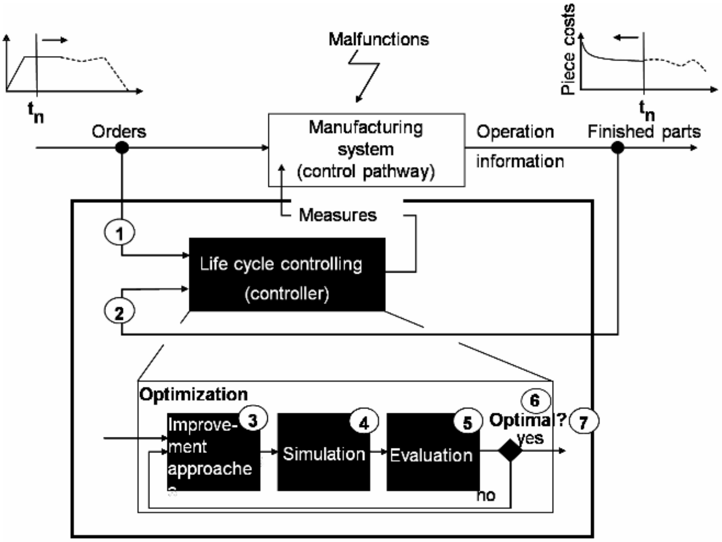


Fig. 3.10: Continuous adaptation of a manufacturing system and product spectrum. (Niemann 2007)

In general, when planning a product or manufacturing plant, precise planning data is only available for a limited period of time. Planning reliability concerning future order quantities and their composition is only present later on. For this reason, the planning measures taken only once at the start of an investment tend to be highly unreliable. Therefore, systems need to be reconfigured and optimised at regular intervals as more and more concrete information is obtained. Figure 3.10 illustrates this problem in the form of a graph. Technical advances also demand constant innovation and this is reflected in the development of new machines either with improved efficiency or with an increased scope of performance.

Consequently, technical, economical and organisational change drivers need to be constantly adapted - especially as far as high-capital investment goods are concerned - in order to achieve optimum machine usage throughout the life cycle of a system. (Niemann 2007), (Spath 2003)



Functionalities:

1. Acquisition of customer orders
2. Integration of operating data
3. Identification of improvement measures
4. Simulation of alternative scenarios
5. Cost-orientated representation and evaluation of scenarios
6. Selection and implementation of suitable scenarios
7. Provision of a dynamic system control

Fig. 3.11: Controlling concept for system optimisation based on a control cycle. (Niemann 2007)

There is therefore a requirement to develop a method which supports the continuous optimisation of manufacturing systems throughout their life cycle in the field of series productions. The method has to be capable of recording the effects of central change drivers on manufacturing systems and of providing systematic control mechanisms for an adapted system reconfiguration in order to ensure production with optimised piece costs in dependence upon the output quantities required. In this book, this control model has been called *life cycle controlling*. (Niemann 2007) Here, the main aspects of controlling include not only system-design functions but also system-monitoring functions, especially an anticipatory acting influence with regard to continuous system optimisation. Figure 3.11 shows this control concept with the necessary sub-functions as a graph.

3.1.5.1 Design concepts for manufacturing systems

The term *manufacturing* characterises the "entire economical, technological and organisational measures involved in the development and processing of materials" (Westkämper 2006). In the process, the term manufacturing in accordance with Westkämper embraces much more than just manufacturing, because it not only includes the "manufacturing processes themselves but also all controlling and organisational functions associated with them […], from development right up to delivering a product to the customer" (Westkämper 2004). Based on this definition, the following existing design concepts for manufacturing systems can be fundamentally classified into: organisational concepts (e.g. Eversheim 1999); organic concepts (e.g. Warnecke 1993); system-related concepts (e.g. Westkämper 2004, 2006) and method-orientated concepts (e.g. Spath 2003).

The analysis of design concepts shows that today's manufacturing systems for series productions have been designed as closed autonomous units. System operation is supported by standardised process sequences and is subject to integrated optimisation attempts with regard to cost, time and quality. The system concept of the Stuttgart company model (Westkämper 2006) is especially suitable as a basis for modelling and representation. The model is characterised by a hierarchical system set-up and performance units similar to itself. Via this set-.up, dynamic alterations to a system can be depicted and described throughout its life cycle. By superimposing methodical concepts, rationalisation measures can be addressed and evaluated with regard to their cost effectiveness. In order to be able to continuously update the actual planning situation, feedback from real company processes is required. This has not been realised in the past in concepts known to date due to the complexity of interrelated effects. As a result, insufficient direct economical feedback has taken place during continuous system monitoring.

Deficits occur as a result of failing to integrate planning and operating data into a life cycle orientated planning system. Such data would enable adaptations and the necessary alterations to a manufacturing system to be pro-actively planned in order to increase its usage in dependence upon a volatile manufacturing programme and to permit the effects (or benefits) to be verified in advance. To achieve this, existing planning data from the rough planning phase from PPS or ERP systems could be utilised which would enable manufacturing orders to be acquired right up to the planning horizon. With current planning systems, order control takes place under the primacy of optimised resource allocation for a defined manufacturing system. However, as the design of a manufacturing system is the object of the control model to be created, a suitable method needs to be developed to resolve manufacturing orders. This would enable a system to be optimally configured based on this. In order to analyse life cycle related potentials (trade-offs), the progression of piece costs over time needs to be investigated over the later life cycle of the system. Due to the complexity of the system, simulation-based planning environments are ideally suited for this. (Niemann 2007), (Gu 1997, Kimura 2000)

3.1.5.2 Operating data for monitoring systems

Desired times for handling orders are generated through preliminary costing. In the final costing, information needs to be constantly monitored and compared with real manufacturing data. The data required for this can be obtained from work plans and from PPS, PDE, MDE and QDE systems (Müller and Krämer 2001). Due to the hierarchical system structure, the manufacturing data can also be used to analyse sub-systems and even individual machines as well as to make comparisons with planning values from the preparatory work. In this way, concepts for improvement potentials can be identified for each level of a manufacturing system. The new values then form the basis for future planning cycles. Deviations from planning values supply information about fuzziness and model correction requirements. They also represent potentials in a manufacturing system which can still be realised by taking specific improvement measures.

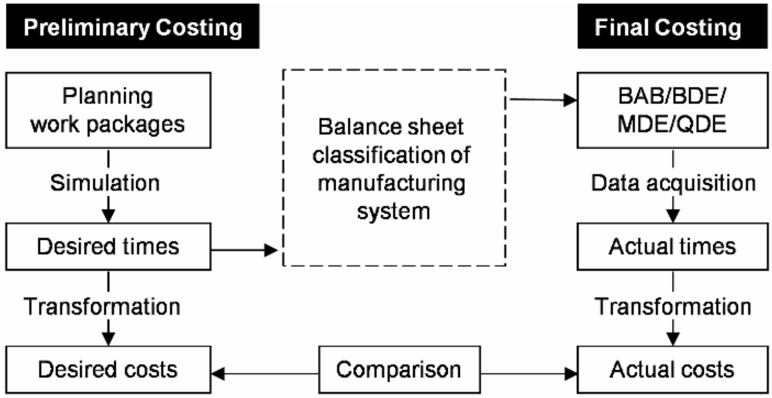


Fig. 3.12: Operating data as a basis for system monitoring. (Niemann 2007)

Figure 3.12 shows a continuous comparison for final costing as well as for correcting the forecast of time and cost data. The control model thus makes the progression of event, planning and evaluation data over time available. In this way, a control cycle can be created which constantly supplies updated references related to the planning cycles to be carried out. However, the improvements made to the system also need to be included in the work plans in order to realise the potentials in future planning cycles. The continuous planning, optimisation and controlling of manufacturing events thus enables the user to permanently control the efficiency of a manufacturing system throughout its entire life cycle. (Seliger et al. 1999), (Hieber and Schönsleben 2001), (Jackson et al. 1997) (Niemann 2007)

3.1.5.3 A reference model for manufacturing systems

First of all, system interrelationships are acquired and depicted using a reference model. In the process, the reference model should be filed with the control model for life cycle controlling to enable the depiction and evaluation of alternative manufacturing scenarios obtained using simulation. Performance units form the basis for this, via which the manufacturing transformation process takes place. The performance unit needs to be included in an information-related system environment within which continuous back coupling takes place with regard to the required performance (result).

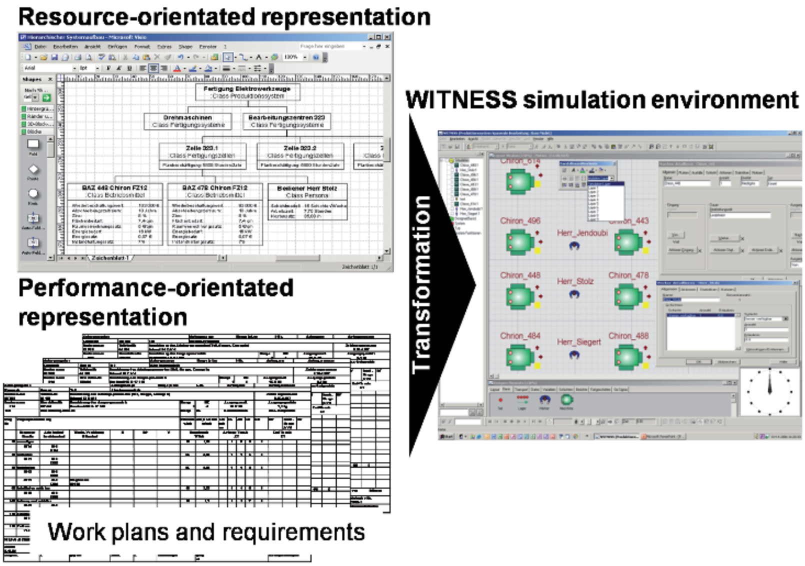


Fig. 3.13: Transformation of the manufacturing system into the simulation environment. (Niemann 2007)

By modelling the system in the markup language UML, it was possible to develop class diagrams in which the Stuttgart company model could be modelled completely with the individual hierarchical levels as well as formally described with regard to the corresponding usage characteristics and costs created. At each level, the classes contain specific and inherited attributes and functions with which they can be represented as far as their tasks and interaction with other classes in the manufacturing system are concerned. Additionally, through inheritance relationships, each individual class obtains all the properties of the class of performance units. (Niemann 2007)

In this way, a system of classes is formed with system structures and elements similar to their own at all levels of the system hierarchy. By precisely specifying the necessary data and also data sources in relation to the time and cost data required, the reference system developed can be coupled with the corresponding operating information system for acquiring and depicting real system conditions. As a result, a general model for manufacturing systems is created which can then be utilised as a basis for simulation-aided life cycle controlling (Figure 3.13). (Niemann 2007)

3.1.5.4 The control cycle for cost controlling

In order to safeguard the benefit of cost-intensive improvement measures in the long-term, a planning horizon needs to take a period of time as long as possible into consideration.

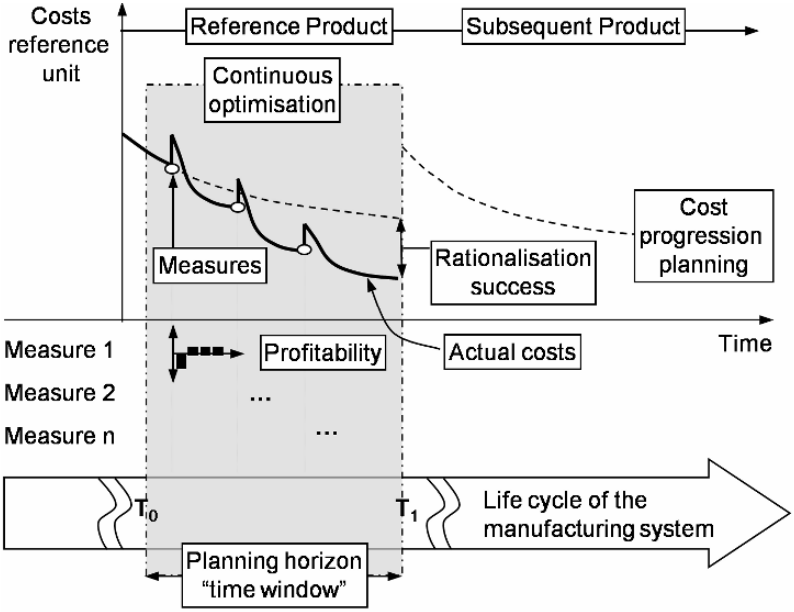


Fig. 3.14: Synchronising the product life cycle with the system life cycle. (Niemann 2007)

Depending on the degree of planning reliability and the volatility of the manufacturing program, this can also be selected directly right up to the intended final shutdown of the system. To do this, the corresponding paradigm of a life cycle-orientated calculation of manufacturing costs and the effect of potential improvement measures during the later life of the system need to be represented. Here, the short-, mid- and long-term effects have to be described and analysed. As planning cycles progress, the planning horizon (period of time) thus shifts continuously along the time axis in the direction of the intended shutdown of the system. (Niemann 2007) This is shown in Figure 3.14.

Due to the fact that the system is subjected to constant dynamics as a result of external and internal change drivers, the profitability of optimisation measures taken must be verified at regular intervals and maintained. The optimum operating point of a system has to be appropriately monitored and updated. To achieve this, the method needs to be transferred to a control model using which system configuration can be continuously adjusted to ensure optimum piece costs in dependence upon the orders being manufactured. (Niemann 2007)

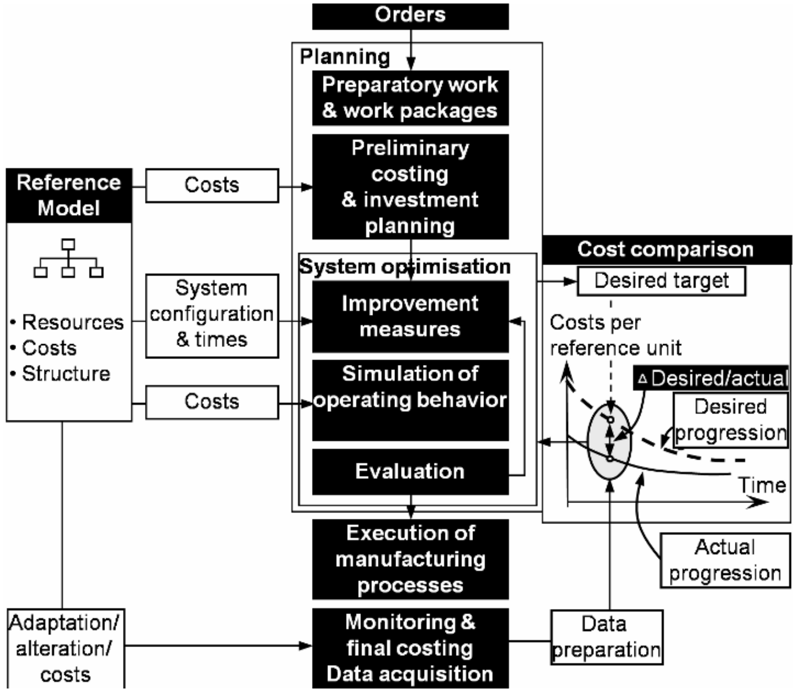


Fig. 3.15: Control cycle for life cycle controlling. (Niemann 2007)

As a result, product life cycles are synchronised with the existing manufacturing system for the duration of the planning time. This is because adjustments made to the system are always orientated towards the development of capacity packages. The controller is made up of both a planning and an optimisation environment in which the path of the manufacturing system's process sequences can be simulated.

In the controller (Figure 3.15), first of all capacitance packages are generated for the manufacturing system from the manufacturing orders. The packages represent the required total capacity of a specific, identical machine type.

Thus, using the work plans and the actual system configuration, the capacities desired can be calculated by adding up the main usage, set-up and technical loss times (Figure 3.16). These must then be compared with the nominal capacity of the capacitance package available.

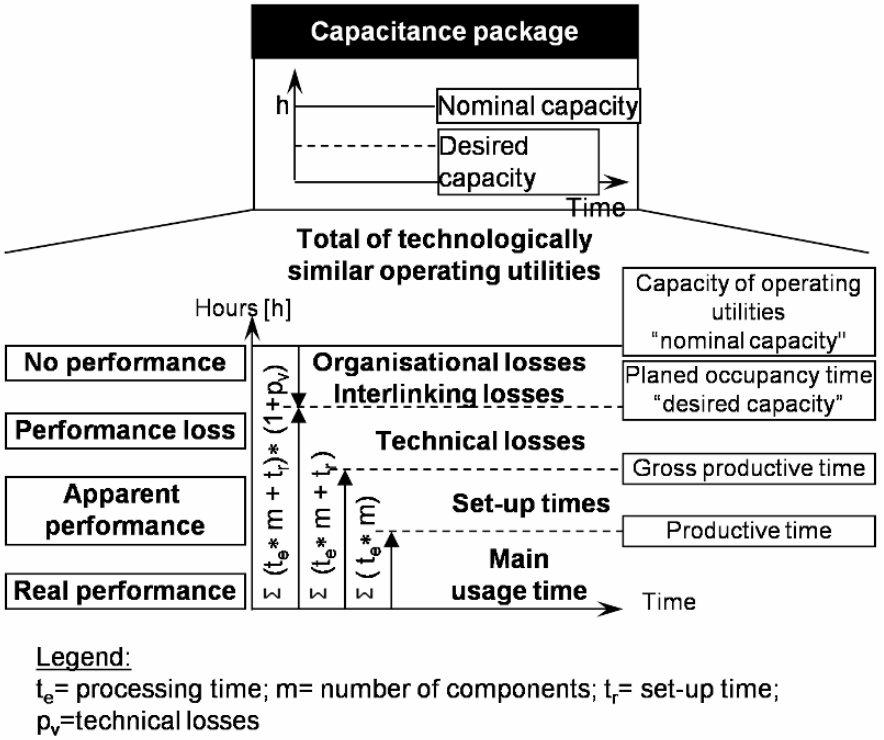


Fig. 3.16: Acquisition of required overall capacity using capacitance packages.

The actual nominal capacity is either already present in the reference model or is continuously imported and acquired via operating data administration. As part of the optimisation, alternative manufacturing scenarios or potential improvement measures can now be evaluated with regard to their effect on the life cycle (trade-offs) and on profitability. (Niemann 2003, 2007). As a result of developing alternative scenarios for the manufacturing system, more optimisation loops may need to be run in this area. For the analysis, these strategic options are first represented in the reference model and are then analysed using simulation.

The results obtained from the simulation give a chronological representation of the individual sequence types based on the current system configuration. The times and piece numbers ascertained form the basis for the cost assessment of system performance for the planning horizon under examination. For the approach selected, concrete operative measures are then developed with which the planned time savings in the system can be achieved.

The measures are then verified with regard to their financial requirement and also to their profitability and are then implemented in the manufacturing system in accordance with corporate management criteria. Manufacturing is carried out under the constant acquisition of operating data which are analysed in the final costing. As part of the controlling process, the times and costs forecast are compared with real system performance in order to monitor the achievement of objectives. The control cycle is closed by re-importing actual data from the final costing into the preparatory work and serves as a planning basis for future preliminary costing processes. Through the direct back coupling of the system planning with a time and cost analysis supported by operating data, a closed controlling system is created for a simulation-based control cycle with which manufacturing systems can be continuously planned, operated and optimised throughout their entire life cycle.

3.1.5.5 Industrial application of life cycle controlling

The method developed has been implemented in a practical application to control the life cycle of a manufacturing system used for the series production of machinable components.

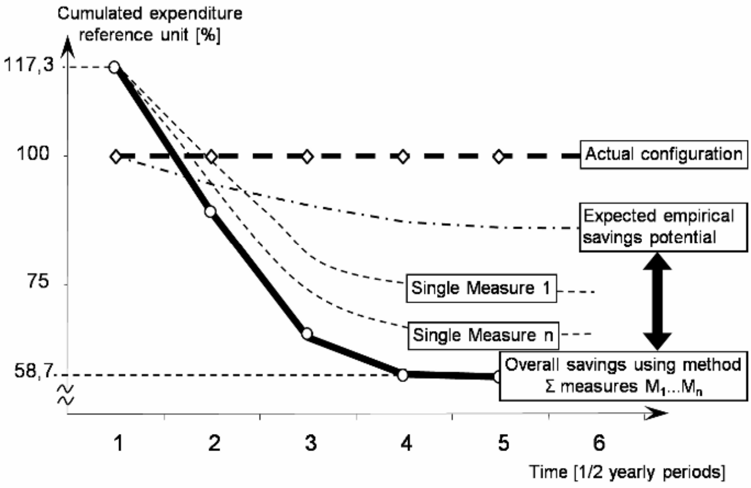


Fig. 3.17: Success of the method compared to empirical learning curves. (Niemann 2007)

By creating a control cycle of planned and actual manufacturing data, it was possible to identify rationalisation potentials and to evaluate them with regard to their profitability. In the process, it was demonstrated that the applied method enabled the company concerned to realise considerably-improved learning curves than could be expected using comparable empirical data (see Figure 3.17). The development of the ascertained cost pathways over time also forms a benchmark for the continuous controlling of system profitability. The increase in learning speed enables comparative cost advantages to be realised which contribute towards ensuring that company competitiveness is safeguarded on a lasting basis. (Niemann 2007)

It became possible to evaluate alternative manufacturing scenarios faster and to learn from the "future" by implementing measures virtually. By coupling planning data with actual data, a control loop of life cycle controlling was created which enabled manufacturing systems to be planned, optimised and monitored continuously throughout their life cycle. The constantly-updated system model thus formed the basis for future planning and optimisation cycles. The practical application of the controlling model has demonstrated that companies are able to realise lasting and effective rationalisation potentials as a result.

3.1.6 Life cycle cost contracts

More and more often, customers are demanding certainty regarding the follow-up costs of their investment goods. To do this, they frequently insist on manufacturers giving contractually-fixed guarantees concerning a large part of the maximum expected operating costs. These life cycle cost contracts (block guarantees) limit cost risks on the part of the customer and involve the plant manufacturer in product responsibility. At the moment, the huge demand for such delivery agreements is only met by a few concrete proposals on the part of the manufacturer.

A study carried out by the Institute of Industrial Manufacturing and Management (IFF) of the University of Stuttgart already shows today that "delivery alone" will no longer be sufficient in the future to establish lasting business relationships with customers. (Niemann,J. and Stierle, T. 2004) However, the internal path towards a manufacturer supplying such "assured" offers is long. To be able to do this, manufacturers need to know the operational behaviour of their products precisely in order to be capable of giving customers a life cycle cost guarantee. Otherwise, considerable risks due to possible penalties could result. The contracts also obligate the system operator to comply with the operating conditions laid down by the manufacturer (e.g. fixed maintenance cycles, etc.). With the aid of an example, Figure 3.18 shows a basic method for designing a life cycle cost contract between the manufacturer and the customer.

The benefit for both partners lies in the exploitation of these synergies. Examples already show that companies consistently implementing this model as a life cycle orientated partnership are able to operate with strategic competitive advantages in the market.

The IFF study also demonstrated that there is a particular lack in services, thus enabling the forceful utilisation of machine performance potentials. (Niemann,J. and Stierle, T. 2004) The potentials here range from disturbance management right up to the preparation of specialised manufacturing know-how. In the future, innovative payment models will also play a role which will be orientated towards the benefits brought by the machine supplied.

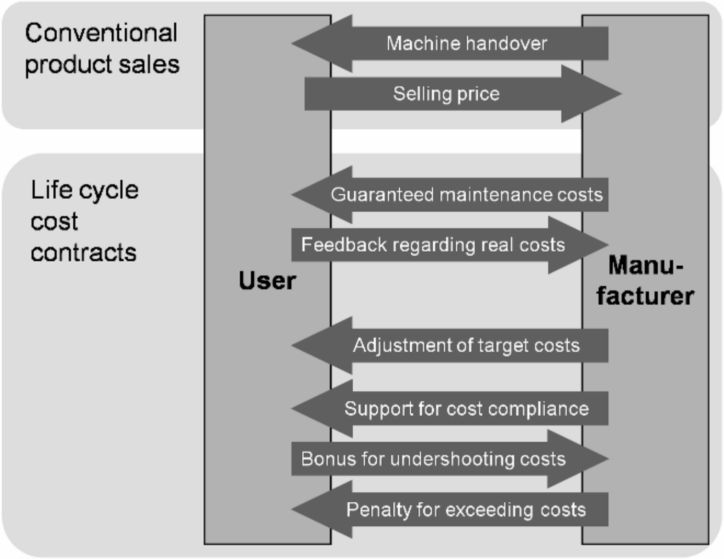


Fig. 3.18: Example of a life cycle cost contract.

In the process, conventional machine sales will be extended by business models using which the machine manufacturer will be paid for the machine performance utilised, ie. the benefit (re-) sold. As a result, the life cycle benefit of the investment becomes a focal point once again and it is in the mutual interest of both the machine manufacturer and the user to optimise this from the point of view of maximising production yield. This especially leads to closer collaboration between both partners in which the conventional customer-supplier relationship changes to become a cooperative system partnership.

3.2 Ecological evaluation

Life Cycle Assessment (LCA) is a concept for the evaluation of environmental performance. It is a method for acquiring and evaluating the effects of products, processes and different types of services on the environment over their complete life cycle from the mining of raw materials and usage of a product right up to its disposal. Weaknesses, both ecological and economical, can be identified by way of life cycle assessment. This comparison is carried out in accordance with the current international norm for evaluating environmental performance (DIN ISO 14040 ff). At the same time, it also enables a basis to be created for the informed communication of environmental protection successes which are related to the product. The use of this method is described in more detail by way of an example in the following:

3.2.1 The application of life cycle assessment

The production of high-precision steel parts usually includes a hardening process for altering the surface structure. Conventional heat treatment methods are characterised by high energy consumption and the utilisation of polluting treatment salts.

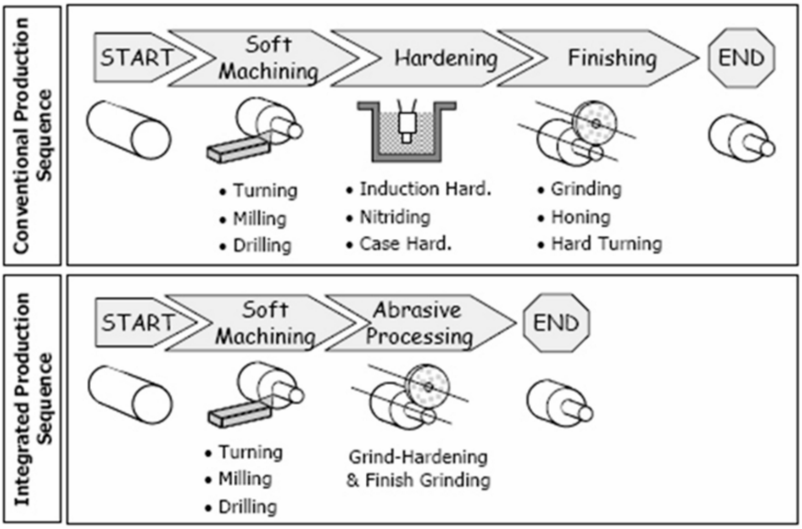


Fig. 3.19: Comparison of a conventional production chain with a production chain including grind hardening.

Grind-hardening is an alternative process which can be used for the simultaneous surface hardening and grinding of metallic components. In a study by Salonitis et. al., life cycle assessment is used for the environmental analysis of the grind-hardening process (Salonitis et al. 2006). In two different pilot cases - the production of raceways and the production of tripod joints - the environmental impact of the grind-hardening process is compared with that of conventional heat treatment methods:. The analysis indicates that the utilisation of grind-hardening significantly decreases the environmental impact. Additionally, the heat treatment process is usually performed by external subcontractors. This involves transporting the workpieces back and forth, further increasing both energy consumption and the environmental impact. The necessary cleaning of the workpieces before and after the heat treatment process also requires copious amounts of water. All the above-named steps can be eliminated by performing both the grinding and grind-hardening processes on the same machine with the same set-up (Figure 3.19).

3.2.2 Further studies on ecological assessment

The environmental assessment (EA) of a process includes evaluation of the consequences for the environment, human health and resources. It is actually a part of a product's life cycle assessment. In the study of Drakopoulos et al., the product is a ship and the specific processes refer to the repair phase of the ship's life cycle (Drakopoulos et al. 2006). In the case of ship repair, where it is evident that the most dangerous environmental processes are cutting and welding, the goal of EA has been to quantify this danger and to benchmark the various different processes used. This study presents an environmental analysis of a number of cutting and joining processes carried out during the repair of a ship's hull. These processes include *oxyacetylene cutting*, *plasma arc cutting*, *shielded metal arc welding*, *flux core arc welding* and *submerged arc welding* and are modelled in terms of their environmental impact. The environmentally-related inputs and outputs of each process are elaborated with a life cycle assessment tool. The impact on various aspects, such as human health, resource depletion etc., is evaluated by the impact assessment methods of "Environmental Priority Strategy (EPS)" and "Eco-Indicator 99". Based on the results, the cutting and welding processes are benchmarked in terms of their environmental impact.

3.3 Interim summary of life cycle evaluation

The chapter has demonstrated that the sustainable design of product life cycles must be coupled with a continuous assessment of the economical and ecological consequences. In order to do this, standardised methods are required for estimating the effects occurring during the life cycle. Here, a qualified evaluation is based on the generation of corresponding life cycle situation-related models (see Chapter 2). However, the methods known to date in research and industrial practice also show that a once-only calculation at the start of production development is inadequate. This is because there is a significant probability that changes will take place during the long life cycle of the product, thus making the original planning measures obsolete. This means that especially cost-orientated planning scenarios will always be flawed by considerable uncertainty. The only remedy is to introduce continuous planning systems which are constantly adjusted over the life cycle in the form of life cycle controlling to support decision-making at each of the planning horizons. The case study shows that a continuous planning approach contains considerable potentials because it enables the user to constantly optimise the product life cycle by "learning from the future".

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