State of the Art Regarding Existing Approaches

Christian Grefrath, Dirk Wagner and Sebastian Stermann

1 Introduction

The purpose of this chapter is to collect information on current methodologies of innovation (management) and solution engineering and to compare them against the requirements identified in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development".

In this chapter, existing methodologies supporting innovation and solution engineering are studied based on a life cycle view presented in Fig. 1. The life cycle description aims to combine the aspects related to strategy development and issues related to the life cycle management of the product and solutions that a manufacturing network is producing. For the sake of clarity, the life cycle is presented as linear in Fig. 1, although in practice the life cycle of one product is at least partly circular. The five stages presented in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development" have been complemented with business strategy development and innovation management phase (see Fig. 1).

In practice, life cycle phases are intertwined to each other and thereby development methods as well as requirements are also linked to each other. For instance,

C. Grefrath
Global Product Line Management, Pumps & Rotary Drilling Equipment,
MHWirth GmbH, Kölner Str. 71-73, 41812 Erkelenz, Germany
e-mail: christian.grefrath@mhwirth.com

D. Wagner (✉)
Product Management Service TLS, TRUMPF Laser GmbH,
Aichhalder Str. 39, 78713 Schramberg, Germany
e-mail: Dirk.Wagner@de.TRUMPF.com

S. Stermann
Front-Office System Planning, Transmission System Operation Brauweiler,
Amprion GmbH, Von-Werth-Str. 274, D-50259 Pulheim, Germany
e-mail: sebastian.stermann@amprion.net

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Fig. 1 Life cycle definition used as a baseline of this chapter

Fig. 2 Phase one of the life cycle model

Aurich et al. (2007) have described the product service system engineering process as life cycle management (LCM) that includes two product life cycles—manufacturers and customers. In the following sections, individual methodologies are discussed, although many of them consider several life cycle phases.

Individual methodologies which belong to one life cycle phase are discussed in the following subsections. This is just a general approach because many methodologies consider several life cycle phases.

1.1 Business Strategy Development and Innovation Management

Current management paradigms emphasise innovativeness, flexibility and agility. To be successful in an ever-changing networked business environment, companies must be proactive and innovative as well as operationally efficient (Gupta 2010). Innovation management and business development (see Fig. 2) are key elements in sustainability.

Today, companies' perceptions about sustainability are already changing. As in the past, company representatives see the potential for supporting corporate reputation, but recently, they have also come to expect operational and growth-orientated benefits in cutting costs and pursuing opportunities provided by new markets and products (Bonini and Gorner 2011). It has been even argued that there is a currently growing market for sustainability and that companies are already using sustainability to gain a position over competitors (Nidumolu et al. 2009). Thus, sustainability must be aligned also to other strategic targets of an individual company as well as targets of its network partners. If the customers are requiring sustainability and consider it critical, the companies must respond to this requirement in order to continue to compete. Furthermore, to be on top, companies must find new ways to implement sustainable development practices.

The Sect. 4 in Chap. "Requirements for Sustainable Solutions Development" does not directly form requirements for business strategy or innovation management. Still, the management paradigms are dealt with here because they form a basis for sustainable development and must therefore be considered. Because companies must be proactive and innovative as well as operationally efficient, several viewpoints regarding sustainable development must be considered and linked to strategic decisions.

1.1.1 Methods Used in Strategy Development

As mentioned before, business modelling process is overlapping with strategy development, because a business model provides a link between the strategy and operations and enables exploitation of entrepreneurial opportunities. Thus, related to the business modelling process, there are several existing methods, which can be utilised also in strategy development, for example, scenario building SWOT (Tukker and Tischner 2006), sustainability SWOT and (value) network or stakeholder analyses.

1.1.2 Methods Used in Innovation Management

Similarly to strategy development also innovation management methods are overlapping with tools supporting business modelling process. These are, for instance, *scenario analyses* and *PESTEL analysis* (political, economic, social, technological, ecological and legal). *Forecasting, backcasting, roadmapping, sign posting and customer observation* are examples of other methods which can be utilised also in innovation management and business development.

1.2 Management of Design, Planning and Development Phase

Most of product's costs are determined during its design phase (see Fig. 3). Thus, approaches regarding design and planning are important to sustainable

Fig. 3 Phase two of the life cycle model

development. However, sustainability of one product is always a limited consideration, because products are typically connected to each other, e.g. their production and use is a systemic phenomenon. Approaches of systems engineering, new product development (including product portfolio management), service development and "design for excellence" are covered here.

1.2.1 New Product Development

Portfolio management is about project prioritisation and resource allocation to achieve new product objectives for the company. It is a dynamic decision process where the list of active new products (offerings) and R&D projects (utilisation of capital and human resources) is constantly revised. One of the most referenced models for the management of the new product development projects is the stage-gate model introduced by Cooper (2000). The model proposes that product development projects are evaluated on the desired gates based on strategically important criteria.

As a very common structure of different development methodologies, "stage-gates" have been used in many development methodologies. This model subdivides the whole development process into different "stages" with set quality controls, the "gates", after each stage. The stage-gate model will be used here too as a basic conceptual model for the development methodology. Hence, the state-gate model will be described in more detail in Sect. 2 in Chap. "Development Methodology Solutions for Sustainable Solutions".

1.2.2 Systems Engineering

Systems engineering is an interdisciplinary field of engineering focusing on how complex engineering projects should be designed and managed over their life cycles. Issues such as logistics, the coordination of different teams and automatic control of machinery become more difficult when dealing with large, complex projects. Systems engineering deals with work processes and tools to manage risks on such projects, and it overlaps with both technical and human-centred disciplines such as control engineering, industrial engineering, organisational studies and project management (Haskins 2007).

1.2.3 Design for Excellence (DfX) and Design for Sustainability (D4S)

Traditionally, design for excellence (DfX) includes many forms of value, such as design for manufacturing, reliability and safety. Currently, also design for sustainability (D4S) is one of the globally recognised ways, how companies work to improve efficiency, product quality and market opportunities (local and export), while simultaneously improving environmental performance. Design for sustainability or D4S is also known as sustainable product design, and it includes the more

Table 1 Comparison of requirements for design, planning and development and current methodologies

Requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development"	Systems engineering	Product and service development	Design for sustainability
Requirements concerning complexity management, modularisation	○		
Requirements concerning configuration principles	●		
Requirements concerning design, construction, durability, in particular how the environmental, customer and social requirements can be aligned with the company's interest and economic expectations		○	●
Requirements concerning costs and benefits as well as added value		●	
Requirements concerning environmental impacts			●
Requirements concerning (innovations and) technology		●	
Requirements concerning human rights, cultures and occupational safety			●

● Fully accomplished requirement; ○ partly accomplished requirement

limited concept of ecodesign (see http://www.d4s-de.org/). The D4S guidelines state that in developed economies, these efforts should be linked to wider concepts such as product–service mixes, systems innovation and other life cycle thinking approaches. Thus, the concept of D4S embraces best how to meet consumer needs—social, economic and environmental—on a systematic way. Both incremental innovation regarding current products and product innovation regarding new product development are included.

The following Table 1 summarises the main contribution of each methodology regarding the requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development".

1.3 Management of Manufacturing Systems

This chapter deals with the different principles regarding the arrangement of manufacturing systems (see Fig. 4).

Fig. 4 Phase three of the life cycle model

One of the key concepts regarding the manufacturing phase is “sustainable manufacturing”, although also many other manufacturing principles have a strong connection to sustainability. Hereinafter, some key concepts are presented. Those are, for instance, sustainable and green manufacturing (or green supply chains). They are often used as synonymous, although some differences can be found within them. Green manufacturing focuses on environmental issues, whereas sustainable manufacturing highlights innovativeness and even new business opportunities offered by sustainability (Jawahir 2008). Thus, the concept as well as sustainability thinking in whole is work in progress. It can be hypothesised sustainable manufacturing would create greatest shareholder value (Jayal et al. 2010). This is a robust hypothesis, which can be either wrong or right depending on level or time of analyses. In the following, the manufacturing principles are covered in a chronological order starting from the most traditional manufacturing approaches. The approaches will be compared to the requirements which have been identified before.

1.3.1 Traditional Manufacturing

In this section, mass production, prefabrication and just-in-time (JIT) production are considered methodologies supporting the traditional manufacturing paradigm.

Mass production (also flow production, repetitive flow production, series production or serial production) is the production of large amounts of standardised products, including and especially on assembly lines. Prefabrication is the practice of assembling components of a structure in a factory or other manufacturing site and transporting complete assemblies or subassemblies to the construction site where the structure is to be located. Just-in-time (JIT) is a production strategy that strives to improve a business return on investment by reducing in-process inventory and associated carrying costs. Just-in-time production method is also called the Toyota Production System. To meet JIT objectives, the process relies on signals between different points in the process, which tell the production when to make the next part.

1.3.2 Lean Manufacturing

Lean manufacturing is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, “value” is defined as any action or process that a customer would be willing to pay for. Thus, lean manufacturing focuses on manufacturing phase and does not consider other life cycle phases (design, use, end of life).

1.3.3 Sustainable and Green Manufacturing

Green manufacturing focuses on environmental issues, whereas sustainable manufacturing highlights innovativeness and even new business opportunities offered by sustainability (Jawahir 2008). International Trade Administration (2007) defines sustainable manufacturing as follows: design and manufacture of high-quality/performance products with improved/enhanced functionality using energy-efficient, toxic-free, hazardless, safe and secure technologies and manufacturing methods utilising optimal resources and energy by producing minimum wastes and emissions, and providing maximum recovery, recyclability, reusability, remanufacturability, with redesign features, and all aimed at enhanced societal benefits and economic impact. On the other hand, sustainable manufacturing is defined as the ability to smartly use natural resources for manufacturing by creating products and solutions via a network of suppliers, partners and collaborators that due to new technologies, regulatory measures and coherent social behaviour are able to satisfy sustainability—economical, environmental and social objectives, thus, preserving the environment, while continuing to improve the quality of human life and remaining financially viable for the long term by returning adequate profits and growth (developed from (Garetti and Taisch 2012). This definition of sustain value project aims to highlight the system thinking and holistic view to sustainability, e.g. how value networks actors can create sustainability together.

1.4 Methodologies Regarding Ethical Sourcing, Trade and Consumerism

"Ethical sourcing" means ensuring that the products being sourced are created in safe facilities by workers who are treated well and paid fair wages to work legal. The ethical sourcing module is also a voluntary supplement for SQF 1000 or SQF 2000 Certified Suppliers.

Also other concepts, such as ethical trading, fair trade and ethical consumer, highlight social issues and global moral within decision-making. Still, as the concepts aim to influence on decision-making of individuals, they are connected also to product use phase. On the other hand, due to various political attributes, it can be stated that they are connected also to the design and development phase. The Ethical Trading Initiative is an alliance of companies, trade unions and voluntary organisations, who work in partnership to improve the working lives of poor and vulnerable people across the globe, whereas ethical consumerism is a type of consumer activism practised through "positive buying" in that ethical products are favoured, or "moral boycott", that is negative purchasing and company-based purchasing. Still, these concepts are often criticised from their Western country or brand owner origins; e.g., the programmes reach only limited number of producers

Table 2 Comparison of requirements for management of manufacturing systems and current methodologies

Requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development"	Manufacturing methodologies	Sourcing methodologies
Requirements concerning business relationships	○	●
Requirements concerning transparency of used components and goods	●	●
Requirements concerning the manufacturing of the solution	●	
Requirements concerning the value network	○	○

● Fully accomplished requirement; ○ partly accomplished requirement

or do not sufficiently consider long-term impacts to local environment in developing countries.

All principles have some overlapping approaches to sustainability. First, different manufacturing principles have been evolved during several decades—each of them highlights different aspects, such as agility, flexibility, efficiency or innovativeness of manufacturing operations. Thus, their connection to sustainability is strongly linked to the economic dimension. Secondly, ethical sourcing and trading approaches focus on the social dimension of sustainability. In Table 2, the requirements for management and manufacturing systems are compared with current methodologies.

1.5 Management of Distribution, Logistics and Services

This section considers the sustainability aspects within present methodologies related to distribution, logistics and services (see Fig. 5).

1.5.1 Green Logistics

Logistics is the integrated management of all the activities required to move products through the supply chain, from raw material to end products. Some examples of green logistics include shipping products together, rather than in

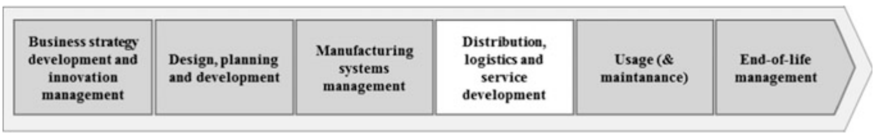

Fig. 5 Phase four of the life cycle model

smaller batches; using alternative fuel vehicles for manufacturing and shipping; reducing overall packaging; utilising raw products which are harvested in a sustainable way; building facilities for manufacturing and storage which are environmentally friendly; and promoting recycling and reuse programmes. Similar means are identified also within green distribution.

1.5.2 Reverse Logistics

The concept of reverse logistics has also been introduced within the discussion sustainability of logistics industry. It stands for all operations related to the reuse of products and materials. Reverse logistics stands the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics, and thereby, it has a clear connection to the concepts of 3R's (Reduce, Reuse, Recycle) and 6R's (Reduce, Rethink, Refuse, Recycle, Reuse, Repair) discussed in the end of life cycle phase of the report. Thus, there is also a connection between reverse logistics and customer retention. Reverse logistics has become an important component within service business development, aiming at retaining customers by bundling even more coordination of a company's service data together to achieve greater efficiency in its operations.

1.5.3 Service Operations

Service involves a provider and a customer working together to create value. Accordingly, service systems can be defined as dynamic configurations of people, technologies, organisations and information that create and deliver value to customers, providers and other stakeholders. Within the manufacturing industry, the trend of customers, lead producers and their suppliers seems to be a forward transfer in their value chains. This means that customers and lead producers outsource manufacturing and their suppliers try to increase services. Suppliers provide not only raw materials and finished products, but also transportation, energy, packaging, design and recycling services.

In the following Table 3, the aforementioned methodologies are compared with the requirements presented in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development".

1.6 Management of Usage Phase

All the requirements related to the usage phase (see Fig. 6) should be considered already in the design and planning phase, where most of product (and life cycle) costs are defined. Similarly, the requirements of usage are also relevant within

Table 3 Comparison of requirements for distribution, logistics, services and current methodologies

Requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development"	Distribution and logistics	Services
Requirements concerning training (education) and assistance		●
Requirements concerning suitable services (monitoring, inspections, consultancy, ICT solutions, etc.)		●
Requirements concerning delivery chain/networks	●	○

● Fully accomplished requirement; ○ partly accomplished requirement

Fig. 6 Phase five of the life cycle model

manufacturing phase regarding the usage of manufacturing equipment, and they are often considered also in manufacturing and maintenance methodologies.

1.6.1 Quality, Safety, Health and Environmental Management (QSHE)

As pointed out in above sections and illustrated in before, there are several management trends with overlapping concepts evolving together. Each of these management trends has their own traditions, and their modern versions also include sustainability aspects; for instance, safety management is closely linked to social and environmental dimensions of sustainability, while environmental management is clearly connected to the environmental dimension. Their focus is typically on management practices of an individual company. Spreading of quality management methods started from using statistical methods for quality control for production. Later on, a number of highly successful quality initiatives have been invented by the Japanese (for example, Genichi Taguchi, QFD, Toyota Production System). Certification according to quality as well as environmental standards is nowadays quite essential, and thereby, many quality management tools, such as Six Sigma, are utilised in companies. Furthermore, emerging management disciplines (like system thinking) are bringing more holistic approaches also to quality so that people, process and products are considered together rather than independent factors in quality management.

1.6.2 Maintenance During Usage Phase

Maintenance involves maintaining and securing the equipment and systems in, or restoring them to, a state in which they can perform the required functions. The challenge for maintenance planning is to identify appropriate objects and tasks for preventive maintenance and ensure that there are adequate resources for the repair actions (Rosqvist et al. 2009). In the literature, there are presented several maintenance programme planning methodologies. Those approaches are standard reliability-centred maintenance (RCM), business-centred maintenance, Waeyenberger and Pintelon approach and value-driven Maintenance.

1.6.3 Performance Management

Performance management is defined as the process of analysing performance-related information (generated through *performance measurement*); making decisions based on this information, planning and implementing actions to improve or maintain the state of performance; and feeding back information intended to improve the process of performance measurement. Furthermore, in order to be able to generate the information that is necessary for informed decision-making, knowledge of influencing factors on performance as well as causal relations between influencing factors and performance characteristics has to be known. Thus, organisational performance is complex and can be affected by a host of different factors.

In the following Table 4, their main contribution, in what sense known management methodologies of usage phase are supporting sustainable decision-making, is evaluated.

Table 4 Comparison of requirements for usage phase and current methodologies

Requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development"	QSHE management	Maintenance and asset management	Performance management
Requirements concerning consumption of energy, water, materials, air, land	●		○
Requirements concerning emissions and waste	●		○
Requirements concerning efficiency and intensity of usage, maintenance		●	○
Requirement concerning the continuous improvement	●	●	○
Requirements concerning safety and health	●	●	○

● Fully accomplished requirement; ○ partly accomplished requirement

Fig. 7 Phase six of the life cycle model

1.7 End of Life Cycle Management

This section considers the present methodologies regarding the end of life cycle management (see Fig. 7). Thus, the concepts related to this phase (for instance, 3R's and 6R's) emphasise the circular nature of life cycles.

1.7.1 Reverse Logistics

Reverse logistics stands for all operations related to the reuse of products and materials. It is "the process of planning, implementing and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics" (Hawks 2006).

1.7.2 From 3R'S to 6R'S

The 3R's (Reduce, Reuse, Recycle) are described as starting point of sustainability implementation programmes. The principles are the following: (1) Reduction: purchasing and using only what is necessary, (2) Reuse: find an alternative use extra materials and (3) Recycling: unused materials are transformed into new products. The focus of 3R's is clearly on environmental efficiency, although implementation of main principles (3R's) also can increase company's profitability.

In the following Table 5, their main contribution, in what sense known end of life cycle management methodologies are supporting sustainable decision-making, is evaluated.

Table 5 Comparison of requirements for end of life cycle and current methodologies

Requirements defined in Sect. 4 in Chap. "Requirements for Sustainable Solutions Development"	Reverse logistics	3R's & 6R's
Requirements concerning recyclability and reusage	●	●

● Fully accomplished requirement; ○ partly accomplished requirement

2 Gap Analysis of Existing Development Methodologies Considering Sustainability

The previous sections considered several methodologies related to industrial management in order to collect information on how they could support innovation management and solution engineering towards sustainable solutions within manufacturing networks. As pointed out before, these management paradigms have overlapping concepts and are all the time evolving together. Although there is a consensus on the importance of networks, most of the management methods still focus on individual organisations.

In the following, gaps of current methodologies are analysed based on Tables 1, 2, 3, 4 and 5:

- Methodologies in *business strategy and innovation management*:
  There are only few tools that clearly link sustainable development to strategic decisions and innovations, e.g. how sustainability can offer competitive advantage, differentiation and new business opportunities
- Methodologies in *design, planning and development*:
  The existing tools focus typically on how to ensure that strategic targets are considered during the new product (or service) development work, rather than setting the strategy, especially with focus on sustainability.
- Methodologies in *manufacturing systems development*:
  The current approaches do not cover network and life cycle aspects, although holistic thinking and integrated approaches are required.
- Methodologies in *distribution, logistics and services*:
  Similarly to manufacturing approaches, the focus has been on individual company, while service thinking highlights that collaboration with customers should be covered.
- Methodologies in *operation and maintenance phase*:
  Modern versions of management methodologies within operation and maintenance phase include also sustainability aspects, but once again the focus is on individual company.
- Methodologies in *end of life cycle*:
  Broader approaches (3R & 6R) already exist, and still network and strategic approaches within them are missing.

3 Conclusion

Existing methodologies could be used in order to support innovation management and solution engineering within the manufacturing industry—also from the sustainability perspective. All the presented methodologies are considering at least some of elements of sustainable development (see Tables 1, 2, 3, 4 and 5). Based on the gap analyses, we summarise that the present methods:

- focus on an individual company rather than a network and
- consider operational issues more than strategic thinking.

According to the gap analysis presented in Sect. 2, system boundaries must be broadened from an individual company to a value network level—and even to business ecosystem including also other stakeholders. The new methods should support actors defining what sustainability means to their solutions within their industry and to business (models) of all involved actors—both at value network and at ecosystem level. In the following chapter, the authors present a development methodology for sustainable solutions.

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