REOCCURRING CYCLIC CONSIDERATION OF END-OF-LIFE REQUIREMENTS DURING PRODUCT PLANNING

Robert Orawski[a], Clemens Hepperle[b], Markus Mörtl[c], Udo Lindemann[d]

Technische Universität München, Institute of Product Development, Boltzmannstr. 15, D-85748 Garching b. München,
Email: [a]robert.orawski@pe.mw.tum.de, [b]clemens.hepperle@pe.mw.tum.de, [c]markus.moertl@pe.mw.tum.de, [d]udo.lindemann@pe.mw.tum.de

Life cycle costs are mainly defined by the early phases of the life cycle. With the need for longer usage time and a more environmental conscious society, the final phases of the life cycle are gaining in importance. Many methods and tools (e.g. Sustainable Product Development) address sustainability aspects in these late phases. The intention of this paper is to identify how these methods take into account the early planning of products and how companies are affected by reoccurring, cyclic utilisation of these methods and tools. Through analysing different methods for reoccurring procedures and discussing them with companies, it can be stated that end-of-life requirements should be implemented systematically considering multiple projects and that planning processes of companies are missing this opportunity for better results by means of omitting implementation of the analysed methods in the early planning.

Keywords: End-of-life, Early planning, Product life cycle, Reoccurring cycles, Integrated product development, Sustainable development.

1. INTRODUCTION

Product characteristics are mainly influenced by the early phases of the life cycle. During the early planning of the product life cycle, engineers set first constraints for the later development, production, usage and recycling phases of the product. This means, decisions in this phase need to be considered carefully and with regard to the following phases of the life cycle. Due to stronger environmental regulations forcing the extension of product life-time, the emphasis is shifting from development and production costs to a holistic attention of life cycle costs, i.e. the usage and disposal phases. Thus, by the increasing emphasis on environmentally conscious product design, the end-of-life and its requirements are to be considered more strongly.

The end-of-life phase consists of potential second and more usage periods and the obligatory disposal of the product. As life cycle costs are defined mainly during the early planning, it is urgent to identify influencing factors for later phases. Research during the last years provided the early planner with a huge amount of strategic principles, approved methods and convenient tools considering the late phases and how to perform an innovation project according to sustainable parameters.

In order to increase the efficiency of the planning department, it is urgent to analyse the methods in use by the company and to distinguish parts within the methods which are to be implemented in the company with a long term view so that interconnected innovation projects benefit from an aligned procedure in the planning department.

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Therefore, the following research questions can be stated:

— How are methods and tools for consideration of the end-of-life characterized?
— How are cyclic procedures represented in these methods?
— How have companies organised their planning department and which methods are utilised?

Different points of view exist on how to describe the product life cycle. Mainly, research splits it into an economical, environmental or a process life cycle. While the environmental life cycle is the choice for estimating the life cycle costs, the latter helps to understand the stages and phases which a product has to pass through in the life cycle. Hepperle *et al*. [1] developed a model in which these stages and phases are described in detail. It is necessary to classify the effects which different phases have on each other, e.g. the end-of-life on the planning phase. Therefore, the life cycle model according to Hepperle *et al.* is used as an orientation for further research. The main phases are structured into product planning, product development and design, production, distribution, utilisation, modernization lifecycle and product disposal. Production process preparation and maintenance are side processes which should be left out in the following, because the focus of the paper is product related.

While the consideration of a single innovation project is returning limited results and disregards the implications of a long term view, the focus in the early planning should address procedures and activities which are interconnected among multiple innovation projects. This work deals with procedures and activities proposed by methods and tools for the early planning dealing with end-of-life requirements, the reutilisation and disposal of products. A literature review of the state-of-art was conducted and identified methods were examined for their activities which are performed several times through each innovation project in which the method is employed. The results were then presented to 12 experts from early planning departments during semi-structured interviews. The results of the analysis of the literature and the feedback by the industry identified reoccurring procedures and activities during product planning. The reoccurring nature of these activities should be considered by each application and their results are to be adjusted for consideration of long-term effects.

2. METHODS

With the problem at hand how to handle the end-of-life during the product planning, there was first analysed, which methods and related approaches are currently available in the scientific community. After the choice of a representative and convenient example according to the research questions, an interview guideline emerged out of the identified characteristics of the chosen method. Later interview partners from the industry were confronted with the summarized guideline during a semi-structured interview. Topics were the end-of-life consideration in the planning processes. The responses from the interviews were then analysed in which extent the end-of-life has an impact on product planning in the various industries.

2.1. State of the Art

The search for related literature began with a differentiation of the end-of-life topic as its view combines modernization and disposal. In both fields, there is a numerous amount of literature developed. Therefore, we classified the identified items into following subjects and chose a representative example for further investigation and basis for the interview guideline:

— observed life cycle phase
— Influenced life cycle phase
— Concretization level
— Process or product related

These items were identified as major classification criteria for organizing the numerous methods and tools during the literature review. It also provided the possibility to choose the method for preparation of the interview guideline.

The criterion 'observed life cycle phase' deals with the life cycle phases from which the requirements are derived from. Each phase has its own set of requirements to be considered during the planning and design of a new product. E.g. the production addresses different requirements on size and modularity than the utilisation phase.

The criterion 'influence life cycle phase' is the important classification whether the observed method is relevant for the early planning. There are methods which deal with the considered final life cycle phase, but give support for handling these requirements in a different phase than the planning phase. E.g. DfX guidelines put their emphasis on the development and design phase and are only partly supportive for the product planning in which the focus is set on more general coordination of constraints than on a specific design parameter.

The criterion 'concretization level' addresses the level of advice which is given to the planner and is distinguished between a strategic level and a concrete designing geometry level. E.g. Strategic principles for the planning process differ from DfX guidelines.

The criterion 'process or product related' divides the focus of the considered method. Process related methods focus on the way how the planner can improve his effectiveness. Product related methods give advice on the project at hand and how to improve the characteristics of a product. E.g. the Framework for Strategic Sustainable Development gives a systematic approach on how to structure the sustainable Product Development. Ecodesign concentrates on the product and how to achieve environmental conscious product design.

2.2. Interview guideline

The interview guideline was developed as a preparation for following interviews with representatives from planning departments in different branches of the producing industry. It was used mainly for two purposes:

In the first place, it provided a structure for the interview, which helped the interviewed persons to prepare for the actual discussion and to address the identified items in the interview itself.

Secondly, it was an essential tool for providing a comparable leitmotif for the later interpretation of the interviews.

After having identified the representative examples by the literature review and their classification, we analysed the suggested approaches concerning impacts on the planning process. An important issue was to detect direct or indirect instructions for the planning process. These were gathered and summarized into an interview guideline.

Apart from initiatory questions regarding describing factors like size and general description of the company, its products and their individual life cycle, the prepared interview guideline consisted of following topics:

- Differentiation of customer groups regarding separate utilisation phases like second-and third-hand users.
- Consideration of a modernization cycle already in a planning phase of a new innovation process.
- Given processes to include the disposal phase into the planning phase.
- Differentiation of different disposal ways like open- or closed-loop recycling.
- Reoccurring processes derived from strategic principles, applied methods and tools and proposed procedures and activities within.

2.3. Interviews

The interviews were held with representatives, each of them but one with numerous years of experience in his and her field of occupation, from several different branches which were in particular (occupation of the interviewed person in brackets) automobile (Chief Operating Officer Innovation and Head of Concept Development), aeronautics (Chief Operating Officer Innovation), plant manufacturer (Innovation Manager), medical equipments (Product Line Manager and Manager Strategic Marketing), house appliances (Deputy Director of Development), textile industry (Innovation Manager and

Innovation Manager), freight transportation industry (Division Manager Innovation and Innovation Manager), and packaging industry (Manager Development Decisions). Thus, the characteristics and challenges of each planning process differed from each other. The reasons for choosing these branches were for the purpose of analysing a diversified product portfolio in order to obtain different points of view on the planning process and the utilised methods therein.

The interviewed companies and their representatives were:

- The According to the interview guideline, the semi-structured interviews were recorded on tape.
- The documentation of the interviews was either transcribed and then passages were structured according to key words or immediately structured by bullet points according to the same key words.
- Thereafter, the documentation was compared to the analysed approaches from the state-of-the-art.

3. RESULTS

Literature review has shown a vast consideration of sustainability methods and tools. Nevertheless, the subject of sustainability covers a broad field during the life cycle and deals with all the phases of a life cycle. Further, each phase is addressed on a different concretization level. This leaves room for different specializations. This work contributes to an overview of state-of-the-art methods and tools and examines their different characteristics according to planning interests. It turns out that there is a focus on the designing phase which shares just a few responsibilities with the planning department of a company. Thus, it can be stated that each method should be carefully analysed when it comes to the decision whether to implement a representative of the end-of-life concerned methods and tools.

3.1. Literature

The examined literature consists of several methods and tools, which were published in the last 20 years since sustainability gained a wider interest in the scientific community.

First approaches and characterization of sustainable product development are examined by van Weenen [2]. He states that elementary needs, life cycle design, product systems, product durability, long-term resource availability and natural compatibility would be central to a concept of sustainable product development. This underlines the approach of this paper in which the interconnectivity of life cycle phases on different concretization levels is expressed.

For supporting the decisions along the presented methods, Life Cycle Assessment (LCA) [3] is a well documented and often applied method in companies. LCA provides the planner and designer with information about the environmental impact level of a product from ‘womb’ to ‘tomb’. In combination [4] with Life Cycle Cost Analysis [5], the planning procedure has two powerful methods for evaluating old products and gives advice to the designer how to change the characteristics of the product at hand.

An early overview of approaches concerning the incorporation of environmental issues in product design provides the orientation along the numerous publications [6]. The main category for approaches is their focus and is dealing with single product life cycle stages, complete life cycles and a view beyond the life cycle. Even later developed methods and tools can be categorized in the proposed scheme and should be utilized in this paper.

In the following, a short description of the examined examples will explain the main differences between them and a summary will assess the differences with help of a table.

A practical framework for planners and their agenda for environmental management was proposed by Tibbs [7] and further developed by Ehrenfeld [8]. It consists of seven elements which cover the system constraints for a new product project:

1. Improving industrial processes and materials use
2. Creating closed-loop ecosystems within the company and their supply chain
3. Dematerializing industrial output
4. Systematizing energy use
5. Regarding the ecosystem capacity by a balanced industrial input and output

6. Integrating company policies to conform to long-term goals
7. Aligning structures, communicative linkages, and information within the company

The Reverse Fishbone Diagram [9] includes a strategy for product retirement planning. It estimates the disassembly and reprocessing costs for further consideration in the design process. This rating process is mainly done during the designing process and therefore, lacks the correct emphasis along the product life cycle according to the focus of this paper. Nevertheless, it is important to examine such tools for their applied retirement plan. Important characteristics for the identification of end-of-life strategies [10] are to be taken into account during the planning phase. It provides the planning department with information about how disposal procedures look like. This can be an advantage in proposing a long-term strategy and cost-reduction for the company and a support for the aligning of several parallel development projects.

Design for X guidelines pose a special group of methods and tools influencing the planning process. As the term 'Design' already states, the focus of these guidelines lay along the development stage of products. Nevertheless, each guideline [11] requires information from the planning process. Without the specific preparation of this information, the designer is not able to utilize the guideline or will do it insufficiently. Beitz [12] for example states that already in the requirement list, there is a section necessary about the given recycling procedure, which again is already drafted earlier in the planning phase. Other guidelines examples [13–19] require similar prepared information.

The Framework for Strategic Sustainable Development (FSSD) [20, 21] describes a way how companies can change towards behaviour of sustainable consciousness on five different levels:

— The systems level defines the constraints of the system in which the company is involved.
— The success level describes the principles of the followed vision towards sustainability.
— The strategic level gives strategic advice for achieving the vision of the company in balance between sustainability and economic key factors.
— The action level provides activities in order to achieve the strategic goal.
— The Follow up/Tools level provides methods, tools and concepts for supporting the activities.

These five levels are interconnected with each other and describe advice on different concretization levels for achieving a higher level of sustainability.

The FSSD is supported by a practical implementation according to Ny *et al*. [22].

3.2. Interview guideline

The examined methods were characterized according to the characteristics enabling the differentiation between planning focused methods and implicitly touching the planning phase in their advice how to deal with end-of-life and its requirements. The overview in Table 1 shows these characteristics and their value.

The method FSSD was chosen as the best example for preparing the interview guideline. The deciding factor was the level of detail. With the high detail level on different levels of concretization, FSSD provides the best starting base and a feasible link for an interview with companies. It has to be considered that the chosen interview partners differ in their experience level in the planning phase and its attached processes. Additionally, the background of the companies varied in branch, size and company culture. The latter is a strong impact factor for the know-how concerning sustainability methods and its implementation in the organizational process structure of a planning department.

3.3. Interviews

The system and structure levels of the examined products are of special interest as they tend to be a long-term setting. End-of-life observations tend to be emphasized differently among the interview partners. One reason is the different background of the companies and another is the difference in characteristics among the provided products. Nonetheless, they are still addressed in the companies.

Table 1. End-of-life methods and tool and their characteristics.

Method	Framework for Environmental Management	Reverse Fishbone Diagram	DfX/ Ecodesign	FSSD
Author	Tibbs	Ishii and Lee	Various	Robèrt
Observed life cycle phase	Holistic industrial ecosystem	Retirement Retirement	Several for each phase	Holistic industrial ecosystem
Influenced life cycle phase	Planning, Development Production,	Planning, Development,	Development, Development,	Planning, Development
Concretization level	Strategic instructions	Working tool	Specific instructions	Strategic to working tools
Process or product related	Process	Product	Product	Process

Practicable methods are still focusing on the design process of products. The structured and combined use of methods for the early planning tends to be missing in companies.

Work on the multi-project-level is in place, but the key factors for monitoring the achieved results in planning have traditional character like costs, time and quality. They tend not to be connected to sustainability principles and if so, then just implicitly.

It varies between the companies how much end-of-life requirements are addressed. Overall, all companies take legal guidelines into account, but these are varying among different branches. On the one hand, the automobile branch must provide a recycling level of 95% in a complex product which needs to be achieved by the manufacturer by huge effort and costs. Household appliances are considered to finish their product life in a shredder and are therefore not regarded too hard to dispose.

Finally, it can be stated, that companies are missing a well structured and interconnected sustainability strategy and following the minimal legal requirements in life cycles.

Thus, reoccurring cyclic consideration of different strategic principles, methods and tools are absent. Hence, synergy effects from structured processes which go hand-in-hand on different levels of concretization are missing in the greater part of the interviewed companies.

4. CONCLUSION

Taking the late life cycle phases modernization and end of life into account during early planning activities, contributes to the overall success of the product. The planner needs to be aware of the importance of situations a product will face after the first use and that these affect the economically successful company. This has been shown in various publications on this subject shown earlier in this paper.

End-of-Life consideration is a heterogeneous point of view. Reutilisation and Recycle phases exist of different challenges and have to be analysed separately, especially with regard to different backgrounds of a company. Reutilisation-oriented companies face the challenge of higher life-cycle costs during the long-term utilisation. Therefore, methods like Design for Reparability are appraised higher. Recycle-oriented companies have to handle the costs at the end of the product life cycle. Design for Disassembly is a method which reduces the costs of the company. Nevertheless, recyclable products need the infrastructure for disposal which is rather a concern for the product planning. As an overall goal, product planning needs to identify the lifecycle related requirements for the product development on a multi-project level.

Although, there is a controversial discussion [23] regarding the success in developing sustainable and environment-friendly products, taking into account the end-of-life perspective and laying a focus on its requirements are essential steps towards gathering interdependencies among product-influencing aspects and their effects on the product planning phase. It should be regarded as a part of the holistic consideration of all the phases for a sustainable product life cycle.

Nevertheless, the huge amount of approaches, methods and tools covers several points of view. Beginning from the point of time in which the contribution is utilized up to varying requirements of

different aspects during late phases, the planner needs to keep in mind a differentiated view of the end of life. This implicates numerous cyclic reconsiderations of different process levels in product planning and the multi-project view.

Additionally, different concretization levels within the contribution address either broader aspects like the general strategic planning or the detailed consideration of a given recycling system. Thus, the planner has the choice to use exactly the method according to the level of information which is needed.

This needs to be taken into account by the interviewed companies. Cyclic behaviour and the related synergy potential for planning departments are considered on a narrow dimension as considering just the recycling phase is an insufficient way of implementing sustainable principles.

In summary, it is found, that end-of-life requirements need a constant review during product planning, each reoccurring innovation project, on different concretization levels of the requirements. Thus, it is essential to consider the requirements on a multi-level approach and to adjust them to strategic sustainability principles the company is following. The interviews have shown that there are different ways of dealing with the existence and importance of end-of-life requirements. Therefore, the cyclic consideration needs to be adjusted for the background of each company, though not omitted at all.

4.1. Outlook

Having defined the process peripherals for utilisation of a specific method in order to address the requirements of a life cycle phase like disposal, it is essential to introduce also the guideline for the proper handling of requirement conflicts between different phases. Normally, this implies several cycles of alignment in order to achieve the final version of the requirement list. Thus, further research will focus on the interdependencies between the life cycle phases and their cyclic alignment process. Thereby, there is potential in the introduction of new methods for the engineer's ease in dealing with different origins of requirements.

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