# Lifecycle oriented planning of mechatronic products and corresponding services

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**Abstract.** The complexity of a mechatronic Product-Service-System (PSS), as a combination of products, IT-components and services, requires a profound system's understanding already in the early phase of the planning process. For a lifecycle oriented planning the different lifecycles of the subsytems and their interrelations with regard to context and time, as well as overlaps through the introduction of a new generation or a facelifted version have to be considered and predetermined. In this paper a framework, based on various existing lifecycle models, is presented to analyze and to deal with these different lifecycle constellations. The framework addresses both the description and temporal representation of singular lifecycle phases in the context of the overall PSS-lifecycle as well as lifecycle constellations of subsequently following PSS-versions.

**Keywords:** Integrated product development, Product-Service-System, Product planning, Lifecycle model, Temporal patterns

## 1 Introduction

### 1.1 Motivation

Producing companies focused for a long time on the production of innovative and high-quality products. In the global economic system however, manufacturers in developed countries can hardly compete with the price level of emerging economies [1]. In order to justify surcharges, companies have to offer their customers additional value [2]. By extending the product to a Product-Service-System (PSS), consisting of the product, IT and services, manufacturers can offer a more sophisticated solution to the customers' requirements and thus achieve a significant advantage.

For the planning of a future PSS the anticipation of the entire lifecycle is essential in order to react fast on external influences and to adapt company processes and the PSS itself to changing conditions and parameters [3]. A mechatronic PSS can be divided thereby into several subsystems with respective lifecycles and temporal aspects that have to be considered. By taking these sub-lifecycles into account during the planning of a future PSS, diverse interrelations can be detected. Next to the lifecycle

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constellations through the different PSS-elements, further overlaps occur when one PSS-version is replaced by a new one or if a facelifted version within one generation is introduced. A systematic introduction of new PSS-versions at the right point of time can account considerably to a company's profit, while a delayed as well as a premature introduction result in increased costs or loss of market shares [4]. Therefore a framework is presented in this paper to explore and visualize the lifecycles of the individual PSS-elements and their interrelations, as well as the constellations and overlaps occurring through updated versions and successive generations.

### 1.2 Background and objectives of research

An integrated lifecycle perspective of PSSs that shall be launched by a company is essential. That means, lifecycle phases from the development and production throughout to the phases of utilization and recycling as well as their temporal constellations should be considered. For example, looking at the singular lifecycle phases, each phase is characterized by its duration. Furthermore, taking subsequently following PSS-versions and adaptations into account, different frequencies can be observed in launching PSSs. As the earlier launched PSSs are still in use and on the market, parallel running lifecycles have to be considered. These examples show that manifold lifecycle constellations occur and have to be considered to plan future PSSs and corresponding resources adequately. Thereby it is also important to analyze at a very early point which factors influence the future PSS and when successive generations should be introduced. In the strategic, cycle-oriented planning these issues are considered systematically by using appropriate forecasting methods and by transferring these results to the development of the respective PSS. In this way the reliability of the planning can be increased, resulting in more efficient processes and significant competitive advantages, such as cost reductions and a higher quality of the PSS. A detailed planning and transparent presentation of the future PSS-lifecycle helps furthermore, to react more flexible on concrete market requirements.

Literature provides many models of product, IT and service lifecycles. However the described complexity in the lifecycle-oriented planning of PSSs, the influences of one discipline on the others, and the associated necessity to anticipate the lifecycles of all PSS-elements and their constellations can be solved insufficiently with current planning methods. Models for the singular lifecycles are often too detailed in the context of PSS-planning and do not specifically consider interrelations to the other existing PSS-elements. Thus, it is necessary to provide a framework for a lifecycle-oriented PSS-planning which allows an integrated and more detailed understanding and better visualization of the PSS-lifecycle constellations than existing models do. Therefore, based on various existing lifecycle models in literature, a framework for the analysis of PSS-lifecycles is presented in section 2. The framework describes and shows graphically the lifecycle phases of the different PSS-elements in context of the overall PSS-lifecycle and sets the cycles of each PSS-version in relation to successive versions. In this way intra-generational as well as inter-generational relations between the PSS-elements with regard to context and time can be identified and analyzed.

The developed framework can be used on the one hand as a tool to consider lifecycle constellations in the planning of a concrete future PSS. On the other hand, the framework establishes the basis for further research on cycle-oriented planning and on the consideration of temporal aspects in PSSs.

Summarizing the paper, conclusions are drawn in section 3 and an outlook on future research is given.

# 2 A framework for the analysis of successive PSS-generations

## 2.1 Lifecycle models in literature

In order to set up a framework for the visualization of the PSS-lifecycle and its constellations various lifecycle models from the single PSS parts as well as integrated models have been analyzed concerning their information about contents and duration of singular lifecycle phases and their relation to other phases or other elements.

In a first step the product lifecycle was analyzed in detail. Next to the economic product life cycle [5] and the extended economic lifecycle [6], which divide the lifecycle into phases according to the economic value of a product, especially models which focus on product states have been considered. According to the different scopes of research, existing models focus on certain parts of the lifecycle; while Ehrlenspiel et al. 2007 [7] analyses the lifecycle of a system and necessary information feedback from one phase to the others, the “Design for X” guidelines [8] focus on the influences and the interrelation of a certain product characteristic or lifecycle phase on the entire lifecycle, such as “Design for recycling” [9]. An aggregated reference model, deduced from the variety of existing product lifecycle models, is described in [10].

Software lifecycle models, such as the waterfall model [11], focus on the steps of development and design of software. The IT of a mechatronic PSS however consists of software and software-near electronics and thus software models only can be used partly. The management of an IT-project over its entire lifecycle, including an update cycle, is described by Zarnekow et al. 2004 [12].

The service lifecycle is divided by Ramaswamy 1996 [13] into the two main phases “Service Design” and “Service Management” with several sub-phases. More sophisticated service lifecycle models can be found in [14] and [15]. A very detailed subdivision of the phases “Start-up”, “Concept”, “Implementation” and “Monitoring” is made by Schneider & Scheer 2003 [16].

The models of the different PSS-components, described above, are practical to gain an overview which lifecycle steps are relevant in the different sectors. In order to identify interrelations between the lifecycles of the different elements, integrated lifecycles models were identified and analyzed in the next step.

Potts 1988 [17] and Blinn et al. 2010 [18] describe the duration of the service lifecycle in comparison to the economic product lifecycle. Aurich et al. 2004 [2] describe the PSS lifecycle phases from the view of a manufacturer and from a user. While a customer only concentrates on the steps “purchasing”, “usage” and “disposal”, the manufacturer has to take the product and the service lifecycle into account, which are run through parallel. While most models focus on certain phases of the

PSS, the “integrated lifecycle model of PSS” by Hepperle et al. 2010 [19] covers the phases of PSS planning, development, production, delivery and decomposition.

The PSS models shown above have a generic character regarding the physical product. When focusing on mechatronic PSSs the IT-components have a significant influence on the PSS lifecycle. The development phase of a mechatronic product and the necessity for a mutual communication and coordination between the disciplines is described in [20] and [21].

Next to the lifecycle of one PSS-version, lifecycle constellations that occur through the introduction of a new product generation and through facelifts were researched. Zaggl 2000 [22] shows that post-use services of one generation are still offered during the market cycle of the next generation. An essential question for the introduction of a new generation is the optimal timing of its launch and the deletion of the old generation. Factors influencing the time to launch can be intended or unintended by the company, as described in [23]. Saunders & Jobber 1994 [24] give a detailed overview which phasing strategies can be used for a switch of the product generation. The chosen strategy has influence how long the two generations are sold parallel.

The influence of the introduction of facelifts on the entire lifecycle is discussed scarcely in literature. Ryan & Riggs 1996 [25] extended the economic product lifecycle to the “Five-Element Product Wave”. Thereby the activity level of the cycles “Design Engineering”, “Process Engineering”, “Marketing”, “Production”, and “End of Life” are described for a first model (referred to as “A” version) and a following facelift (referred to as “B” version). A scheme, which shows the lifecycles of successive product generations as well as the facelifts within one generation, was presented by Hepperle et al. 2011 [3]. The lifecycles were divided very abstract into development, production, utilization, and recycling. This scheme provides a good basis for the visualization of successive product versions, but does not include services or IT.

Phaal et al. 2004 [26] describe technology roadmapping, which is used for the development, presentation and communication of strategic plans and shows the development of a technology in a time-based graphical diagram. However, the visualization of single lifecycle phases and PSS specific constellations are not discussed.

Thus, a division of PSS-lifecycles into the cycles of their subsystems and an analysis of the PSS individual lifecycle constellations can be carried out insufficiently with current methods. While the economic lifecycles give information about profits and loss of the PSS at a certain point of time and thus indicate the economic useful duration of the lifecycle, lifecycles with regard to product states and working phases show the single working phases of each PSS-phase in detail and examine the interrelations between the PSS-steps, but do not include a temporal reference.

### 2.2 Framework for the analysis of PSS-lifecycle constellations

The visualization of the framework for the analysis of PSS-lifecycle constellations is shown in Fig. 1. It distinguishes the PSS-elements “Development Product”, “Development Services”, “Development IT”, “Pre-Production”, “Production”, “Distribution”, “Utilization Product”, “Utilization Pre-use Services”, “Utilization Services during product use”, “Utilization Services after product use”, “Utilization IT” and

“Disposal” for each PSS-generation as well as for facelifts within one generation. These elements are based on the superordinate cycles of the integrated PSS lifecycle of Hepperle et al. 2010 [19] and were extended if necessary. The main objectives of the framework are the analysis of the different cycles of a PSS, the identification of influences of a cycle on other cycles, and the visualization of the different PSS-cycles in a time-context. Thereby each element is characterized by its starting point and its duration. In order to calculate these attributes certain input-values have to be defined by the user PSS specifically. In the early phase of planning of course not all cycle times can be determined yet definitely, as they are not influenceable by the company (e.g. utilization time, availability of new technologies) or not yet predictable (e.g. delays in production or distribution), but the reflection of estimated cycle times can be used as a basis for the identification of appropriate planning approaches and for the synchronization of future PSS generations.

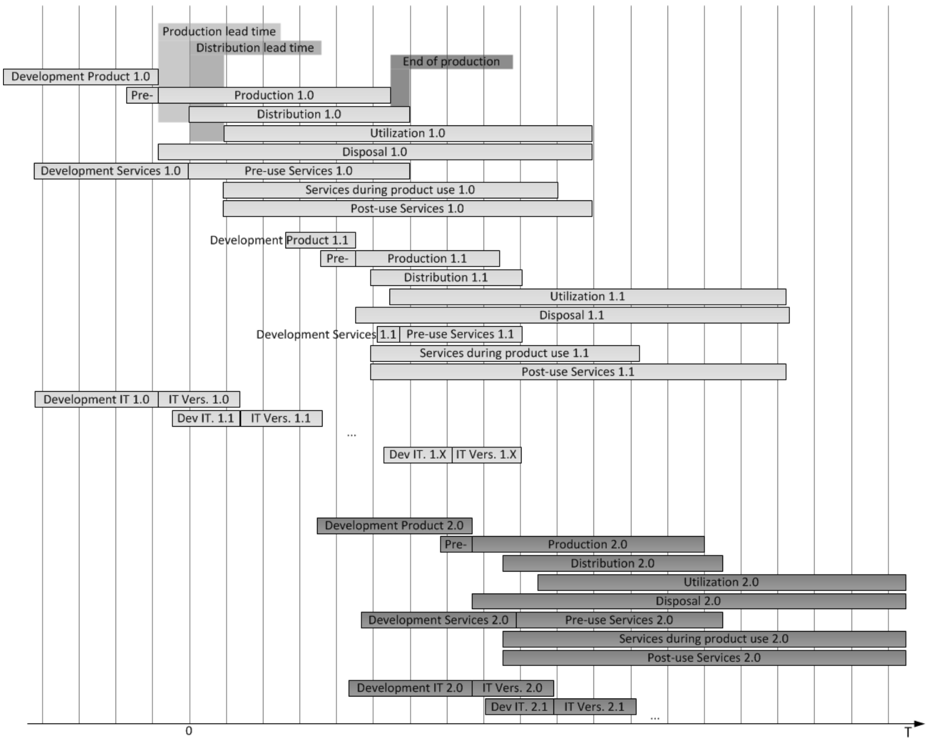


**Fig. 1.** Extract of the lifecycle-visualization of two PSS generations, including a facelift

For a definition of the starting point and the cycle time of the different PSS-cycles, the following 15 input values were identified, based on existing literature partly described in section 2.1, and included for the positioning of the elements in the framework. Each input value can be set by the user for every PSS version separately or, if appropriate, can be kept constant over each generation or over the entire PSS.

The “development time of the product” is a complex process and often makes interdisciplinary teams necessary [27]. The total time that has to be considered for the development phase of the product, reaches from target identification to the date at which the product is produced for the first time for commercial sale [28].

Parallel to the development of the physical product the service part of the PSS has to be designed and the “development time of the services” has to be defined. The tasks include the “Definition of requirements”, “Creation and evaluation of design concepts” and “detail design of service”. Furthermore the service implementation has to be planned and prepared [19]. A constant communication with the product development team is essential as the product design has a significant influence on the technical services (e.g. maintenance or spare part supply) and vice versa [2].

Due to the fast technological progress of IT, the supply of spare IT-parts is a big challenge and has to be considered already during the development cycle. While new IT-hardware should be introduced in correlation with a new product version, software updates can be developed and introduced more frequently if an appropriate interface is installed in the product [29]. Thereby the service intervals of the product have to be taken into account or possibilities for a remote update have to be implemented.

In the “pre-production” phase the results from the product development are transferred to physical production. For complex systems this is carried out in several steps. The pre-production steps, especially in the automobile industry, are summarized as pilot series and consist of a “preproduction series” and a “zero series” [30].

After the development and the pre-production are completed, the product is ready for series production. At this point the first product for customer use is manufactured and thus is often referred to as “Job No. 1” [30]. The “production lead time” defines the time between the start of serial manufacturing till the product can be distributed.

The “end of production” parameter defines the time between the end of the distribution of a current product version and the end of its production. Depending on the production process and the strategy of the company the end of production can lie before or after the distribution end.

The “distribution lead time” defines the period between the sales of a product (e.g. when the contract of purchase is signed) and its initial use (e.g. after it has been delivered and installed), thus the “utilization cycle” is shifted back in the PSS lifecycle.

One of the key factors in lifecycle oriented PSS planning is the “distribution time” of the product. A too early launch can result in high costs and cannibalization of sales of the previous generation. On the other hand a delayed introduction gives competitors the chance to capture market shares and does not utilize fully the customers’ willingness to pay to receive an up to date product [31]. Multiple factors can influence the time of launching a new version, intended or unintended by the company as described in the framework by Hepperle et al. 2010 [23].

The “distribution overlap” describes the time in which an old and a new product version are offered parallel. Thereby the used phasing strategies [24] have a crucial influence on the duration. Facelifts usually contain only superficial changes or design updates and thus a fast switch is aimed.

The “utilization time of one product” is hard to predict as a product failure can occur randomly. The expected average technical lifespan of a product version is indicated by the failure rate, which is identified statistically [32]. The time in which it is economically reasonable to maintain a product is referred to as economic lifespan [32]. The economic lifespan of a product is important in lifecycle oriented development, because the customer on the one hand expects a product with a long lifespan. For the producer on the other hand the utilization time indicates the period in which after sales services can be offered [33].

The "utilization time of the IT" has to be considered in accordance to the utilization cycle of the physical product. While the electronic components have to be introduced in coordination with a new product version or can be exchanged during servicing, the software can be updated more frequently.

The offered "disposal time for customers" is influenced by external context factors, such as environmental legislation on the "polluter pays principle" [34] or the potential value of returned products. Next to the disposal time for customers, products also have to be disposed already during the production (e.g. through manufacturing errors) and thus prolong the entire "Disposal" cycle.

"Pre-product-use services" are services offered before purchasing a product (pre-sales services) and those that accompany the purchasing process [35]. The cycle of pre-product-use services thus begins before the first unit is sold and ends with the sales of the last product of this version.

With the beginning of the product utilization cycle the "services during product use" are offered to the customers. Next to standard services, such as guaranty, maintenance and support [35], further services during product use often form an essential part of a PSS [36]. Thus the duration of the cycle "services during product use" is strongly interlinked with the product utilization cycle.

"After-product-use services" are related mostly to the disposal of the product. For companies that offer after-product-use services on a voluntary basis the decision of quitting these services can be made upon profitability, while other companies are forced by law to offer disposal services for the products they sell.

The definition of each input value, described above, poses the biggest challenge in the usage of the framework. Thereby experts from different parts of the company have to contribute their estimations on future cycle times. Each input value influences the lifecycle of one or more elements of the PSS. While the duration of some elements is determined directly through an input value (e.g. post-use services), the position or the duration of other elements arises from calculation methods, including numerous input values. For example the production lead time and the distribution lead time do not appear directly in the results of the framework but are considered in the position of the production cycle and utilization cycle respectively.

The overall starting point is set to the beginning of the distribution cycle, in accordance with the economic lifecycle [5]. In context to this point all other PSS-elements are positioned according to the input values. The input values "Production lead time", "Distribution lead time", and "End of production" are included in Fig. 1. to visualize their influence on the positioning and duration of the respective cycles.

In order to carry out a customized planning of a mechatronic PSS and consider company and system specific time horizons the framework was embedded as a software prototype. The calculated results are presented in the form of a road map (as shown in Fig. 1.), which shows the development of the PSS and the (temporal) interrelations between the different elements in a time-based graphical diagram.

The resulting framework describes and visualizes for every version of a mechatronic PSS the cycles of each PSS-component during the development, market cycle, and after sales cycle. The focus lies on the identification of interactions between the different elements, which can be analyzed further during the planning process and possible unintended overlaps can be eliminated already in the early planning phase.

## 3 Conclusions and future work

Lifecycle oriented planning of mechatronic PSSs requires a profound knowledge of the lifecycles of the product, IT, and services as well as their constellations over successive generations. The framework presented in this paper supports the planning process and enables the visualization and in-depth examination of these elements.

Based on various existing lifecycle models in literature a framework has been developed, which on the one hand takes the product-, IT-, and service-specific factors into account and incorporates facelifts as well as successive PSS-generations, but on the other hand keeps an appropriate level of abstraction in order to facilitate the handling of lifecycle constellations during the planning process.

For each element of the framework several input values have been defined. Their origin and influence on the lifecycle of the respective element have been described in detail. Building on the input values, the beginning and the duration of each cycle within the PSS can be defined. For an analysis of the lifecycle constellations and for a better communication of the PSS-plan, the results of the calculations are expressed in a graphical form. This PSS road map forms the fundament for further planning steps and visualizes temporal overlaps of the different PSS-elements of successive generations. A reflection of the identified overlaps in the created road map reveals potentials for optimization of the positioning and length of the cycles of the PSS-elements before the actual product, IT, and service development begins.

Concerning the number of considered elements, further research will be conducted on the appropriate level of abstraction. As it was the goal to create a visualization of the single lifecycle elements of a PSS, the number of implied sub-cycles was limited. In practice however, it can become necessary to examine the sub-elements of a certain PSS-element in detail, as their cycles may vary strongly. For example the generation of principle solutions in the product-development process may require most of the time. By identifying this time-consuming sub-element an optimization of the development cycle can be carried out more precisely and efficiently. Next to the cycles of the different PSS-elements other cycles and context factors will be included in the framework. Context factors in the fields of “Technology/knowledge”, “Socio-economics”, “Politics/legislation” and “Resources”, as described by Langer & Lindemann 2009 [37], could be visualized by the point of time when they come into effect or by their duration. Thus, the introduction of future PSS-versions can be aligned more effectively to crucial context factors and to the PSS introductions of competitors.

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