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SUITABILITY OF PRODUCT DEVELOPMENT METHODS FOR HYBRID PRODUCTS AS BUNDLES OF CLASSIC PRODUCTS, SOFTWARE AND SERVICE ELEMENTS

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ABSTRACT

The requirements engineering of hybrid products is an important field that still has a paucity of investigation to date. This paper analyzes the suitability of product development methods for the requirements engineering (RE) of hybrid products. The strengths and shortcomings of these methods regarding hybrid products are stated and fields of improvement are derived.

To successfully differentiate from competitors, classic products are no longer sufficient. Therefore, many companies offer holistic solutions to customers' problems. These solutions consist of bundles of classic products, software and services called hybrid products or product service systems (PSS). Hybrid products are characterized by a high number of components that are developed by different disciplines, by a high degree of technological integration and by a high degree of customer-integration. Due to their unique characteristics, hybrid products need holistic handling. Especially interesting is the specification and handling of the requirements for hybrid products called requirements engineering. This phase of the development process is very important for the later success of the product.

The characteristics of hybrid products were thoroughly analyzed, and requirements of the RE for hybrid products were derived. A structured literature review was carried out to find the state-of-the-art of RE in product development including common textbooks and publications on respected conferences and journals in product engineering. In total, 15 textbooks, 79 journal articles and 137 articles of conference proceedings were analyzed. This provided the state-of-the-art of RE indicating the approaches used. An important aspect of the research was the matching of these approaches to the requirements defined earlier. This resulted in a list of 13 fields of RE presenting the strengths and shortcomings of the approaches in detail from which two major fields of improvement could be derived, those which need to be addressed in practice.

The results show that RE for hybrid products has special needs, particularly in interdisciplinary cooperation and customer integration. The methods for RE in product development are well elaborated upon, but need to be adapted to hybrid products. There is a need for further analysis and integration of RE into the overall development process of hybrid products, as well as further development of hybrid products in practice.

1 INTRODUCTION

Today, companies deal with the many challenges of shortened development time, increased quality requirements and increased competition, thus forcing companies to differentiate themselves from competitors [2, 3]. Differentiating by classic products is no longer sufficient to satisfy the market [3, 4]. This is due to the fact that customers today demand "a product, which solves a potential problem, fulfills the customer needs and provides a benefit for the customer" [5]. In response, many companies focus not only on the development of classic products, but also on offering solutions for solving customer problems [3, 6, 7]. As a result, integrated bundles of product- and service-elements have emerged [3, 8-10] called hybrid products (also called PSS – Product Service Systems) [3, 9, 11, 12]. A product can be a classic product or software, or a combination of the two elements.

Both in the literature and in practice, products and services are developed and handled separately [3, 13]. The development of a hybrid product needs holistic handling [3]. Especially interesting for us is how the requirements of hybrid products are elicited and managed during the development process and also after the development has been completed.

Requirements Engineering (RE) is understood as "the process of discovering the purpose [of the system in development], by identifying stakeholders and their needs, and documenting these in a form that is amenable to analysis, communication, and subsequent implementation" [14]. RE is an important and crucial phase in the development process [15-17]. Several studies purport that between 40% and 60% of errors in software products can be traced to faulty RE [18, 19]. Similar studies are available in engineering [20] indicating that 40% of errors can be traced to faulty requirements. For the success of a product on the market, it is important to understand customer wishes. In the development of medical devices, about 30% of project time is spent on eliciting the requirements [21]. The RE is therefore of immense importance in getting the requirements right [22]. Especially for hybrid products, RE plays an important role because of the integration of many disciplines with different background knowledge of RE in the development process.

The rest of this paper is organized as follows. The next section provides a background for the special characteristics of hybrid products. Section three outlines the requirements of the RE-process for hybrid products. The fourth section describes the method used to analyze the RE approaches taken in different disciplines in the literature, and then to check the applicability for hybrid products. As the main focus of this paper, the fifth and sixth sections focus on the analysis models and the RE structures according to the RE phases, respectively. In the seventh section, the findings are reported, showing how RE methods of product development can be applied to hybrid products. The final section reviews the groundwork for integrating the RE process of the three disciplines that are relevant for hybrid products.

2 CHARACTERISTICS OF HYBRID PRODUCTS

In order to analyze whether specific concepts of the requirements' handling in the product development are suitable for hybrid products, it is important to understand the characteristics of hybrid products. Thus, the importance of hybrid products in general will be shown and their special characteristics elaborated upon.

A hybrid product is a service bundle adjusted to the individual needs of a customer [11, 23]. Another attribute of hybrid products is the holistic benefit-generation of the customer [11]. Customers and the fulfilment of their needs, as much as possible, are central for the development of hybrid products. Several studies show that the importance of bundles of products and services is increasing. An example of the importance of service bundles is Sturm and Bading's [13] work where 1641 medium-sized companies were interviewed regarding their products and services. A surprising 59.8% of the interviewees assessed customer-specific bundles of products and services as being very important for success in the market, and 73.7% considered the integrated development of products and services as being very significant.

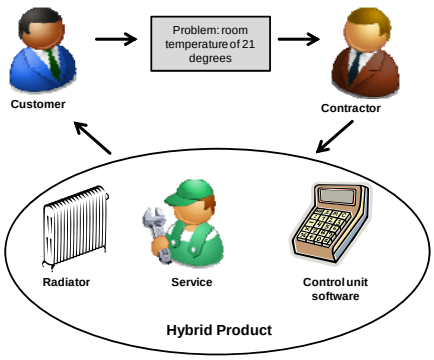

Figure 1. Hybrid Product

The example in figure 1 will clarify the concept of hybrid products. The customer's problem is that he wants a room temperature of 21 degrees. The contractor in attempting to solve the customer's problem offers a bundle of elements such as radiator (hardware), control system (software) and maintenance and repair services (service). The customer does not receive the elements separately but as a bundle.

There are other aspects to be considered. Hybrid products contain both material and immaterial parts. The customer-integration is also highly valued [3]. Further, hybrid products are characterized by different life-cycles of single elements. According to Böhmann and Krcmar [4], integration, individualization and transformation of solutions are parts of the attributes of hybrid products.

Integration signifies the technical-organizational combination of parts of the solution. These parts are then integrated into the value-creation process of the customer's process [4]. Different disciplines are also involved into the development process. Thus, it is important to arrive at a complete understanding between the involved disciplines.

Individualization means adapting the hybrid products to the customer-needs [13, 24]. The individualization is especially important in the context of fulfilment of customer-wishes and the integration into the solution [25]. In this context, the success of a solution-supplier depends on the abilities to customize solutions. If these goals cannot be fulfilled by combining existing solutions available on the market, they need to be fulfilled by individualizing products and components [26]. Thus, the customer-orientation is essential for hybrid products [27].

Transformation means that the customer-value increases by the introduction of a solution [4]. The activities of the transformation include the analysis of the environment, an assessment of the conditions, as well as the planning and implementation of the changes of the structures and systems for the customer [4].

3 REQUIREMENTS ENGINEERING

This section elaborates upon aspects of requirements engineering (RE) as gleaned from the literature review, the results of which are described in section 4. Based on the characteristics of hybrid products, the requirements for the RE of hybrid products are derived.

3.1. Definitions of Requirements Engineering from the Literature

The handling of requirements is a very important task in every development process. Even though nearly all textbooks on product development dedicate a special section to this subject, a common terminology is still missing. In software engineering, an important part of hybrid products, RE plays a vital role [28, 29]. Since in software engineering RE is seen as

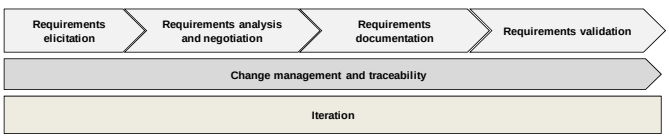

Figure 2. Requirements Engineering (according to [1])

a special discipline, there has emerged a common terminology of process phases. These process phases according to [1] are shown in figure 2.
The literature review work indicated that the phases and their definitions could be categorized into various RE approaches of product development. An effort was made not to omit possible methods applied in product development, but rather to indicate when they did not fit into these categories.
The phases of figure 2 are described in detail here [1]:

- *Requirements elicitation*: The elicitation has the goal of getting the requirements from stakeholders and other sources of requirements. An important aspect is to identify all sources of requirements [29].
- *Requirements analysis and negotiation*: The analysis of requirements has the goal of concretizing the requirements and of analyzing interdependencies between requirements. If conflicts between requirements are found, they have to be resolved by negotiation between the stakeholders [30].
- *Requirements documentation*: The documentation should document and specify the requirements. During this activity the requirements elicited and analyzed in the previous phases, are documented according to predefined documentation standards. The result of this activity is a final requirements document [29].
- *Requirements validation*: The goal of the validation is to assure that the requirements represent the wishes and imagination of the customer.
- *Change management and traceability*: The change management handles not only changes of requirements, but also assesses the impact of these changes [1]. The requirements-traceability "aims at defining relationships between stakeholder requirements and artifacts produced [during development]" [31].

3.2. Requirements Engineering for Hybrid Products

The hybrid products have special characteristics that need to be regarded by the RE process. In this section, the requirements to the RE process that are based on these characteristics are derived.

1. *Dividing of requirements according to different disciplines*: Because hybrid products consist of parts developed by different disciplines, it is necessary for the development process to adapt the requirements according to these disciplines. Also, requirements that affect all disciplines have to be handled explicitly.
2. *Elicitation of requirements for all disciplines*: The requirements elicitation methods have to regard the different nature of requirements for various disciplines. The requirements for the service elements of a hybrid product are often implicitly expressed.
3. *Different terminologies in elicitation*: To realize the cooperation between the disciplines mentioned earlier, it is necessary that the disciplines are able to communicate effectively. Especially in elicitation, it is important to have a common language with customers, other disciplines, and between the disciplines.
4. *Different kinds of requirements*: The requirements for hybrid products comprise requirements of classic products, services and software. Some of these requirements can be stated in a quantified form, others need to be stated in a qualitative form. These different kinds of requirements need to be handled adequately.
5. *Interdisciplinary cooperation*: A hybrid product consists of closely related parts that are developed by different disciplines. Therefore, the interdisciplinary cooperation is very important.
6. *Customer-integration*: A hybrid product has the goal of solving a customer's problem; it is thus important to understand the problem and to develop a solution appropriate for the customer. To achieve these goals, it is necessary to integrate the customer into the RE process.
7. *Management of requirement changes during development*: The customer has the possibility of changing his requirements to the hybrid product while it is under development. These changes can affect the overall product or only some parts of it. Methods for handling such changes have to be available.
8. *Management of requirement changes in the operation phase:* Because of the different lifecycles of the single components of hybrid products, it is possible that a part of the hybrid product needs to be changed after delivery, that is, these changes have to be supported.
9. *Incorporation of non-functional requirements*: Many requirements for hybrid products do not specify the functionality of the product itself. These non-functional requirements have to be handled adequately.
10. *The origin of requirements needs to be documented*: In the interdisciplinary environment of hybrid products it is important to know the origin of requirements. There must be a possibility to trace every requirement to the stakeholder from whom it originated.
11. *Structuring of requirements according to the discipline they belong to:* Most of the requirements for hybrid products have a clear relation to one of the disciplines involved; these requirements need to be structured according to these disciplines. Also, the origin of the requirements in regard to the discipline they belong to is important.
12. *Prioritisation of requirements*: Each discipline has its own methods for the prioritisation of the requirements. The prioritisation of customer requirements to the hybrid product needs to be understood by all disciplines, and they need to be prioritized consistently. Another aspect is that the requirements handled by each discipline have to consider the prioritisation of the requirements to the hybrid product. It is also important that the requirements for services, which are often only implicitly stated, are remembered to be prioritized.
13. *Negotiation between disciplines*: If there are conflicts between the involved disciplines, there must be methods provided to resolve them.
14. *Validation of requirements*: Once the requirements have been analyzed and documented they need to be validated. The validation methods have to cover the needs of all three disciplines.

4 RESEARCH METHOD

As the primary source of information, the top-10 textbooks on product development, selected according to amazon.com/amazon.de (accessed on 12.08.08) sales rank, were analyzed. Because RE is a process-oriented topic, only the books describing process models (these are [2, 32, 33])

were selected. While analyzing these books, references to other books discussing process models (these are [34-36]) and books covering RE in general (these are [37-40]) were discovered, and thus were included in the literature review.
In order not to miss the latest developments in the area of RE in product development, the journal articles of the last eleven years (1997 to 2008) and conference proceedings of the last seven years (2002 to 2008) were also analyzed. In identifying the journals and conference proceedings, the internal lists of the Institute of Product Development of the Technische Universität München (http://www.pe.mw.tum.de) were used. Within these publications, the search for the keywords listed in table 1 was used.
As the goal was to analyze the RE approaches in different disciplines and then to check their applicability for hybrid products, the focus was on the phases and applied methods of the RE-process. The keywords referred to the different stages of the requirements engineering and also to different methods within these stages. The different types of requirements and the distinctions in the handling of different types of requirements were relevant for the literature analysis. All papers and articles with keywords in the title, abstract, introduction (or specially defined keywords) were analyzed.

Table 1. Keywords for literature selection.

Keyword	*Keyword*
requirements engineering	traceability
requirements verification	requirements documentation
functional requirements	customer requirements
Stakeholder	customer requirements/ customer needs
requirements elicitation	use case / use-case / usecase
requirements analysis	product requirement
requirements management	scenario
requirements validation	quality requirement
non (-) functional requirements	requirements specification
CARE	

According to these keywords, 137 papers in conference proceedings and 79 journal articles were found that were relevant for our review.

5 SUMMARY OF THE ANALYZED MODELS

All analyzed models recognize the important role of RE in the development process. This section summarizes the main approaches to RE encountered in the review.

5.1. General process models

The "Münchner Vorgehensmodell" of Lindemann [2] divides the development process into seven phases connected in the form of a network with each other. A standard path through this model is proposed, but it is also possible to run through the process steps in a different manner which covers the real run of a development process. The model offers the possibility to go back to prior phases whenever necessary and to change an element on a different dimension. It is thus possible to change, concretize or repeat an element that has already been constructed.
Pahl and Beitz [33] present operative recommendations expanded by individual thoughts for the development process.
The integrated product development of Ehrlenspiel [32] relies on the tight cooperation of all people involved in the development. For RE, the activity of "task clarifying" is of interest. The requirements are elicited in this phase, and a potential product is evaluated concerning its weaknesses.
The VDI-Guideline [36] forms the basis for a universal methodical development characterized by its close relation to practice. It suggests splitting the problem into smaller sub-problems and even further into single-problems. Solutions for these single-problems can be developed individually. These solutions are then combined in a solution for the initial problem.
Ulrich and Eppinger [34] describe a generic process for the development that consists of six phases. Of these, the first two phases of RE, product planning and concept development, are relevant.
The authors in [35] describe a whole development process in which the focus lies on the construction process as being part of the development process. The parts of this process are: creation of an order, order receipt, clarification of the development task, design phase, elaboration, etc.

5.2. Approaches for requirements engineering in product development

The approach of Jung [37] presents a process model for the requirements handling in an interdisciplinary environment. The focus here lies on the elicitation, negotiation, specification and further processing of requirements. Also, the improvement of the communication between different disciplines is taken into special consideration.
The model of Kruse [38] is based on the framework for interdisciplinary RE, and the methodical basis for this approach is defined.
The methodical RE of Humpert [40] is based on the semantic model of object orientation known from software engineering. Using this concept, he integrates the development methodologies of mechanics, electronics and software into a common development process. He also takes the economical considerations into account and describes the use of information technology to support the approach.
The process model of Ahrens [39] for RE is an iterative model that incorporates existing methods of product development. The model is offered in the form of a collection of methods for the activities of the RE.

5.3. Conference proceedings

A total of 137 articles of conference proceedings, meeting the criteria defined earlier, were analysed. All articles were categorized as shown in table 2.

5.4. Journal articles

A total of 79 journal articles handling the topic of requirements engineering was identified. All articles were categorized as shown in table 3.

Table 2. Conference proceedings.

Category	*Number of articles*
customer requirements	15
requirements elicitation	8
change management	5
articles not relevant for the literature review	44
RE in general	12
case study	9
types of requirements	7
Traceability	11
tool support	8
PSS (product service systems)	2
requirements analysis	3
interdisciplinarity	2
product requirements	3
prioritization	1
functional requirements	4
requirements verification	1

Table 3. Journal articles

Category	*Number of articles*
case studies	6
requirements elicitation	3
types of requirements	30
validation	3
tool support	2
RE in general	10
stakeholder	4
requirements analysis	11
traceability	4
verification	1
modeling of requirements	5

6 REQUIREMENTS ENGINEERING STRUCTURED ACCORDING TO THE RE-PHASES

This section describes the methods and techniques that were applied in product development and structured according the RE-phases defined in section 3.1.

6.1. Elicitation

All analyzed approaches highlight the importance of the requirements elicitation. Sources of requirements can be customers, the market, laws and standards, competitors' products, sales departments and suppliers [2]. One of the main sources of requirements is the customer. Thus, integration into the RE process at an early stage [39] is important.

For the elicitation of requirements, various techniques are applied, i.e., text analysis, mind mapping or reverse engineering [2]. Also, more advanced techniques, i.e., scientific research, are proposed [2, 35, 40]. Eliciting requirements from customers can be supported by interviews, questionnaires [2, 32, 34, 35, 39, 40], focus groups and observation [34, 39, 40].

During the RE it is important to consider that not all requirements can be expressed directly. Thus, explicit and implicit requirements need to be distinguished [2].

Checklists, containing a collection of frequently recurring requirements that can be used in different projects, are widely used for elicitation [2, 32, 33, 37-39]. They help not only to omit requirements, but for different projects they can also be applied in a slightly adapted form.

The customer formulates the requirements in natural language, exclusively from the point of view of the user. For the product development, the product properties have to be described solution-independent and, if possible, in quantified form. To achieve that, it is necessary to understand the customer-requirements fully [39]. Thus, Kruse [38] introduces different types of relationships between requirements.

Ehrlenspiel [32] purports that not only the requirements of the end customer are relevant, but also the requirements of intermediary customers, such as companies that deliver the product to the end customer. Additionally, the requirements of the manufacturer and the sub-contractors need to be considered.

The analyzed conference papers and journal articles handle the elicitation extensively: [41] propose, for example, advanced methods for elicitation relying on interviews; [42] try to integrate the elicitation and the integration of the RE into the development process; [43] highlight the importance of domain knowledge during elicitation. Case-studies of elicitation in practice are also presented: [44] describe the elicitation in the automotive domain; [45] and [21] describe the elicitation for medical devices.

Last, the principle of the customer value chain analysis is discussed by [46], the concept of which is to support the selection of the right stakeholders and the elicitation of requirements.

6.2. Requirements analysis

The goal of the requirements analysis is to define what the system has to provide. During the analysis the problem has to be rendered more precisely. For that purpose, the requirements are concretized and completed. When concretizing the requirements, objectives regarding their fulfillment can also be attached [33].

In order to analyze the requirements, various techniques such as abstraction and black-box representation can be applied [37, 40]. The representation of the system under development (as black box) means that the focus is on the purpose that the system has to achieve. Function modeling is a method that helps to understand the system's functions at the abstract level, which means that the system's functions are described in a solution-independent way.

The next step during the analysis is to transform the customer-requirements to requirements expressed in the "language of the developer." Therefore, relationship-matrices and QFD (quality function deployment) are used [2, 33, 34, 38, 39]. Also, many conference papers and journal articles describe applications and variants of the QFD method; for example, [5] describe a web-based implementation of the QFD-method where a customer-satisfaction index is also calculated automatically; and [47] introduce the property-based

development and use QFD to connect the product-structure with the expected properties of the system.
To increase the clarity of the requirements, it is reasonable to structure them. There are different criteria for structuring:

- content: structuring according to technical and organisational requirements [2, 32].
- importance: structuring according to demands and wishes [35].

A structuring concept for requirements in the automotive domain is developed by [48]. Further, [49] presents a concept of handling requirements according to the emotional aspects of customer and functional requirements.
Another task of the analysis is to weight the requirements. The requirements are weighted according to their importance for the system under development. By weighting them, the focus of the development can also be considered [2, 32]. The parameter for weighting can be defined by the customer [34].
For refining the requirements and integrating the customer into this process, the QFD method can also be applied [50].

6.3. Requirements negotiation

The goal of the requirements negotiation is to resolve conflicts between requirements. Two or more requirements are in conflict with each other if they try to pursue contradictory goals [32]. An important aspect is also checking the requirements for redundancy and inconsistency. It is important for conflicts to be resolved early in the process. Most approaches use consistency-matrices for identifying the conflicts with the fields of the matrix containing the dependencies between the two requirements [2, 35]. Other techniques to identify conflicts are function modeling, mind maps, and impact-nets [2].
Internet technologies can also be used to support the negotiation process between different stakeholders [51], and here [52] define a common language between different stakeholders based on a modeling language similar to UML.

6.4. Requirements documentation

All requirements have to be documented. Most authors propose requirement lists for this purpose [2, 32, 33, 35, 36, 40], which have to be continually analyzed, checked and kept up to date [32, 35]. In interdisciplinary projects it is especially important that all participating partners take an active part in writing the requirement lists.
Normally, the requirement lists are created in cooperation with the customer. Only Breiing and Flemming [35] state that the requirement lists are provided by the customer. Requirement lists can also be structured (i.e., [34] propose hierarchical lists).
SysML is a language based on UML and allows documentation of the relations between requirements [53]. A modelling approach for functional requirements based on the design matrix concept is described by [54]. Other approaches use petri-nets and entity-relationship models [55].

6.5. Requirements validation

Validation of requirements means ensuring that the requirements represent the product according to how the customer wants it. If differences between the analyzed requirements and original requirements are discovered, these differences have to be clarified with the customer [2, 32]. Other methods for the validation of the requirements are analyzing the properties of already existing similar products, and interviewing the experts or the customers, sales- or service-employees. During the validation the requirements are to be checked for completeness and consistency. Prototyping can also be used for validation [56].

6.6. Change management

The goal of change management is to ensure that changes of requirements or properties of the system under development are handled adequately. Changes of requirements have to be documented in the requirements list [36]. The requirements list should be enriched by fields such as “date of last change” or “last editor” etc. [39].
Reasons for changes can vary from new technologies or changing market requirements to the changing wishes of customers [57]. For successful change management to occur, it is necessary to consider the changes and also the impact of the requirement changes throughout all phases of the development process [57].
A case study on change management in the automotive domain is presented in [58]. The authors describe a knowledge based approach, where the impact of change is assessed for different subsystems. The consequence of changes is that the development occurs in several iteration loops. To handle these iterations efficiently, standardization and guidelines are proposed by [59].

6.7. Customer integration

The wishes of customers are central to the success of a product on the market. The essential requirements of the product are defined by customers [2, 38]. Therefore, communication with customers is important for the development process. Development and design have to understand the vision of customers, as they are often not able to express their wishes precisely. So-called “interface problems” arise when communication problems between customers and developers emerge. These problems can only be solved through intense communication with the participants [32, 34]. The customer-requirements must be elicited as early as possible in the development process.
An example of the role of a customer in the development process is stated in the case-study on RE in small and medium size companies [60]. The authors point out that the companies realize the importance of the customer-integration for the RE process, but they do not actually integrate the customer in the development process.

6.8. Interdisciplinarity

In interdisciplinary projects it is especially important to communicate intensively with all participants. This communication is also profitable for RE [32]. The goal of communication in such interdisciplinary projects is to generate a common understanding of the problem to be solved [37]. In the field of RE the involvement of multiple disciplines dictates an increasing number of requirements and overall complexity. Furthermore, the different disciplines define the term “requirement” in various ways [2, 37-39]. Concrete methods for supporting this interdisciplinary communication are not provided [2].

7 FINDINGS

Based on the results of the analysis that were presented in section 6, it was analyzed whether the requirements to the RE-

process for hybrid products were fulfilled by the approaches of product development. Also the most important fields of improvement for the RE-process are presented.

7.1. RE of product development applied to hybrid products

This section deals with how the RE-methods of product development can be applied to hybrid products. The fulfillment of each requirement to the RE-process stated in section 3.2 is briefly depicted.

1. *Dividing of requirements according to different disciplines*: The customer states requirements for the entire hybrid product. These requirements are then concretized and transformed into requirements that can be realized by each discipline. Most RE approaches use the QFD-method for transforming customer requirements to technical requirements. This method is not well suited for hybrid product because it focuses on quantifiable requirements. The requirements to immaterial parts of the solution cannot be described in quantified form. Furthermore, if a new product is developed, it is hardly possible to confront the new requirements with the requirements of already existing products, as proposed in QFD.
2. *Elicitation of requirements for all disciplines*: The elicitation methods in product development focus on technical requirements; however, in the context of hybrid products it is also necessary to elicit service requirements that are often expressed implicitly among the technical requirements. The proposed elicitation methods, such as interviews and focus groups, are well-suited for technical requirements, but it is necessary to focus especially on requirements to services. Techniques such as groupware can be applied [61], but are marginally discussed in the analyzed literature. More problematic is the elicitation of the implicit requirements for the service elements if the main stakeholder is the market. In such a case, the market analyses have to be applied, something that is challenging for this kind of requirements.
3. *Different terminologies in elicitation*: For the elicitation of explicit customer requirements, interviews, questionnaires, focus groups, etc., are used. In interdisciplinary work there are problems that can arise. The developers need to understand the requirements of other disciplines and thus to ask the customers the "right" questions. To some extent, even the methods for elicitation are suited for the requirements of only one discipline, i.e., checklists, search matrices and function modeling are only suited for product development. The immaterial requirements of services cannot be elicited using these methods. It can thus happen that requirements of one disciplines are missed [2].
4. *Different kinds of requirements*: There exist two fundamentally different types of requirements: qualitative and quantitative requirements. Product development mainly focuses on quantitative forms [2, 33], where a concrete "requirements value" can be stated for an attribute that describes the property of an object (i.e., material). Nearly all requirements of service engineering (and some of software engineering) cannot be expressed in a quantifiable form. Thus, the methods of product development cannot be applied to them. Similarly, methods such as the method of Jung [37] can hardly be applied to service engineering because there the requirements are refined by incrementally completing the solution. In service engineering it is difficult to model the solution precisely enough in order to apply these methods. Software engineering has many non-functional requirements that can be also divided into different categories to be handled variously [62].
5. *Interdisciplinary cooperation*: The development of hybrid products presumes a strong cooperation between all involved disciplines. The integration of different disciplines is successfully handled in mechatronics. But here there are different technical disciplines that are integrated, and these disciplines have similar technical terms and mindsets [37]. When integrating technical and non-technical disciplines (for example, product development and service engineering) the importance of communication is ever more important because the different terminologies have to be overcome [37, 38]. The analyzed literature does not propose how to overcome these problems even though all authors recognize the importance of interdisciplinary cooperation. The approach of Kruse [38] is to generate a inter-domain understanding, but to focus on technical disciplines.
6. *Customer-integration:* Hybrid products are characterized by customer-individual development, whereby the integration of the customer is very important. In all analyzed approaches the customer plays an important role. The need for integration of the customer into the RE is highlighted in all approaches. But methodical support for the customer-integration is missing. The customer is only mentioned in the early phases of RE. The customer-integration rests upon the marketing division which elicits the requirements or depends on the discussions with the developers that take place in order to generate a better understanding of the customer problems.
7. *Management of requirement changes during development*: If requirements change during the development process, they are usually not re-evaluated, and not all stakeholders are informed about the change. The change management of the requirements is only handled implicitly. In the development of classic products, most changes affect the properties of products and are therefore targeted at the solution level. The changes of such properties are usually transferred back to the requirements level, but the impact of these changes for other requirements is not assessed adequately.

   The changes of requirements for hybrid products can affect the entire hybrid product or only single components of them. In the latter case it is especially important to analyze which requirements are related to requirements of other components. Also, these related requirements have to be regarded as they can be affected. Therefore, the approaches of [38, 40] can be used, but the creation and documentation of relationships have to be adapted to hybrid products. It is especially difficult to create relations to requirements for services.
8. *Management of requirement changes in the operation phase:* After the development of a hybrid product is finished and it is delivered to the customer, the requirements of the hybrid product in general and the requirements of single components can still change. These changes are not handled by any analyzed approach.

9. *Incorporation of non-functional requirements:* Non-functional requirements can be categorized in various categories, i.e., legislative requirements, quality requirements, etc. Methods to incorporate these types of requirements are generally difficult to handle. Also, in software engineering this type of requirements is neglected.
10. *Structuring of requirements according to the discipline they concern:* The structuring of requirements is done according to characteristic features described by the product life-cycle phases, characteristic features, the units or functional aspects. In the case of hybrid products, it is also important to structure the requirements according to how they belong to the single disciplines. The structuring also has to regard the different kinds of requirements used in the involved disciplines.
11. *Prioritisation of requirements:* All approaches recommend weighting the requirements, whereby a recommendation can be given in which requirements are to be realized with high priority. Most approaches propose weighting requirements by categorizing them into claims and wishes. Because the requirements to the services can often not be expressed by the customer directly, the prioritization can be problematic.
12. *Negotiation between disciplines*: The requirements conflicts can be discovered by cross linking. Lindemann [2] discusses the cross linking of requirements in great detail. He uses consistency matrices, impact nets and mind maps for this purpose. Especially important are contradictory requirements which have to be discovered. After these requirements have been discovered, the conflicts need to be resolved, and how that can be done is not handled by Lindemann. The approaches of Humpert [40] and Kruse [40] solve that problem by building hierarchical structures and relationships between requirements. Thus, they can also analyze the nature of the conflicts. These approaches are also suitable for hybrid products.
13. *Validation of requirements*: After the requirements have been analyzed and documented, the development of the solution begins. To validate that the product is built according to how the customer intended it, design drawings are shown to him. He then evaluates this preliminary design. Other disciplines that are involved in hybrid products have different methods of validation. In software engineering the documented requirements are discussed together with the customer, or else functional prototypes are created to show a slim version of the final solution. A method for validating the requirements directly with the customer is not discussed in the analyzed literature.

7.2. Fields of improvement

The most important fields of improvement of the RE-process in product development are presented here. These fields of improvement are based on characteristics of hybrid products that are the reasons for multiple shortcomings.

- *Improve interdisciplinary work*: The problems that arise due to the interdisciplinary character of hybrid products can be solved by improving the interdisciplinary cooperation. The problems in eliciting requirements, in understanding them, in finding a common terminology and in prioritizing the requirements can be traced to interdisciplinary problems.
- *Customer-integration*: Since many of the problems described in section 7.1 are related to communication problems, the integration of the customer into the RE-process is very important. By intensively communicating with customers, many misunderstandings can be avoided.

To implement these changes, a RE model, consisting of a process model and artifact model, should be developed. The process model describes the methods that are used and the artifact model describes the results produced by the methods. Already established methods for RE have to be adapted to hybrid products; for example, the QFD must incorporate immaterial parts. Similarly, customer-integration can be enhanced by computer-aided workshops.

8 CONCLUSION

The importance of RE for the successful development process has been recognized in product development. RE is widely accepted, but it is seen as an initial step in the development process, whereby the customer explains his wishes and places the order. Due to the integration of three disciplines, the development process of hybrid products has unique characteristics. The most significant characteristics are the interdisciplinarity, customer-integration and change-management.

As our findings have shown, single methods for RE in the product development have been well elaborated upon, but many need to be adapted to hybrid products. They need to be integrated into the overall development process of hybrid products so that the special characteristics of hybrid products are respected. Furthermore, some aspects of hybrid products as, for example, handling the requirements of the service elements or change management, are missing.

This paper and its profound analysis of the RE in product development lay the groundwork for integrating the RE process of the three disciplines that are relevant for hybrid products.

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