Developing Quality
– Managing Requirements over the Entire Product Life Cycle

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Abstract

Purpose: The consequent alignment of organizations efforts on requirements towards customer satisfaction sets out the fundament for corporate success. To achieve this objective, the entire life cycle of a product (PLC – Product Life Cycle) has to be considered as relevant for product development. Within the PLC, requirements appear in different instances. Looking comprehensively at the product development process, it seems straightforward to document the information collected during the life cycles of different products and to make it accessible for future development projects.

Approach: This paper presents an approach to reasonably consider, document and link requirements with requirement-relevant instances in order to achieve an improvement to product development. This approach ensures the use of an up-to-date requirement set at each stage of the entire PLC by instantaneously taking upcoming information into account.

Originality/Value: Although the consequent structuring of requirement-relevant instances allows the selective allocation by relevance, all information is documented so that this provides advantages to subsequent projects. With the "reuse" of requirements, this information comes into focus again and the consequent and structured documentation offers the possibility to improve the initial requirement set and therefore to start with a better information base.

Findings: Employing a continuous consideration of requirements, today's problems in product development may be resolved and the development process may be adjusted to future needs.

Keywords: Requirements management, Product development process, Product life cycle

Category: Research Paper

THE ROLE OF REQUIREMENTS WITHIN PRODUCT DEVELOPMENT

The consideration of requirements takes a central position within the context of product development. This development comes along with the more rigorous warranty deeds and the increasing customer orientation and – more recently – the spectacular failures and delays of various multi-million-dollar projects like the baggage handling system at Heathrow Airport in London (failure) or the development of the Airbus 380 (delay). Against this background the precise elicitation, structuring and processing of requirements, in short the requirements management, plays a crucial role within an organization and especially within product development. Furthermore, numerous standards and guidelines in the field of quality management build up on the orientation of organizations on requirements. State-of-the-art process models presuppose well-defined requirements as the initial point of the product development (Möhringer, 2005, Ehrlenspiel, 2003, Pahl/Beitz, 2003). This includes external as well as internal requirements.

MISSING CONSIDERATION OF REQUIREMENTS OVER THE ENTIRE PLC

Following the common understanding, successful product development is based on a profound understanding of the "Voice of the Customer" (cf. Katz, 2004). As there are in addition to the customers further involved persons or organizations whose specifications have an effect on the product, the stakeholder concept often is employed (cf. Jockisch et al., 2007, p.34). According to Ulrich and Eppinger the stakeholders "(…) are all important parties who are involved with the effective delivery of the product to the end user and the support of the product throughout its life cycle" (Ulrich/Eppinger, 2004). According to the ISO 9000 as the most relevant standard (DIN, 2006), quality aspects are closely tied to requirements. For instance, the "degree to which a set of inherent characteristics fulfils requirements" is defined as quality (DIN, 2006, p.22). An orientation on their requirements and a systematic management of the requirements is therefore one approach to successful product development. There already exist well-established supports to document requirements such as requirement list, tender specifications or performance specifications (VDI, 2001). As helpful as they are to give an overview of the stated requirements, they tend to be static documents, which do not evolve over time. Furthermore they are largely one-dimensional, meaning that they do not consider interactions between requirements. Bearing in mind further need for methodological support, e.g. for the elicitation and structuring of requirements or the conversion of requirements into product features, tools like the QFD (Akao, 1990) are largely applied. Within its underlying interactions with the products functions and processes (cf. Winzer et al, 2007); requirements tend to behave dynamically over time. Moreover, to work on the basis of an up-to-date requirements set, the classical time frame of requirements management – so far commonly the phase of the product development – has to be extended to the entire PLC. The consideration of quality as the fulfilment of

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requirements as well as the orientation of process models upon requirements justifies an in-depth analysis.

For further processing, it has proven to be essential to characterize the requirements in adequate detail. This concerns an explicit description in terms of formalization (Crostack et al., 2007) as well as an attribution of channel, source and further information (Jung, 2006).

Supplementary to their elicitation, a continuous requirements management has to consider and to support the structuring and processing of requirements. This includes the identification of interrelations, the orientation on decisive criteria and as interface to the design process, the translation of requirements into product features. Well-established methods like QFD only partially consider these aspects. Particularly, the retention of a current requirement set is only partially addressed. In terms of a continuous requirements management over the entire PLC, it becomes evident, that the existing static methods do not cope with the dynamic development of the requirements.
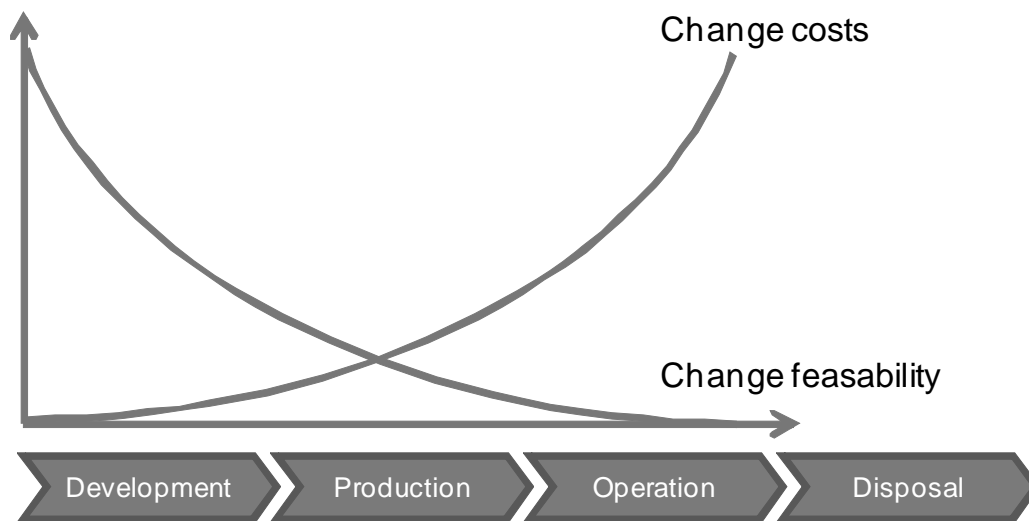

Figure 1: Development of change costs and change feasibility during the PLC

As figure 1 depicts, changes in product features are feasible in the early stages of the product development at a relatively low cost. As product development evolves or the product is already in operation, the change costs increase dramatically as well as the change feasibility decreases.

At the beginning of each product life cycle, the investigation of the stakeholders' needs and expectations results in an initial set of requirements. In the course of the development process:

  - new requirements appear,
  - existing requirements get modified or replaced,
  - requirements turn out to be no longer relevant.

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Supplementary to the dynamic development of requirements, further articulations are made by the systems' stakeholders. As the following detailed explanations show, they are closely tied to the requirements and have to be considered in order to employ a continuous requirements management.

Already in product development, but especially during the validation stages, **change requests**, **failures** and **disturbances** appear. Within the operation of a technical system, **complaints**, **damages** and **warranty claims** may occur.

All the highlighted expressions do have a common basis in the comprehensive consideration of requirements over the product life cycle. However, some of these "requirement-relevant instances" occur in downstream stages of the PLC. That may be a reason for their merely isolated treatment.

This paper presents an approach to reasonably consider, document and link requirements with requirement-relevant instances in order to achieve an improvement to product development. This approach ensures the use of an up-to-date requirement set at each stage of the entire PLC by instantaneously taking upcoming information into account.

Although the consequent structuring allows the selective allocation by relevance, all information is documented so that this provides advantages to subsequent projects. With the "reuse" of requirements, this information comes into focus again and the consequent and structured documentation offers the possibility to improve the initial requirement set and therefore to start with a better information base.

REQUIREMENT-RELEVANT INSTANCES

As well as the consideration of requirements in the beginning of the product development is largely common sense in engineering, it is almost impossible to gather a complete set of requirements to engineer a product upon. This is due to the isolated static recording in the beginning of the product development. Even using sophisticated methods and tools to elicit requirements (Jockisch et al., 2007) it is likely to exclude stakeholders or implicit requirements. Referring to this problem, iterative approaches to a continuous updating of the requirement set during the product development are discussed in literature (Sitte/Winzer, 2007). They basically build up on the idea that the requirements set is improving, if information out of the product development process is used to refine it. But as these approaches lead to more sophisticated requirement sets, tender and performance specifications, they stop with the end of the product development process. As further requirements appear afterwards – during downstream stages of the PLC, we develop the concept of requirement-related instances to overcome the current static documents replacing them by a dynamic requirement set.

The ISO 9000 (DIN, 2006) defines the term requirement as "need or expectation that is stated, generally implied or obligatory."An initial requirement, stated in the beginning of the product development process, could be the following:

> *"The appliance has to convey packaged goods at a minimum speed of 2 meter per second."*

Requirements tend to evolve dynamically over time. Supplementary information about changes and modifications as well as about their non-fulfilment or non-consideration appears. Already in the product development stages, wishes, needs or expectations to

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alter the requirements may be articulated or carried out. To maintain the link to requirements we introduce the term requirement-related instances for the following:

A **change request** can refer to either a requirement or a feature to fulfil a requirement. Whereas in the first case the requirement itself is directly modified, in the second the requirements are modified indirectly by the justification of this modification and its consequences. As often not requirements but characteristics are subject to change requests (as for the following instances as well) the relationship between product characteristics and requirements has to be considered. To achieve this, structured approaches to link product features and requirements like QFD or DeCoDe (cf. Sitte/Winzer, 2004) can be employed.

> *"The appliance has to convey packaged goods at a minimum speed of 3 instead of 2 meter per second."*

Within the entire PLC, requirements that are not fulfilled become visible in the form of **nonconformities**, defects, failures, disturbances, damages or faults. All of these instances (in the following referred to as nonconformities) presuppose an implementation of the requirements in product characteristics. They initially arise in test stages and may occur until the end of the PLC.

> *"The appliance conveys packaged goods at a maximum speed of 1.5 meter per second."*

If nonconformities occur after the delivery of the finished product they are often not recorded or even perceived by the manufacturer, but by the customer. If these nonconformities exceed a tolerated extent, the customer will make a **complaint**.

> *"The goods do not arrive in time."*

In this case either a defined and considered requirement has not been fulfilled or the requirement has not been considered in product development. The former indicate a noncompliance with a (contractually) guaranteed specification and result in **warranty claims**. Complaints which are not based on considered requirements may pinpoint the customers' needs or expectations which have not been fulfilled and thus implicit or new requirements.

Although customer complaints generally occur in the operation stages, even in upstream stages of the PLC complaints may be made – mostly by internal stakeholders. Figure 2 displays the appearance of requirement-related instances during the PLC.

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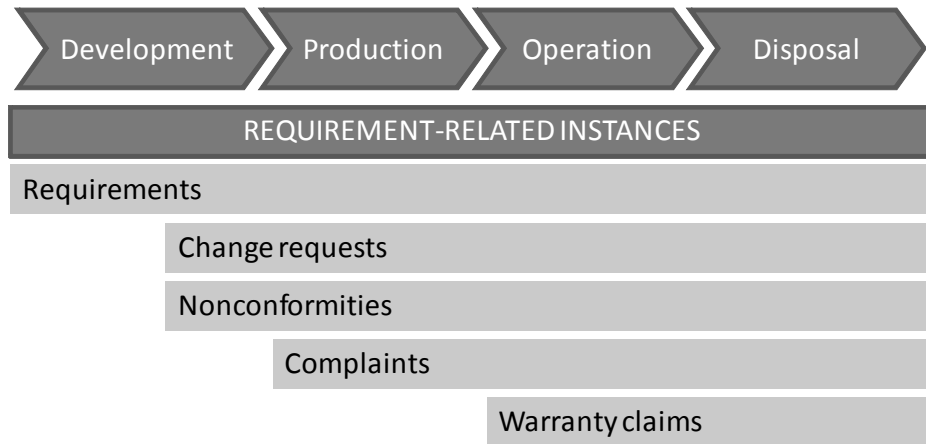Excellence; 20-22 August; 2008 in Helsingborg; Sweden

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Figure 2: Appearance of requirement-related instances during the PLC

Even though these instances refer to requirements and consequently to the fundament upon which product development builds up, there exist only isolated approaches to collect and structure this information.

NEED FOR A CONTINUOUS REQUIREMENTS MANAGEMENT

Because a statement regarding a products' quality is implicitly assuming a profound knowledge about the requirements of the involved stakeholders, it is necessary to observe them over the entire PLC. Within its progress, new requirements appear, existing ones get modified and previously important requirements may turn out to be irrelevant. Because requirements trigger the product development in order to achieve good quality products, a continuous management of requirements allows the transfer of knowledge in terms of requirements patterns to future development processes. In case of a structured documentation of the requirements and their history, patterns of implementation that proved to be successful may be transferred to other development projects and even create new product ideas. Due to a qualitatively as well as quantitatively better data pool, product development can be adjusted to meet the requirements, thus over- and under-engineering may be prevented. Additionally, the continuous alignment on requirements enables a functional dimension. If requirement-relevant instances are explicitly defined, they provide guidelines for an integrated development over various engineering domains, avoiding misinterpretations due to different domain-specific vocabulary, backgrounds or experiences. Based on information flows, an approach to accomplish a continuous requirements management to collect, document and link these requirement-related instances will be presented.

CONCEPT FOR A CONTINUOUS REQUIREMENTS MANAGEMENT

According to (Pfeifer, 1996, Winzer, 1996) information flows provide the background for a dynamic planning, controlling and managing of business processes. They represent the interfaces between the several subtasks (processes) of an organization. The analysis of the information flows aims at a representation of accumulations and deficits of information as well as at the exact description and definition of the information required

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within the respective processes. This analysis provides starting points for an optimized configuration of information flows. Because information flows connect processes and sources of information (imu, 2003) their consideration along the entire process chain allows an optimization and therefore an optimization of the business processes (Braunholz, 2006, Müller, 2006).

Requirements and the considered requirement-relevant instances represent a subset of process information. The application of the information flow analysis could therefore be useful to specify the requirements for the given processes to trace and manage them along the process chain and therefore over the entire PLC.

CREATING A DYNAMIC REQUIREMENT SET

To manage requirements over the entire PLC using the concept of information flows we firstly consider the entirety of requirement-relevant instances as a **requirement set**. This set contains the information about requirements, change requests, nonconformities, complaints and warranty claims coming from inside or outside the organization (internal or external information). To orientate on requirements the interrelations between requirements and the other instances are analyzed (cf. figure 3).

		REQUIREMENT SET							
		R_1	R_2	R_3	R_4	...	R_{32} New	R_{33} New	R_n
REQUIREMENT-RELEVANT INSTANCES (requirements – R, change requests - CR, nonconformities - NC, complaints - C, warranty claims - WC)	R_1						N		
	CR_1	C							
	CR_2			C					
	NC_1			C					
	C_1							N	
	WC_1				D				

Information (internal) →
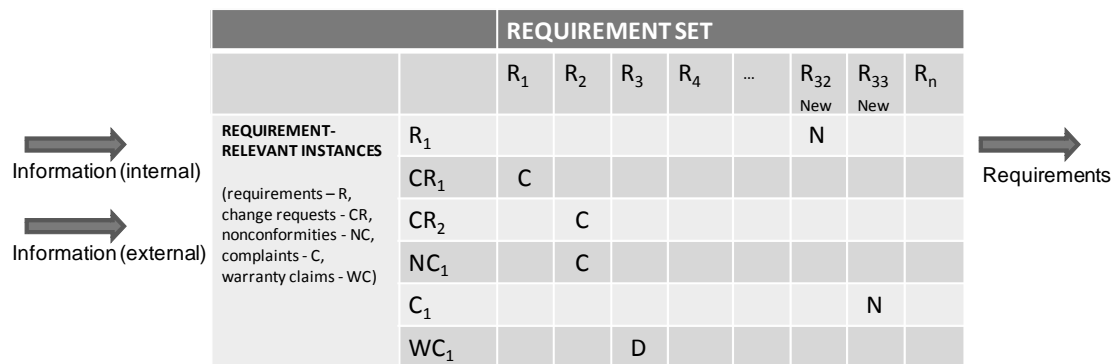Information (external) →
→ Requirements

Figure 3: Information as in- and output of the requirement set

By means of this comparison it becomes possible to analyse and rate the requirement-relevant instances. Based on this comparison, requirements get changed (C), new requirements appear (N) or requirement turn out to be irrelevant and get deleted (D). After the identification of these relations, the requirement set has to be updated in order to be used within the following processes. If a requirement-relevant instance causes an alteration of a requirement, additional information about its fulfilment may be additionally assigned. Using this approach alongside the PLC a dynamic requirement set can be created. The update of the requirement set should be carried out directly following a process step to display the contribution of the respective activities regarding the fulfilment of the requirements.

STRUCTURE OF THE REQUIREMENT SET

Dealing with the elicitation and the collection of requirements inevitable problems of imprecise, diffuse or mistakable formulation occur. These problems are closely tied to

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(partially) incomplete requirements. Therefore research (Gebauer, 2001, Heimannsfeld, 2001, Jung, 2006) has been done to establish (semi-)formal descriptions of requirements to start the process of requirements management on a common understanding of the requirements. Although the specification of the elements of a requirement does not solve all problems in the field of requirement elicitation – as recurrent difficulties to establish classifications or concepts of formal ontology show – but offers the opportunities of a structured data filing. Crostack (Crostack et al., 2007) defines source, priority, reference, surrounding conditions, and status as key elements of requirements. Upon this base a template to document requirements in the field of intralogistics has been created. The structure data filing by the help of this or a similar template supports a distinct definition of requirements. This has to be considered at the latest during the connection with the further requirement-relevant instances and – considering interdependencies – in the course of developing product and process attributes.

In addition to the requirements the further instances have to be filed in a structured way. Because the continuous consideration links them closely to requirements, their structure has to build up on the requirements' structure as well. In particular for the rating of the importance and the appropriate measures, the structure has to be amended by attributes about the relevance of the information. The scope of the requirement-relevant instances may be diverse, depending on the reference as a change request, nonconformity, complaint or warranty claim. E.g. the appropriate initiation of recall actions regarding urgency issues may be an outcome of the dynamic matching with the requirement set.

USING THE REQUIREMENT SET

The updated requirements originating from the requirement set constitute the input information for the operation of the respective downstream processes. However, caused by the operation of process steps requirements-relevant information may be altered, deleted or result in new requirements. This implies that requirements have to be verified with respect to their up-to-dateness (figure 4).
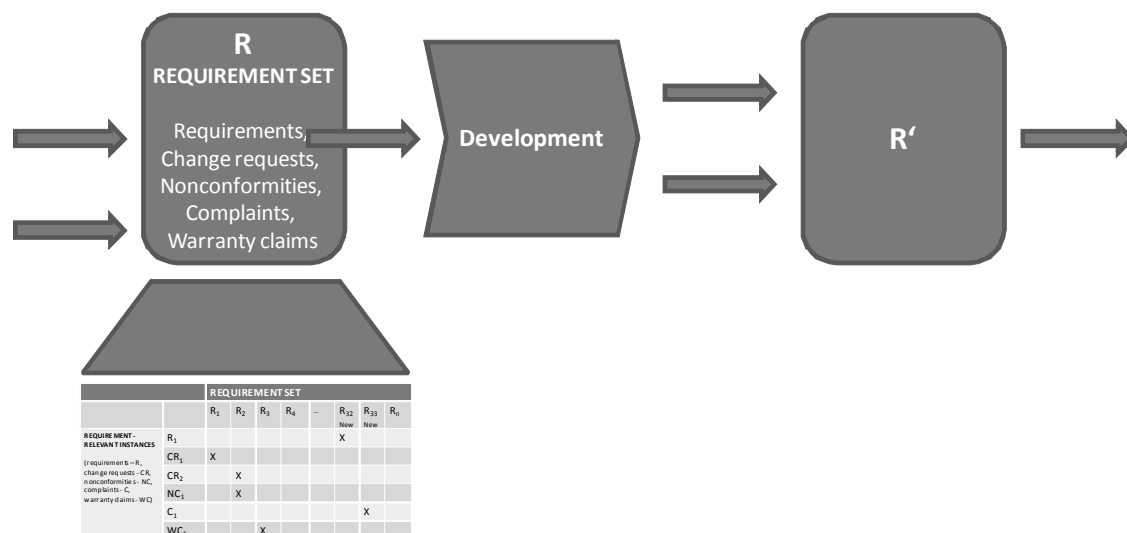

REQUIREMENT SET		R₁	R₂	R₃	R₄	–	R₃₂ New	R₃₃ New	Rₙ
REQUIREMENT-RELEVANT INSTANCES	R₁						X		
	CR₁	X							
(requirements – R, change requests - CR, nonconformities - NC, complaints - C, warranty claims - WC)	CR₂		X						
	NC₁		X						
	C₁							X	
	WC₁			X					

Figure 4: Operation of the requirement set

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SYNCHRONIZATION GATES

The division of labour and thus the parallelization of processes within a production system frequently lead to problems regarding the definition of the interfaces. Therefore it may be possible to simultaneously carry out the updating of a requirement set in distinct processes. This may implicitly cause different views and ratings. Knowing the information flows, synchronization gates as displayed in figure 5 can be defined at positions within the process chain to level the fuzziness of the requirement set due to its parallel treatment. They allow a comparison of different requirement sets, resulting e.g. from parallel processes. Therefore the requirement-relevant instances can be consolidated and passed on to the following processes. A tracing of the requirements and its relevant instances thus becomes possible. By the means of these synchronization gates it can be guaranteed, that the relevant processes including their information are considered in order to maintain a current, valid and adjusted requirement set.
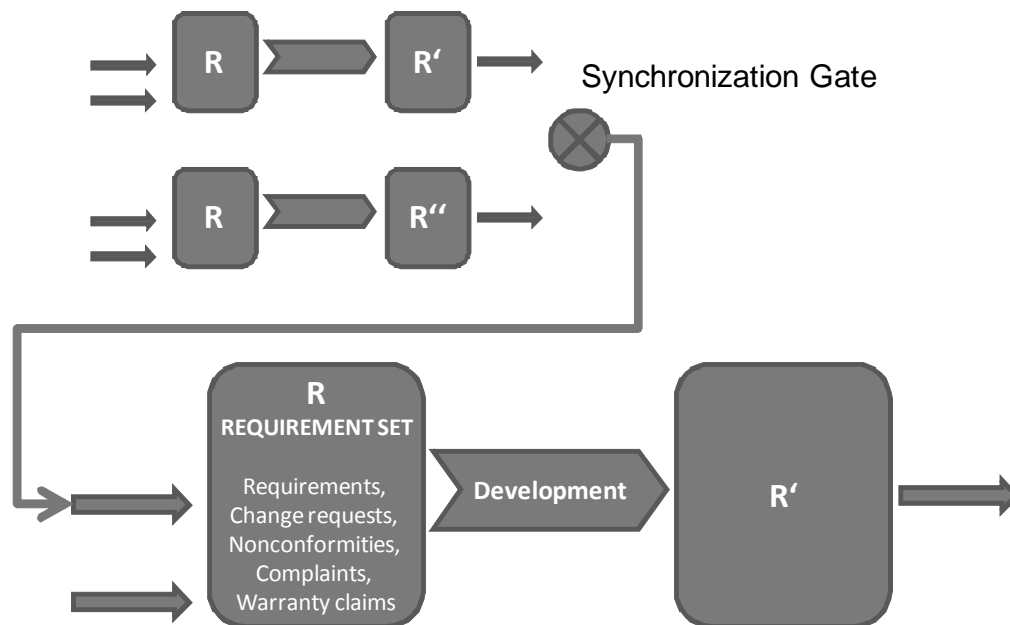

Figure 5: Positioning of synchronization gates

FINDINGS

The concept of employing requirements as a pre-requisite of product development is already widespread. Quality as well as customer orientation and strategy concepts build up on this idea. Though, running business processes, ruptures of a comprehensive requirements management often occur. This paper pinpoints the different instances of requirements and potential interfaces following the objective to achieve a requirements management over the entire PLC.

We developed an approach for a continuous requirements management based on systematic connection of requirements with downstream so-called requirement-relevant instances. To analyze their development over the entire PLC, a concept based on the consideration of information flows was presented.

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Employing a continuous consideration of requirements, today's problems in product development may be resolved and the development process may be adjusted to future needs.

1. Products may better fit the actual requirements and thus an over- or under-engineering may be prevented.
2. Expensive product recalls can be avoided.
3. Based on a common understanding of requirements different involved parties, languages and organizations may be coordinated more easily.
4. By a comprehensive orientation on requirements, the development of follow-up products can be started earlier.
5. The development stages of follow-up products shorten because of already documented interrelations between requirements and design parameters.
6. A more structured filing of the collected knowledge becomes possible.

The research approach does not focus organisational or computing aspects of requirements management but is limited on a comprehensive structured consideration of requirements over the PLC and the integration of existing methods.

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