Components of a requirement of an intralogistics facility

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Abstract:

Originality / value

In this paper, we present the steps taken to develop the prototype of an IT-based requirements management system for the domain of intralogistics facilities. So far, there is no RM system which takes into account the specific constraints of the intralogistics domain and which uses domain ontologies to facilitate the machine-understanding of stakeholder demands.

Purpose

When planning and designing large production or conveyor facilities according to customer needs, a large number of stakeholders along the product life-cycle and an accordingly large amount of demands have to be considered. Thus, computer-based methods have to be developed which “understand” all requirements and prepare them for further processing.

Methodology

Comparable approaches from requirements engineering and software engineering and their respective limitations were used to form a baseline model in which core components (e.g. “source” and “intended feature”) were identified. Next, example requirements were taken from interviews, literature or sales catalogues. A comparison of those requirements led to a requirements data model. It represents the information possibly contained in a stakeholder’s demands. This data model was implemented in a relational database, and a framework to create and use domain ontologies to integrate domain knowledge and logistics-specific wording was developed.

Findings

The data model is sound with respect to all requirements studied so far. The attributes collected during the original template creation serve as the foundation for an intralogistics ontology. The application collects additional attributes which can later be used to extend the domain ontology. This enables a designer of intralogistics systems to use additional structuring techniques and thus facilitates the planning of such a system.

Keywords

requirements management, intralogistics, data model, domain ontology, transport components

Paper type

Research paper

Introduction

The long-term objective of this project in the context of the German Collaborative Research Centre 696 (hence the prevalence of German references) is the development o a semi-automatic planning system which uses techniques such as Quality Function Deployment to infer the best design and layout parameters of an intralogistics system from a given set of stakeholder requirements.
The term *intralogistics* in general refers to in-house conveyor systems used to transport goods between specified locations (ten Hompel, 2007). Common examples of intralogistics systems include belt conveyors in airport buildings, used to transport luggage and other transit goods, or conveyors and sorting facilities used by postal services. The *intralogistics facility* comprises all the technical, economical and socio-economical aspects of those material flow systems. From a technical point of view not only the conveyor system along with its technical components (up to the control software used to organise the material flow) has to be considered, but also the context in which it will be used.

In most cases, intralogistics systems are used as a means of transport within the production process of a company, i.e. the *customer* obtains an intralogistics facility in order to produce goods using this facility. Only few organisations (e.g. waste disposal or postal services) employ those systems as a direct means of doing business. Therefore, we focus our work on requirements management and analysis for business-to-business relations between companies and the stakeholders involved.

Our approach is a comprehensive analysis of all stakeholder demands. Those demands, often referred to as requirements, shall eventually be transformed into a real product using techniques such as Quality Function Deployment (Akao, 1992). The requirements management system will have to support not only the customer, i.e. the company ordering and purchasing the facility, but support all stakeholders concerned with it. This way, each and every demand which arises along the product life cycle can be made available when first planning the entire intralogistics system. However, the product life cycle is not a fixed sequence of processes, but may vary according to the point of view of the stakeholder. Nevertheless, a common and simplified product life cycle model identifies the following stages: planning, design, assembly, use, maintenance and disposal. Each stage may also be subdivided into smaller tasks. Such a model helps to identify every stakeholder involved, thereby revealing possible human or organisational according to the stakeholders involved.

Including all the relevant demands of every stakeholder along the product life cycle is one of the main problems facing the producers of intralogistics facilities today (Crostack, 2006). Up to now they concentrate solely on performance and robustness issues, mostly unaware of the implications of their design for maintenance tasks and the overall flexibility of the facility. Most of those problems arise from the use of out-of-the-box design of conveyor systems. The available standard components each producer has in its repertoire are used to assemble and build the “required” facility (ibid.). At this stage, the planning is driven primarily by the experience of the designer, not by the actual requirements of the stakeholders who will have to work with the system in the future. This lack of individual design, of “customising” and shaping of the systems to the demands at hand leads to a lot of in intralogistics facilities being “oversized”. This, in turn, results in both much higher acquisition and operating cost than would otherwise be necessary. Using our requirements management system we want to customise facilities according to the original stakeholder requirements.

Aim and related work

When planning and designing large production or conveyor facilities according to customer needs, a thorough understanding of each stakeholder's requirements is essential for the planning system to translate those demands into the system they describe. However, a large and often inhomogeneous group of stakeholders express their wishes and requirements concerning the planned facility. Due to the large number of stakeholders along the product life-cycle, an accordingly large amount of requirements has to be processed during facility planning. Therefore, computer-based methods have to be developed in order to

- store and retrieve requirements according to search criteria
- cope with the amount of requirements and product specifications
- process (compare, weigh, change,…) requirements and subsequently design the desired facility.

The last part necessitates that the underlying IT system "understands" the desired property expressed in the stakeholder's requirements. At this stage, we assume that each requirement contains or otherwise expresses at least one property of the intralogistics facility to be built. The exact definition what this "property of a system" might be, will be determined in the course of this work.
The logic behind our requirements management system consists of several building blocks. Foremost, there has to be a definition of the term *requirements* which must encompass all the relevant pieces of information needed to describe its purpose (i.e. the target property of the final system intended by the stakeholder). We can then use this definition to deduce information categories characterising such a requirement. Those information categories then lead to an abstract data model for stakeholder requirements. In addition, this data model is then used as a foundation for a relational database model, on top of which the prototype of a web client-based requirements management application is build. This way, the application serves two purposes: on the one hand, it helps validating the data model, identifying requirements whose information cannot be mapped to the data model, and on the other hand, it may be used to identify common terms and wording in the field of intralogistics requirements.

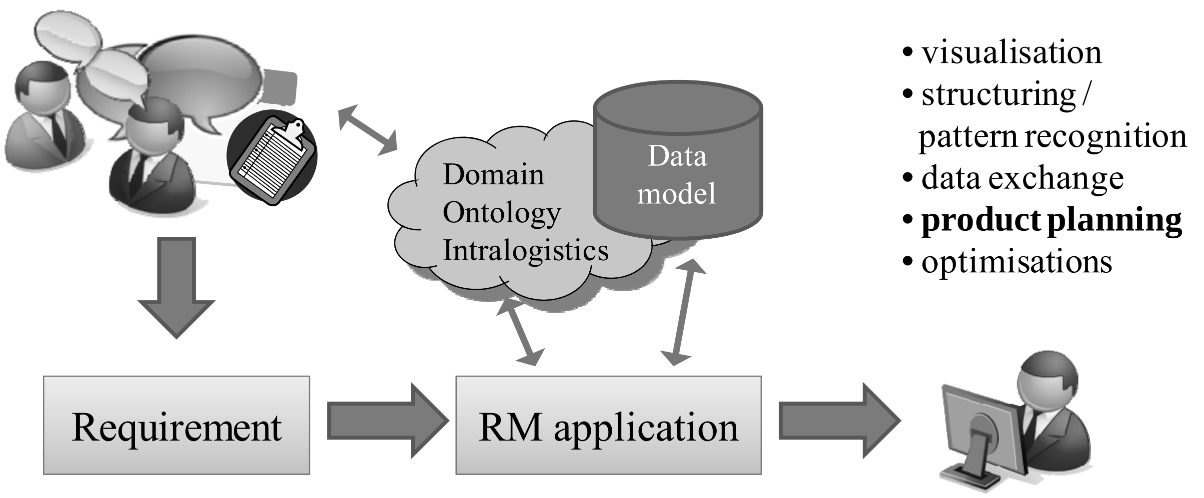

Figure 1: Aim and constituent components of our requirements management system

The latter part is of particular importance, since we try to support the requirements of all stakeholders involved with an intralogistics facility and their corresponding "voice of the customer" (Griffin, 2003). Even the coarse distinction into planning, design, assembly, use, maintenance and disposal stages shows the varying technical background of the stakeholders considered. We refer to this background as the *domain* of a stakeholder. Therefore, there are several (distinct or overlapping) sub domains within the domain of intralogistics systems, each which their own technical terms. Analysing requirements expressed by different stakeholders, we have to consider variations in the meaning, in the semantics of the terms used. In order to capture those distinctions and similarities, we create and use a domain ontology for the field of intralogistics. The concept of ontologies is taken from knowledge management methodologies, where they represent real-world objects, concepts and terms and the conceivable relations among those entities.

There are several comparable approaches to requirements management in literature. Excluding psychology-centred methods towards requirements elicitation ("marketing", customer feedback and interview techniques), we distinguished two main schools of requirements management. The first one stems from traditional design concepts in mechanical engineering, while the second one, requirements engineering, concerns itself with requirements arising in software development.

In mechanical engineering (Pahl, 2006) concentrates on the implications of customer requirements on the design of a product. He presents a list of properties common to most products, like geometry, flexibility, functionality, etc. This list should be used to help capture all necessary requirements as well as identify missing requirements. This approach, however, is too broad to be used in our system. (Kläger, 1993) proposes a requirements model for design problems (for a CAD environment) as a part of a conceptual product model. (Kickermann,1995) and later (Heimannsfeld, 2001) describe a general requirements management process which concentrates on the formalisation of requirements via textual analysis and the formalisation of a system model. All three concepts, along with (Krusche , 2000), concentrate on structuring functional requirements and try to devise methods to infer a feasible solution for a construction problem. In (Humpert, 1998), a requirements model is developed in order to identify relations between requirements. Each approach lacks the support of a product life cycle model for the desired system and thus lacks support for the demands and varying domains of stakeholders in the context of an intralogistics facility. (Rzehorz, 1998) and (Müller, 2007) employ knowledge management techniques (e.g. software agents) to map requirements to possible solutions, including constraints on their practicability, but both assume requirements can be sufficiently formalised and "understood" by a computer.

In the field of software development, we considered the works of (Rupp, 2005), (Ebert, 2005) and (Schienmann, 2002), along with result from (KARE, 1998). Due to the immaterial nature of software, software requirements and requirements management have a strong focus on traceability, testing and project management issues where the tasks ensuing from each requirement have to be controlled. Again, each approach presents a data model for customer requirements, but they mainly rely on manual detection of dependencies and manual assignment of solutions. Models and reference processes have to be ported to the domain of intralogistics. Additionally, the stakeholders' different domains and their correspondingly different languages have to be taken into account.

The data model and its information categories

Hence, in short, our research objective was to establish a unified model for requirements in the context of intralogistics facilities. The requirement model should incorporate the specific

domains of all groups or representatives involved, since the quality of the planning process directly depends on the ability of the planning system to represent and understand requirements and to handle them in an efficient and mostly automated way.
In the following, we describe the development of a data model and its use in a requirements management application. When appropriate, the use of our domain ontology is sketched. Since its development is still an ongoing task, it will only be presented as part of an example.

At first, we checked the aforementioned approaches from requirements engineering and software engineering for a suitable definition of "requirement". Since the domain of intralogistics so far lacks common requirements management techniques, we devised a first requirements definition as a starting point:
"Using a requirement, a stakeholder describes a future property of an object, a process, an action or a person".
This definition helped identify three basic components of our requirements system:

1. *Stakeholder*: as already mentioned, our approach tries to encompass each stakeholder concerned with the intralogistics facility. Unfortunately, there is no comprehensive and generally accepted list of stakeholders in intralogitics. As a workaround, we propose to use a product life cycle model to identify stakeholders and map them to certain stages in return.
2. *Target*: each requirement is targeted towards some part of the intralogistics facility. This part may either be a technical component (like a belt or a drive in the context of belt conveyors), or an "organisational component" of the system, like a requirement describing some future process.
3. *Property*: the "target" of a requirement is only one part of the actual demand. Apart from the component itself, we also need to know which feature of this component is expected by the stakeholder. This way, every target component offers a set of properties which represent either static aspects (attributes) or dynamic aspects (behaviour) of that component.

Next, we broadened our analysis and tried to compile a data model which can be used to structure the information contained in a stakeholder requirement. This data model also should represent a requirement with the least possible loss of information. Therefore, we reviewed existing data models (see above) and their respective limitations. As a guideline, we extracted quality criteria form (Rupp, 2005) and (Humpert, 1998), like clarity, "disambiguity", verifiability, traceability and foremost "independence from implementation".

The comparison of existing approaches yielded some valuable ideas for a baseline model in which core components of a stakeholder's demand were identified. Next, customer-specific as well as customer-unrelated requirements were gathered as prototypes for requirements. They were taken from interviews conducted with stakeholder representatives, from literature or sales catalogues. We then compared those requirements for similarities and differences, identifying common information categories which we assembled in our requirement model. In order to structure the information contained in this template we grouped similar information categories.

We then subdivided all information categories into primary, secondary and tertiary data. Primary data comprises all information directly accessible when gathering requirements during requirements elicitation. Secondary data represents further knowledge which we can gain by considering several requirements at once, like interdependencies or constraints. Tertiary data result from combining requirements and dependencies with additional knowledge about the intralogistics system, e.g. a chain of technical implications. The latter type of data has been included to facilitate future work such as translation of requirements into product features, but it will not be considered in the following.

Each information category describes an aspect of a stakeholder requirement. For each such category, a set of attributes has been gathered, representing the possible range of values for the category. Figure 1 depicts the relevant categories and the corresponding headings. We defined those headings to be “source”, “priority”, “reference”, “situation” and “constraints”. Apart from those, the storage of central master data has been proposed to simplify retrieval of the requirements, like requirements text, date and time of elicitation, project reference etc.

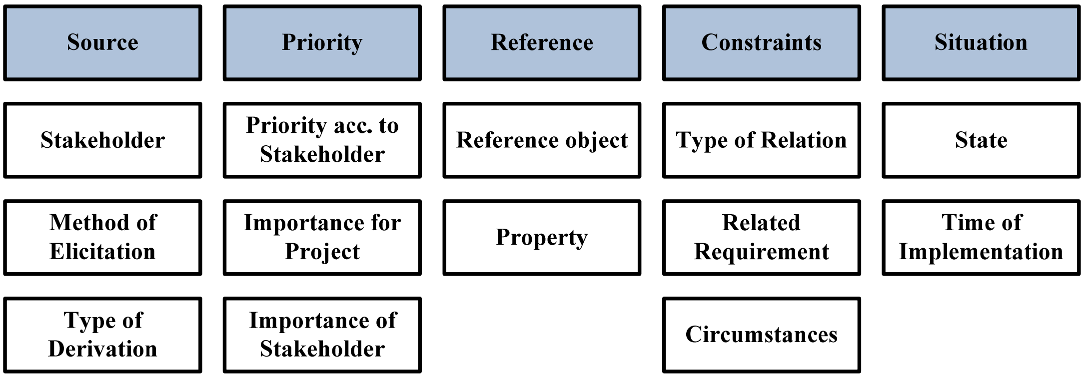

Figure 2: Information categories grouped together under five topical headings

The “source” of a requirement consists of:

- *Stakeholder*: this category represents the stakeholder who expresses a requirement. However, a requirement can originate from a lot of different types of sources. Thus, a stakeholder might be
  - a real life person with whom an interview has been conducted
  - a role name for a group of people who share a common goal
  - an abstract source such as a job norm (or law, standard, etc.) dictating certain properties of our facility

  Furthermore, when combining group names, role names and individual stakeholders, we get not just a list of stakeholders but an extensive stakeholder hierarchy, which can be represented as a tree or as a graph of stakeholders. This way, we can keep track of the original stakeholder and his relations to other stakeholders who may have contradictory requirements.
- *Method of elicitation*: this category states which kind of techniques have been used to gather the requirement. Possible methods range from simple “text-based” research (in the case of job norms or existing requirements specification documents) to sophisticated interview techniques applied when talking to a group of domain experts.
- *Type of derivation*: this category expresses the type of interpretation a requirement has undergone prior to its being entered into our requirements management system. A requirement taken from job norms or other standards can be analysed “as is”, while statements taken from interviews may be interpreted, resulting in a possible shift in their intended meaning.

Our approach which tries to consider every stakeholder of the intralogistics facility has to include interview techniques as well, because it may help bridging the gap between what is expressed as a requirement and what is actually wanted.

The "reference" category of our data model is our main interface to the domain ontology for intralogistics. We distinguished a reference object and its property, both information categories depending on each other. They are used to describe the intention of the requirement, i.e. its target and the feature it should provide. Therefore, possible reference objects and their possible properties in the context of an intralogistics facility have to be stored in a "system model". This model also must include abstract concepts like flexibility as well as technical features of an intralogistics facility ("the speed of conveyor xyz").
Due to the large amount of stakeholders, the representation of abstract concepts is a difficult task. Depending on the stakeholder, the meaning of "flexibility" may vary enormously. A facility manager may take "flexibility" to mean "extensible for future products" whereas a worker with the facility may see flexibility as "varying degrees of speed". Those distinctions in meaning have to be captured in our domain ontology, rendering the data model independent of actual terms and notions.

A requirements management system for different stakeholders will have to cope with certain relations between requirements, such as requirements contradicting each other or their being supplementary to one another. In order to prioritise those requirements, three different methods have been included. Firstly, the importance of a requirement can be determined from the point of view of the stakeholder expressing it. For example, a requirement derived from law texts is of great importance in the realisation of the facility. Otherwise, the stakeholder himself must provide an estimate of the importance of his demands. Secondly, the importance of the stakeholder himself has to be assessed. Thirdly, the importance of a requirement in the overall planning process must be determined. It may vary significantly from the priority a stakeholder has awarded to his demand.

The "constraints" category is used to formalise dependencies between requirements. The *type of relation* offers the possibility to characterise those dependencies. A "refinement" for instance signals that a requirement A is more detailed than requirement B where both A and B have the same target component. The *circumstance* offers additional explanation why the dependency holds. Both notions are subject of current research.

Once processing of the requirements has started, the "situation" category keeps track of the *state* of those requirements. The *time of implementation* defines the point in time when a requirement first has to be implemented in the facility.

Use of our data model

These findings with respect to the necessary information categories make up our first prototype for the requirement data model. Due to the broadness of our approach, the possible attributes of each category have not been analysed "in depth". So far we have only got a general idea which attributes might be applicable in the context of certain categories. For instance, the stakeholder hierarchy is still incomplete, but a general model of different perspectives can be applied.
However, the implementation of our data model in an application prototype helped significantly in the gathering of further attributes which will now be provided to the user. This way, we were able to extend the possible "range of values" for each category.

The data model was transferred into a relational data model using entity-relationship-modelling. Based on this implementation, a web application prototype was developed (Crostack, 2007). The application itself is browser-based, being written in PHP and run in an Apache+MySQL environment (URL 01) (URL 02) (URL 03). As discussed above, we have identified the information categories necessary to describe and structure the information contained in a stakeholder requirement. The content of each category is analysed during further research. Comprehensive coverage of every possible attribute is infeasible, since we aim to support a large group of stakeholders. Common terms used by each stakeholder have to be included in our domain ontology in which each technical term can be equipped with contextual semantics so that we can give the "correct" meaning to every known target object and every property. Terms and word so far unknown to the system pose an additional problem to the domain ontology, since it has to be extensible and it has to be developed incrementally. Therefore, we devised an approach to cope with additional attributes for the existing information categories.

At first, we had to consider the internal structure of our attributes. It became clear, that the denomination "range of values" may just be seen as an analogy. It is misleading in several ways:

1. As previously stated, the range of values, i.e. the set of possible attributes for an information category, may not be complete. Since we follow a knowledge-based approach towards requirements formalisation, and knowledge is always extensible, so are our attributes.
2. Attributes for some fixed category may not be of equal value or of equal rank. As we have seen in the case of the "stakeholder" category, attributes like stakeholder roles may well be subdivided into more specific ones. The "manufacturer perspective" can contain several role names such as "buying agent", "designer" or "assembler" which in turn can be divided into role names of their own (see figure 3). This results in the attributes being arranged in a tree or a directed graph.
   On the other hand, the attributes for the requirement's entry date are nothing but a list of all possible dates, none of with is more important than the other.
3. There are dependencies between certain attributes. This became most obvious with the "reference object" and "property" categories. The attributes of the first one comprise all technical and organisational aspects of the intralogistics facility. The attributes of the property category have to reflect all features of the reference object.

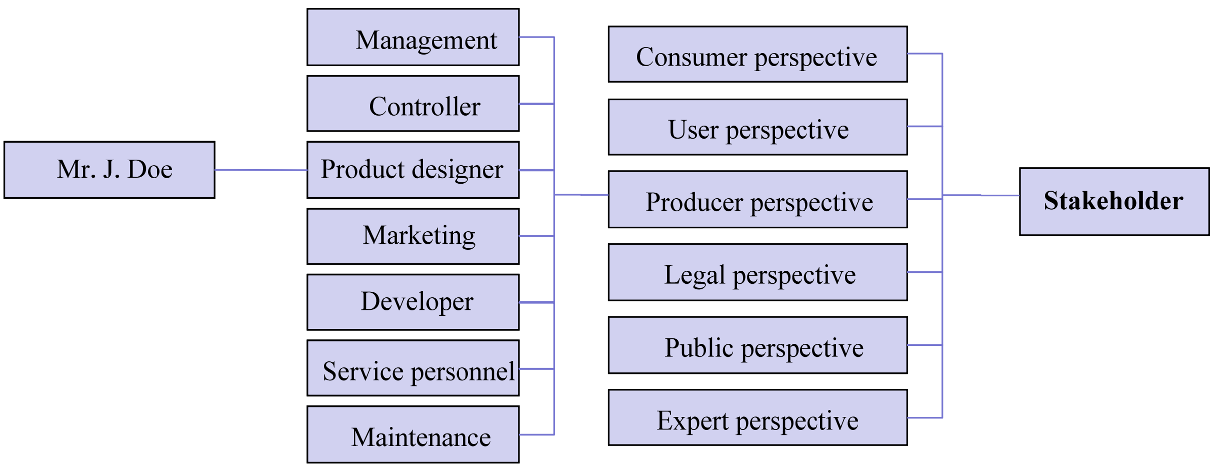

Figure 3: The stakeholder hierarchy presented as a tree.

To help gather attributes for our information categories we offer three different kind of input mechanisms in out requirement management application.

1. We provide the user with a preselected and pre-structured list (or graph) of possible attributes, one of which the user can choose to characterise the requirement at hand.
2. The user is offered a text field for free text input. If no pre-structured attribute seems fit, the user can enter a term of his own.
3. Terms and items previously entered for this category by this or other users are also made available in the application. Unfortunately, due to the nature of our information gathering, terms entered this way cannot be structured by the user.

The identification of relevant information categories and attributes and their transformation into data objects allows for the use of additional structuring techniques. For instance, clustering methods can be applied to find patterns and related requirements. Those results can then, in turn, reduce the number of requirements needed to consider when designing the desired facility.

Conclusion and future work

So far, we have assembled a list of about two hundred example requirements. They were taken from literature on intralogistics and material flow systems, derived from products found in sales catalogues and from interviews with colleagues working in special subdomains of intralogistics, e.g. drive optimisation. We entered those requirements into our data model and evaluated its ease of use and the completeness of the chosen information categories. Table I shows the results.

Category	**Result**
Stakeholder	necessary, but no complete list of stakeholders available yet
Method of elicitation	pre-structured list of methods taken from literature
Type of derivation	"taken directly from text", "interpreted from text", "interpreted from interview"
Priority acc. to stakeholder	important, but very difficult to obtain
Importance of stakeholder	can only be estimated
Importance for whole project	Important, but unable to obtain any results, since the scope of the project cannot be defined
Reference object	"Target" of a requirement. Has to be extensible set of terms
Property	Relates to reference objects. Defines features of the desired facility
Type of relation	"part-of", "includes", "leads-to", "contradicts"
Referenced requirement	The end point of the relation
Circumstance	additional description
State	List of possible states: "open", "in review", "accepted", "implemented".
Time of implementation	Can be split into specific dates and temporal dependencies between requirements

Table I: Analysis of categories

Our analyses show that we have identified the most important pieces of information necessary to document stakeholder requirements without loss of information, and due to the use of a domain ontology without considerable loss of meaning. However, there are several information categories which we could not fill in without much extra work. Every category with regard to the importance of a requirement poses a problem, since the required information is not available. Up to now, stakeholder requirements have not been gathered in a structured and standardised process. Thus, there is not method available to assess the importance of a certain requirement for the success of the implementation of an intralogistics facility. Therefore, a simplification of our model would be to merge the three priority-related categories into one, for the time being, until more precise result can be obtained. Towards this goal, methods of rating and ranking, as well as sophisticated techniques like AHP (Saaty, 1990) might be employed.

Although this approach may be used in different applications, all research conducted so far concentrates solely on the intralogistics domain. Due to the large amount of time needed to create useful domain ontologies, no comprehensive analysis of large requirement set has taken place yet.
Our findings will help enforce the use of requirements-based planning and design methods especially in the business-to-business sector. Stakeholder demands can be documented in a straightforward way using both a data model and domain ontologies. By giving meaning to known terms and relating them to one another, automatic reasoning about requirement dependencies and their later transformation into a product is made possible.

List of References

Akao, Y. (1992): QFD-Quality Function Deployment. Verlag Moderne Industrie, Landsberg/Lech 1992

Crostack, H.-A. et al. (2006): Neue Herausforderungen des Anforderungsmanagements für Hersteller logistischer Anlagen (Logistics on Demand), Verlag Praxiswissen, Dortmund

Ebert, C. 2005): Systematisches Requirements Management, dpunkt.verlag GmbH, Heidelberg

Griffin, A.; Hauser, J. (2003): The Voice of the Customer. Marketing Science,

Heimannsfeld, K. (2001): Modellbasierte Anforderungen in der Produkt- und Systementwicklung. Aachen: Shaker Verlag 2001, zugl. Dissertation technische Universität Clausthal,

KARE report KARE/IT/R2.3 (1998): Preliminary study report on the requirement formalisation, Technische Universität Clausthal – Institut für Maschinenwesen, Clausthal-Zellerfeld,

Kläger, R. (1993): Modellierung von Produktanforderungen als Basis für Problemlösungsprozesse in intelligenten Konstruktionssystemen, Shaker Verlag, Aachen, 1993

Kickermann, H. (1995): Rechnergestützte Verarbeitung von Anforderungen im methodischen Konstruktionsprozeß. Dissertation TU Braunschweig, 1995

Krusche, T. (2000): Strukturierung von Anforderungen für eine effiziente und effektive Produktentwicklung, Diss. 60 (2000) Braunschweig, TU Carolo-Wilhelmina

Humpert, A. (1995): Methodische Anforderungsverarbeitung auf Basis eines objektorientierten Anforderungsmodells, Heinz-Nixdorf-Inst., Univ. Paderborn, Paderborn,

Müller, D. (2007): Intelligente Unterstützung für ein aufgabenorientiertes Anforderungsmanagement in der integrierten Produktentwicklung, Shaker Verlag, Aachen

Pahl, G.; Beitz, W. (2006): Konstruktionslehre. Methoden und Anwendung, Springer Verlag, Berlin, 7. Aufl. 2006, ISBN: 3540340602

Rupp, C. (2005): Requirements-Engineering und –Management – Professionelle, iterative Anforderungsanalyse für die Praxis, 3. Aufl. München u. a., Carl Hanser Verlag

Rzehorz, C. (1998):Wissensbasierte Anforderungsentwicklung auf der Basis eines integrierten Produktmodells, Shaker Verlag, Aachen

Saaty, T. (1990): How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research Nr. 48

Schienmann, B.; Strassenburg, S.; Schelling, A. (2002): Erfolgreiches Anforderungs-management. In: Betriebswirtschaftliche Blätter 12, 2002

ten Hompel, M. et al (2007): Materialflusssysteme: Förder- und Lagertechnik, Springer Verlag, Berlin, 3. Ausg. 2007, ISBN: 3540732357

URL 01: www.php.net

URL 02: www.apache.org

URL 03: www.mysql.com