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EXPLORING REQUIREMENTS MANAGEMENT IN THE AUTOMOTIVE INDUSTRY

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Abstract

This paper presents an empirical study carried out in the automotive industry, with the aim to bring forward new experiences and knowledge on management of requirements in practice. Adopting a qualitative systems approach, and using multiple information sources, the requirements management process during the development of a passenger car cockpit has been mapped out. The logical reconstruction of the requirements management process is complemented with descriptions of associated phenomena, such as important events and attitudes. Findings are presented, analysed and discussed considering also factors underlying observed phenomena.

1. Introduction

Throughout the development of a new car model, thousands of requirements are established, communicated, transformed into solutions, and followed up. These activities, which we refer to as requirements management, involve several disciplines and extend through all development phases. During their long period of gestation requirements are changed, prioritised, compromised, balanced, and hopefully, but not always, fulfilled through a solution. The result does not always mirror the driving factors for the project, and is then most likely to be regarded as less successful than what was originally expected.

Our general aims in this study are to bring forward new experiences and knowledge on requirements management in the automotive industry. These in turn will constitute a base for proposing improvements in industrial practice, as well as a base for methodology development in academia. More specifically, the study aims to map out the requirements management process in an industrial case: Including identification of progress, changes, deviations, and compromises regarding the requirements and their fulfilment, linked to the different phases of the product development. Besides, the rationale for present, selected solutions is searched for in order to enhance the understanding of the decision process, which is not only based on articulated requirements. Factors underlying the observed phenomena, such as important events, inter-personal communication, and attitudes towards requirements and their fulfilment, are taken into account. This paper concisely presents the study. The full study is described in an internal report [1].

The main body of this paper is arranged as follows: Section 2 frames our theoretical and hypothetical starting points, and presents the development project. Section 3 summarises the research approach. In section 4, findings are presented and discussed. In section 5 we discuss the research approach and use of results. Finally, in section 6, we state our key conclusions.

2. Setting

2.1. Our Starting Point and Reference Frame

Many product development methods described in literature basically prescribe a well-structured, sequential main flow for the product development, starting with a requirements specification, or design specification, and ending with a product solution, e.g. VDI Guideline 2221 [2]. Furthermore, specifications are prescribed to be established early and kept in focus all through the development, e.g. as proposed by Pugh [3]. In Systems Engineering literature [4], requirements and their management is perhaps an even more central issue.

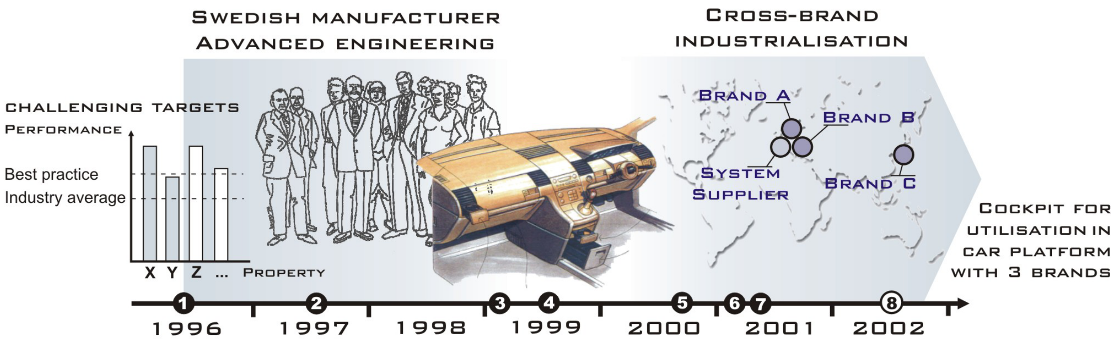
The procedures prescribed for development projects in industry are basically not far removed from those described in literature, but practical development activity is often different. In practice, not only are the product and the set of requirements complex, but so are also the social system and the industrial system dealing with the development. This makes it particularly interesting, but of course also difficult, to carry out an empirical study on requirements management in industrial practice. Actually, very few such empirical studies have been carried out, compared to theoretical, prescriptive studies. Through a purely empirical study, Hooks and Stone [5] reflectively describe how requirements were managed in a NASA project. However, there exist empirical studies on design teams in industrial practice focusing other areas, such as communication flows in international product innovation teams [6], collaboration between main and sub-suppliers [7], and teamwork [8].

In carrying out the study, our intention has been to create a broad empirical view of requirements management. A further notion is that specific issues identified can be opportunities for future in-depth studies. Consequently, in this study a rather broad set of research hypotheses has been considered. These involve:

- Failure of the requirements specification to highlight the key issues for development, resulting in different interpretation by different parties.
- Insufficient knowledge about requirements, or their context, limiting the holistic view needed to develop attractive solutions.
- Insufficient follow-up of the requirements specification fulfilment, along with lack of function or attribute responsibilities, resulting in driving factors being lost during the development.
- Mismatch between the development competencies available at the car manufacturer or at the system supplier and the needs of the specific project, affecting the development leadership and the ability to develop solutions meeting the requirements.
- Late introduction or changes of requirements and features, causing expensive changes, project delays, and affected product attribute balance.
- Communication problems, intra-company as well as extra-company, leading to inefficient requirements management.
- Unclear roles, resulting in inefficient work-split and division of responsibilities.

2.2. The Case Studied

The case studied is the development of a passenger car cockpit, a major sub-system with a multi-technology content. The driving thought behind the development of the new cockpit system solution has been to increase the performance/cost ratio by physical integration thinking, besides raising the product performance with regards to strategic goals. Thus, the requirements specification itself has been very challenging.



Important events:
1. The advanced engineering project within the Swedish car manufacturer is started. The intention is to co-operate with an already established car business partner
2. The system supplier gets involved in the advanced engineering project
3. The ownership structure of the Swedish car manufacturer is changed
4. Inter-brand platform co-operation is established
5. Concept is approved to be utilised by companies within the group
6. The system supplier is chosen for platform industrialisation and production
7. Cost savings and re-balancing of functional content are done
8. Point of research study

Figure 1. The evolution of the project illustrated, focusing on important events.

The development of this cockpit was started in spring 1996, being originally an advanced engineering project at a Swedish car manufacturer, and has gradually been extended and, now, become an international industrialisation project involving several car manufacturers and suppliers (figure 1). One of the authors played an active part in the advanced engineering project, at that time being a design engineer at the Swedish car manufacturer. Following a systematic design methodology adapted from Hubka [9] a number of concept alternatives were generated and evaluated, resulting in a concept proposal challenging traditional cockpit solutions. During summer 1997 a French system supplier was selected to be involved in the advanced engineering as a development partner. Platform development activities were initially run in co-operation between the Swedish car manufacturer and its previously established car business partner. However, in early 1999, the ownership structure of the Swedish car manufacturer, and consequently the business scenario, was changed. As a result, since the summer of 1999, the project has evolved into an international product platform project involving three brands in three countries with different cultures, see figure 1. Late in the year 2000, the cockpit concept that resulted from the advanced engineering project within the Swedish car manufacturer was formally approved, to be utilised by companies in the group. In the beginning of year 2001, the system supplier previously involved in the advanced engineering was selected for cross-brand platform industrialisation and production (the extension of parts to be produced by this supplier differs between the brands). In addition to these major strategic events, specific events of great importance include cost savings and rebalancing of functional content. Within the Swedish car manufacturer, intensive cost saving and rebalancing rounds were run during the spring of 2001.

The organisational and geographical location for the overall management of the project has changed throughout the course of the project. During the platform development phase, extending from mid 1999 to mid 2001, the project was mainly managed from a common headquarters, while the current industrialisation management is mainly shared between the three brands' sites. Now (2002), the whole development, from the early concept phase to the current industrialisation, has been followed up through this empirical study focusing on requirements management. The Swedish car manufacturer and the French system supplier constitute the base for our observations and data collection.

3. Research Approach

As our belief is that requirements management is a complex activity affected by a great number of dynamic factors and interesting phenomena, we have adopted a qualitative systems approach in the research. This approach requires a detailed documentation of the case and a rigorous data collection, in order to identify underlying factors, to minimise bias, and to increase the transparency of the observations made. Here, the principle of multiple information sources has been adopted. The physical product has been inspected, focusing on requirements fulfilment, documents have been studied, with both management and fulfilment of requirements in mind, and interviews have been carried out to map out the requirements management process in practice. In this section, the research approach is summarised. A full description of the approach is available in an internal report at Chalmers [1].

The interviews constitute the most important information source. In total, 24 semi-structured, approximately two-hour interviews have been held (with 25 interviewees). The selection of interviewees was carried out following a heterogeneous, purposive sampling strategy [10]. In line with this strategy, the interviewees were selected according to their role, or importance, in the development project. They represent different project phases and disciplines within the Swedish car manufacturer and at the system supplier. The interviewees have experience in product development ranging from two to twenty-seven years. The interviews were held in a relaxed atmosphere on site at the respective companies. After each interview session, the notes were collated, transcribed and checked by the researchers involved in the interview in question. The full transcription was then sent to the interviewee for approval and possible changes. Complementary conversations have been used to resolve unclear interview responses, e.g. when making the data analysis.

The analysis of the information emerging from of the product study, document study, and interviews has been done in an integrated fashion, and collaboratively by the researchers. The very rich and varied material has been condensed using stepwise data reduction. Throughout the analysis, our general intention has been to provide a rich and many-sided view of the requirements management process and its phenomena. Preliminary findings have been presented in industrial and academic seminars, to people involved in and having deep knowledge, or long experience, of concept development and management of requirements in automotive engineering. Most of the people who attended the seminars have their background in the Swedish car industry, international truck industry, or academic product development research. Through these seminars, important feedback has been provided to the researchers prior to final analysis and presentation of findings.

4. Presentation and Discussion of Findings

In this section findings are presented and discussed in relation to guidelines given in product development literature and the hypotheses earlier presented. The findings include descriptions of concrete requirements management issues, as well as interesting phenomena related to the overall development system. There is no point in abstracting general findings from an empirical study in a complex environment without providing a full picture of the context, e.g., the studied project, interrelated factors or phenomena, and real-life examples. Therefore, key findings are presented along with the broad empirical data revealed in the study.

4.1. The Respondents' Self Reports on Requirements

Regarding important factors to pay attention to when selecting design solutions, a dominating opinion among the interviewees is that design solutions should balance functional properties with cost and aesthetics. Some of the respondents also stress the importance of having a holistic, long-term strategy in mind. Naturally, the interviewees also answer from their specific profession's perspective, such as taking geometrical fit and finish, quality, ergonomics or manufacturability into consideration.

To the direct question "Do requirements have to be fulfilled?", about 50% reply *"Yes"* and 50% *"No"*. However, after a short reasoning by the interviewee the answer often evolves and becomes many-sided. A reply that fulfilment is essential is usually followed by the statement that conflicting or unfulfilled requirements can be negotiated. On the other hand, a reply that a requirement does not have to be fulfilled is subsequently followed by the statement that legal demands have to be fulfilled, and that the intention is to meet all requirements. This reflects the various approaches described in academic literature, e.g. considering prioritisation of requirements [2], or categorisation of requirements as demands and wishes [11], [12].

Although the awareness and understanding of the importance of working actively with requirements management has increased in industry, many of the respondents give the advice to proceed with caution and not focus too much on fulfilling requirements. If all requirements specified were complete, set to a reasonable level, correct and well balanced — meaning that internal requirement conflicts were resolved — a fundamental emphasis on fulfilling all requirements would consequently lead to a very good product. But, since requirements are often incomplete and conflicting, a strong effort to fulfil them, without having a flexible approach, might lead to sub-optimisation or project stagnation. This is indicated by several of the interviewees. An associated aspect is sub-optimisation due to particular requirements being too strongly promoted by certain individuals and disciplines.

4.2. Management of Requirements in the Studied Context

Requirements management, in a wide sense, is not a new issue in the automotive industry. Consequently, associated competencies and organisational structures are well established. However, the process is not static, and considerable change has occurred during the professional life of the interviewees. This is evident in the responses given. The most significant change refers to the generally increased focus on requirements in the automotive industry. Operations in general have become more target-oriented, involving more focus on requirements. Furthermore, requirements specifications have become more unambiguous, more structured, and comprise more traceable requirements. Also, subsequent activities, such as follow-up and balancing of requirements, have become more strictly managed. Thus, the processes for managing requirements in the automotive industry are approaching the ideal given in academic literature.

The Swedish car manufacturer has a well-established organisation, involving specialised competencies, dedicated to manage the setting, breakdown, and follow-up of product requirements. Formally, the breakdown of product requirements follows a top-down process starting with overall business and user requirements and ending in component requirements, via complete vehicle and systems requirements, see figure 2. Thus, the approach has similarities with Systems Engineering. Roles associated with each breakdown level provide for the supply and follow-up of corresponding requirements documents with different levels of abstraction and detail. During very early phases, before having any formal requirements specification, e.g. in advanced engineering, a preliminary specification is used based on

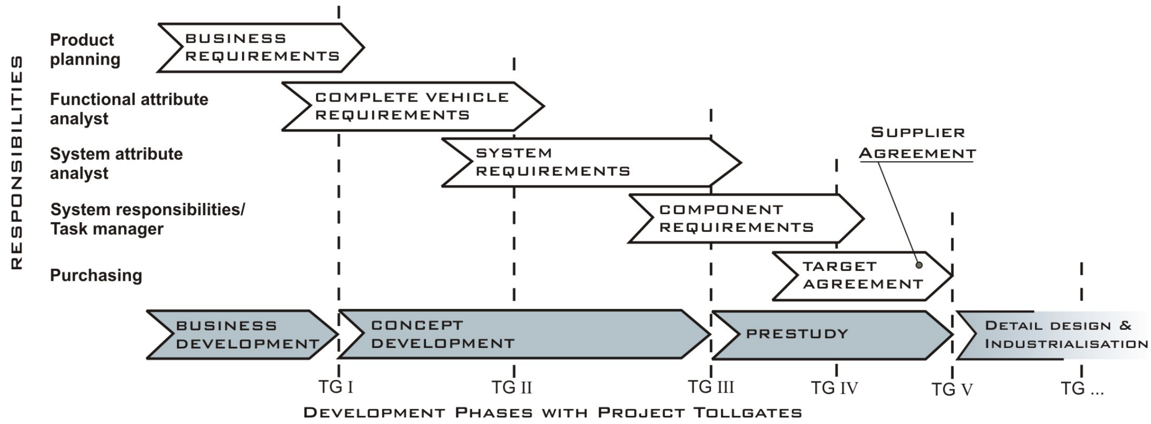


Figure 2. Formal process for breakdown of requirements at the Swedish car manufacturer.

assumed overall prerequisites. Knowledge gained in advanced engineering projects often constitutes a contribution to the formal requirements breakdown process.

Within each development task (sub-project), a standardised design prerequisites document is elaborated on; to capture all engineering requirements for the component or system in question, and summaries of relevant business, complete vehicle, and system requirements. This design prerequisites document is essential during the product development activity within each task, and also constitutes the main reference document for the target agreement between purchasing and (external) supplier.

The shift towards more outsourcing also contributes to a big change regarding the role and management of requirements, relevant to both the car manufacturer and the supplier. The supplier has to manage more complex systems and larger projects, and is thus deeper into car engineering. This also means that the car manufacturer has to make more precise requirements specifications. Often, the requirements specification is also closely connected to contracts between the car manufacturer and the supplier. The evolution can be summarised using the following quotation: *"Everything has changed. When I started the activity on IP (instrument panel) we didn't talk about cockpit. I started with restyling of R4 (restyling of Renault 4 in 1975). It was just a styling part with two switches. It barely had any requirements - they fitted on two A4's. Now it's a book…"*

4.3. Opinions on the Requirements Specification Used

In the minds of the interviewed project members, the requirements specification, particularly the design prerequisites document, is generally seen as a well-functioning document to present important issues for the development. Over the years, the requirements specifications have evolved to become rather complete and well-structured documents, but there is still improvement potential. The main criticism among the respondents refers to the interrelationship between design prerequisites documents for different interdependent systems and components. Even though it is explicitly desired, so far there is no over-arching cross-system design prerequisites document clarifying interfaces and capturing common, important requirements for interdependent systems and components. Furthermore, there is a lot of back and forth referencing between documents, and the access to referred documents is sometimes limited, at least for the supplier. Also related to the use of the documents, is the considerable scale of them and the huge number of requirements included, which complicates an overview. Consequently, some of the respondents request an over-arching cross-system design prerequisites document providing a summary of most important requirements. A further step could be to emphasise a set of key issues, approximately ten, in order to provide a shared cognitive map for the development, and to facilitate evaluation activities. Similar views can be found in academic literature, e.g. by Roozenburg and Eekels [13] who argue that a specification should be concise to be used actively.

However, even if the design and organisation of the requirements documents were perfect, and the content appeared to be complete, the fact remains that some issues are really difficult to state requirements for. The ability to specify technical requirements is seen as good, while more abstract issues, such as perceived tactile feeling in controls and aesthetic values, are said to be more difficult to capture in a requirement. Nevertheless, such factors are highly relevant to the attractiveness of a product. As pointed out among the respondents, it is also important to clarify the meaning and context of the requirements, e.g. to relate them to car type and the end customer experiencing the car in all senses.

Finally, presenting requirements is not just a matter of organising and writing a specification document. As stated by one of the respondents, it is also very important to appropriately communicate the requirements to those concerned. Formal and informal meetings, e-mails, and databases can play important roles, as they have in the studied project.

4.4. Interpretation of the Requirements Specification

With this huge quantity of requirements and number of people involved it might appear prone to misunderstandings and differing interpretations of the requirements specification. Early in the study, we speculated whether different parties would tend to favour their own interests by interpreting requirements differently. This does not really seem to be the case, but there are examples of disagreements between car manufacturer and system supplier originating in their own interests or reference frames. A cause for disagreement, apparent through the interviews, is different views on the importance of a particular requirement or its fulfilment. As stated by respondents at the car manufacturer, the system supplier makes their own prioritisation of the requirements given by the car manufacturer, e.g. to reduce workload, although this should be the responsibility of the car manufacturer. This shows that the car manufacturer has to be much clearer in the prioritisation of requirements.

However, the most significant problem related to the interpretation of the requirements specification are misunderstandings due to the requirements not being clear enough. Responses from several of the interviewees emphasise the importance of providing adequate information, clarifying the context and underlying intent of each requirement, and specifying content and interfaces. The latter is shown to be an important prerequisite, particularly to allow accurate weight and cost assessments, but is nevertheless difficult in early phases when the product definition is incomplete. Another issue in clarifying the requirements relates to the verification (test) method. Considering statements of the respondents, the meaning of a requirement is dependent on the prescribed verification method. Furthermore, it is stated that testing is necessary to really understand how to fulfil a requirement. This emphasises the importance of specifying verification methods for the requirements. Indeed, guidelines found in literature [4] state that each requirement should be assigned a method of verification, including specification of system level for verification, and type of verification, e.g., testing, inspection, or analysis.

In an overall sense, however, the team members' views of driving factors for the project match well the most central requirements stated in the specifications.

4.5. The Evolution of the Requirements in the Project

Having imagined the importance of the requirements for the development work, it certainly becomes interesting to follow the requirements' evolution throughout the development

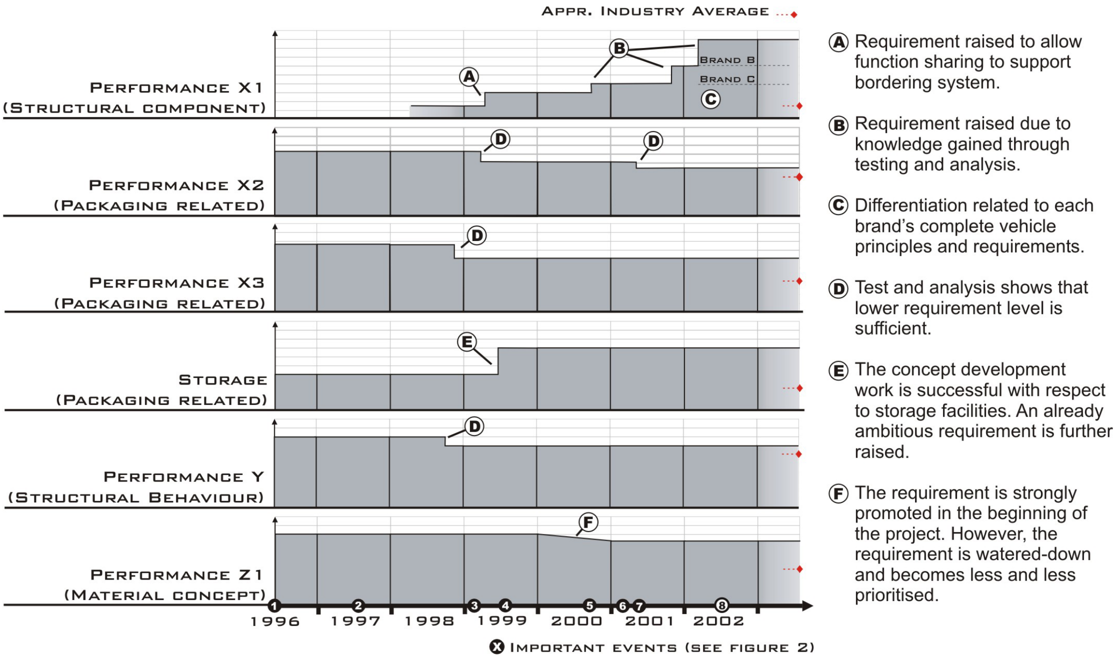


Figure 3. The evolution of six essential product requirements.

process. Based on the results of our studies, it appears clear that requirements are changed, added, and reprioritised throughout the course of the product development. Underlying factors for changes in the requirements specification include changed prerequisites and knowledge gained through the development work.

In figure 3 the evolution of six essential requirements related to product performance or function is reconstructed and put in relation to underlying factors. In reality, and apparent through the interviews, the requirements are not necessarily changed in discrete steps as in the figure. In many cases, a definite change of a requirement in the specification is preceded by discussion and testing of preliminary or orally given requirements.

Weight and cost requirements have been a challenge and kept in focus all through the project but have been adjusted to match technology and function content. An adequate reconstruction of the evolution of weight and cost requirements is very difficult to present here due to that the specification of their related content and interfaces is not clear and varies over time. This reason is also common for the apparent difficulties to adequately follow up weight and cost requirements in the development project.

4.6. The Actual Process of the Follow-up of Requirements

Naturally, the final levels of the requirements do not automatically determine the final performance and functional content of the product. Rather, the final state of the product is determined by how successfully the requirements have been incorporated into design solutions, as a result of activities such as follow up, prioritisation, and balancing of requirements. However, through this research study, these issues have shown to be both more problematic to manage and less sophisticatedly organised than the requirements specification itself. This might be explained by the fact that the complexity of the product and the associated industrial system increases during the course of the project, and thus ideal, well-organised approaches become more difficult to apply, but nevertheless important. As stated among the respondents, in the concept phase it is easy to incorporate all requirements but during the industrialisation phase a lot of requirements have to be reprioritised.

An opinion frequently given by the respondents, regardless of background, is that everyone in the project is responsible for the follow-up of the requirements fulfilment, and thus the matter is a part of the daily work. A few respondents at the car manufacturer also emphasise that some individuals within the company feel the responsibility to act as champions in the continual promotion of key targets and concept principles. As stated by one of the respondents: *"If you are passionate about cars you fight for the best solutions"*. However, as mentioned in section 4.2 and shown in figure 2, there are also certain competencies at the car manufacturer dedicated to managing requirements, including follow-up of requirements fulfilment. Examples are the competencies *Functional attribute analyst* and *System attribute analyst*, whose responsibilities are related to a specific vehicle attribute. As expected, but nevertheless varying from case to case, the requirement specialists have had central roles in the planning of tests, testing, and evaluation of the technical solutions in relation to their respective attribute areas. They have also repeatedly reported on the requirements' fulfilment status, mainly in connection with tollgates. However, since this reporting is not well known among the interviewed project members, it appears that the feedback of the requirements' fulfilment could be improved. Today, the requirement specialists report mainly to the management of the overall car project, but reporting to all concerned project members would provide valuable feedback and increase the motivation to consider the requirements.

In practice, daily work and regularly held meetings in the core team, with more or less permanent members from the car manufacturer and the system supplier, have been very important to follow up the fulfilment of all kinds of requirements. It is evident that this continual communication and co-operative work has been fruitful in many ways, not least with respect to central project purposes and product requirements. However, it is interesting to notice when studying the project documentation that the reporting and feedback often mirror mainly the issues focused or analysed in the work. Thus there is a risk that issues or requirements not focused fall between two stools. This is further supported by views among the respondents, meaning that focused requirements are followed up through daily work or regular meetings, while other requirements are barely followed up at all.

Having analysed the data from the different information sources it can be concluded that most of the central purposes of the project have been taken care of. Nevertheless, there is a great improvement potential when it comes to the follow-up of the requirements and their fulfilment. It is apparent that the priority given to the different requirements in the practical work situation does not adequately reflect the requirements specification or the emphasised central purposes, but rather reflects the resources of the corresponding requirements specialist organisation, or focus of the approaching tollgate. Specifically, it can also be pointed out that requirements not promoted by requirements specialists, or not even covered by specific attribute areas, seem to be implicitly suppressed. Thus, it is desirable to approach a more continual cross-requirement follow-up, providing all involved with a current overview of all requirements' fulfilment status.

4.7 Fulfilment Evolution of Some Key Product Requirements

Looking specifically at the product requirements in the project, one can observe that some requirements, such as packaging related, have to be provided for early and thus their potential for fulfilment is determined early. On the other hand there are also product requirements whose fulfilment is determined late, such as requirements on structural performance, or other requirements that are subject to optimisation and studies of complex inter-relationships. In any case, early consideration of requirements favours their fulfilment. Of course, the requirements' final fulfilment status is also dependent upon how they are continually attended to. Logging the fulfilment of the six essential product requirements earlier presented, these

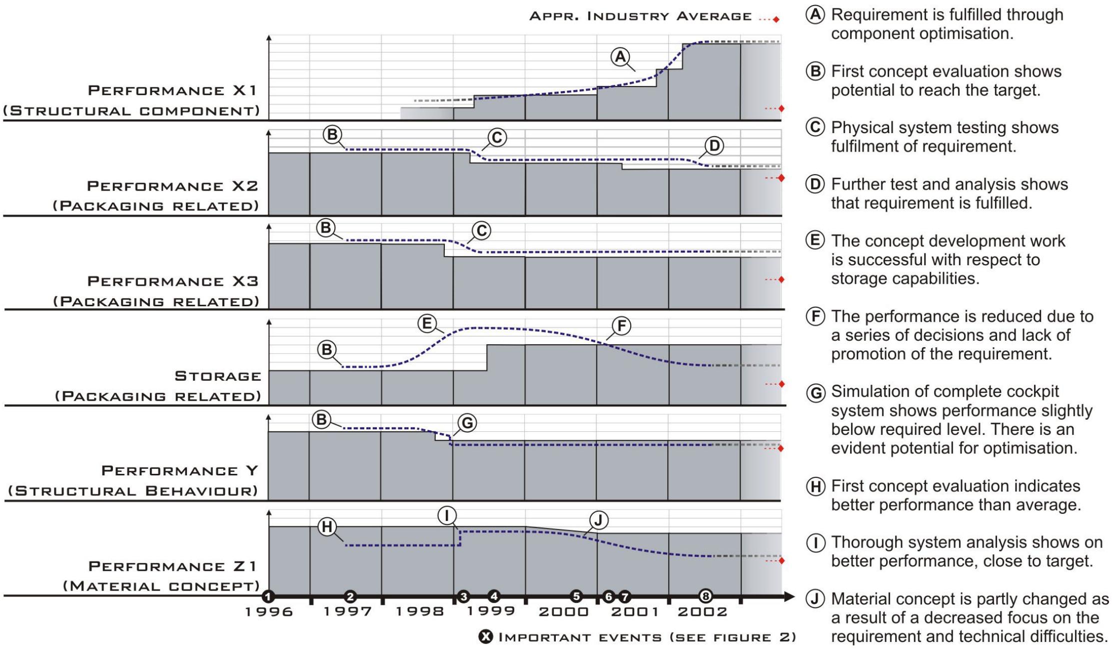


Figure 4. The fulfilment evolution (dotted line) of six essential product requirements.

phenomena are apparent, see figure 4. However, the fulfilment of the product requirements is affected by many other factors which are apparent when following each of the six requirements' fulfilment efforts throughout the project, see remarks A to J in figure 4.

The packaging related requirements *performance X2* and *X3*, have been decreased because of the knowledge gained through analysis and physical system testing. This showed that the requirements on the system could be decreased without affecting overall product performance with reference to complete vehicle requirements. However, it is obvious that if these requirements had not been identified and analysed from the beginning and incorporated into the concept, the search for satisfying solutions would have been very difficult. By addressing these issues from the beginning, the concept solution was architecturally prepared to incorporate the high requirements. This reinforces the value of having a complete requirement specification early in a development project, as often argued in academic literature.

One of the aims of this project has been to create a unique selling point by providing outstanding *storage* facilities, an aim that the whole cockpit concept from the beginning has been prepared for. These efforts were more than successful, and by 1999 the fulfilment of the related requirement far exceeded the expectations. As a consequence, team members and the assignment leader realised that the target, justified by objects possibly stored and their size, could be set higher and the requirement was increased. In spite of these efforts, and the early over-fulfilment of the requirement, the fulfilment of this unique performance level has not been maintained. This has been caused by a series of minor decisions that taken together certainly affect the fulfilment of the requirement. For example, a neighbouring, performance-critical system was left to be designed later in the project and was then allowed additional packaging space. These decisions have been influenced by the fact that there has been no individual responsible for the promotion and follow-up of the requirement's fulfilment, making it politically unproblematic to suppress.

The requirement on the structural behaviour (*performance Y*) was assessed to be reached during early concept evaluation. Subsequent analysis showed that a reduction of the requirement was possible. The first simulation of the complete cockpit system presented performance slightly below the decreased requirement, a very good starting-point for optimisation work. However, at this moment (three years later) performance is still slightly below the requirement level. The optimisation work has been complicated by inter-dependencies between sub-systems and the efforts have not yet been fruitful, although the potential evident.

The last requirement in the graph (*performance Z1*) is related to a core attribute of the brand and was strongly promoted in the beginning of the project, although it is not yet a well-established customer value. However, since the requirement has not gained the support it should deserve in the organisation and management, as stated, its significance has been suppressed and it has become less and less prioritised in the daily work. Add to this technical difficulties and compromises and it is easy to realise why the requirement's fulfilment status is far below the target, yet performance is the industry average. In other words, a requirement that is declared to be important and brought into a specification does not necessarily mean that it will be taken into consideration and fulfilled.

In 1999, design engineers of the core-team in cooperation with design engineers at another development department realised that a structural component in the cockpit structure could be utilised to support a bordering system, i.e. an opportunity for function sharing was identified. As a result the requirement for *performance X1* was increased in order to allow the identified function sharing. The requirement has been fulfilled through reasonable efforts in component design and optimisation activities, even though the requirement has stepwise been further raised due to knowledge gained through testing and analysis. This will result in an overall product that is actually better than expected with reference to the original requirement specification. This has been made possible by engineers that not only look at their own system's interests but also have the competence and possibility to design in a larger context.

4.9. Balancing Product Performance Versus Cost

The highly ambitious targets regarding reduction of product cost and weight have not been reached with the resulting cockpit. Even though the concept's potential cost and weight reduction is partly counteracted by the increased product performance, it is evident that the focus on overall solutions saving cost and weight has become weaker during the course of the project. For instance, the philosophy of physical integration thinking and function sharing that was adopted in the advanced engineering phase has stepwise been watered-down throughout the project. Supported by the interviews, underlying factors for partly retreating from the philosophy include difficulties and unwillingness, at the suppliers as well as among specialists within the car manufacturer, to abandon traditional components and interfaces. In other words, established organisational and supplier structures impede the development of integrated concept principles with architectures optimised with respect to overall performance/cost ratio. On the other hand, a far-driven integration and function sharing might complicate detail optimisation and product design changes.

Late changes (after target agreement, late spring 2001), especially late addition of requirements or features, is a factor that is stated to increase the product cost. It is evident that there have been a lot of late changes, and they are said to have generally been well taken care of through a clear change request procedure. However, there has been a tendency to make decisions at detail level, with limited consideration of overall solutions and overall cost. Another observation is that team members at the system supplier feel that there has been a flood of change requests from the car manufacturer, and that there is no filter, meaning that any engineer can ask the supplier to investigate changes without realising cost and workload consequences. However, even if it is clear that the supplier needs to focus on industrialisation activities, some prioritised changes during the late phases of the product development are inherently necessary to achieve an optimised and up-to-date product.

Over-ambitious requirement levels, e.g. on product performance requirements, certainly may result in a high product cost, but have above all shown to be a factor that might complicate balancing of product performance in relation to cost. In the studied project, individual requirement owners have tended to add a negotiation margin to the requirements. In the spring of 2001, during the progressing industrialisation, the product cost appeared to be too high and intensive cost saving and rebalancing rounds were run. As a result, a lot of changes were made at detail level, including features just eliminated, with limited consideration of overall system solutions and performance/cost ratio. Thus, the product cost was certainly reduced, but the remaining overall system solution still holds prerequisites for features, or performance levels, that are not utilised.

Nevertheless, balancing of overall product performance and performance/cost ratio is a well-known difficulty within the car manufacturer as well as at the system supplier, and a number of structured methods aimed to support balancing activities have been used in different stages of the project. These methods have strengths regarding evaluation and selection of system and component solutions in relation to strategic requirements and cost, and have definitely facilitated the development of a balanced basic concept. However, the analysis of the interrelationships between different systems, or components, is less well supported.

Based on the interviews, it is clear that the daily work is important to stepwise develop a balanced solution. This view is certainly relevant as feedback is continually given in relation to important issues for the development, and as the team members are generally well aware of the most important driving factors. Thus, single balancing activities using well thought-out balancing approaches are not solely determining the balance of the final result, especially as prerequisites are changed and knowledge is gained through the course of the project.

Thus, it can be concluded that balancing is a challenging and multi-facetted task, and it is difficult to provide recommendations covering all aspects. However, reflecting on our observations, we would like, once again, to emphasise the importance of making decisions with regards to overall performance and overall performance/cost ratio. We also encourage a more extensive interdisciplinary requirement analysis and validation dialogue in early phases; in order to obtain a base of shared knowledge and system models, in turn facilitating the development of customer-attractive and cost-efficient product solutions.

5. Discussion of the Research Approach and Use of the Results

The main contributions of this kind of empirical study are the experiences brought to light to provide a deeper understanding of the nature of development activities in practice, and to clarify related central issues, phenomena, and problems. Furthermore, specific phenomena identified, might point out directions for future research and theory development.

When it comes to validity of the results, it should be emphasised that findings from a complex, real-life project are very difficult, or meaningless, to prove in a mathematical manner. Therefore, in this research context, trustworthiness is perhaps a more relevant quality epithet. When carrying out an empirical study, the research approach itself is central to provide trustworthy results. This motivates the attention paid to the research approach in this study, e.g. the thought-out strategy for parallel, multiple data collection and analysis.

Results of qualitative case studies can be argued to lead to generalisation by *recognition* (Svensson et al., [14]). Then, the ability to generalise results is dependent upon how observers of the results react, e.g. if they recognise the phenomena and causal relationships put forward. Thus, the consideration of feedback from the presentation of preliminary results that have been done through industrial and academic seminars plays an important role in arguing for the generalisation of the results presented here. In reflecting the background of people participating in the seminars, and their feedback, the results can be stated to adequately depict the situation in the automotive industry, which in turn has similarities with other branches of industry dealing with multi-technology products.

6. Conclusions

The work procedures practiced for management of requirements in the automotive industry and those described in academic literature are becoming more harmonised. Thus, in the automotive industry requirements are established relatively early in the development process, managed in a structured fashion, and have generally become more and more in focus. Consequently, associated competencies and organisational structures are well established.

The requirements specification used in the context studied is generally seen as a well-functioning document to present important issues for the product development. This view is supported by the fact that the team members are generally well aware of the most central issues for the project. However, misunderstandings have occurred because requirements were not clear enough. Furthermore, the overview of specifications and their requirements for different interdependent systems and components has been found to be complicated due to the sheer scale of the documents and the frequent cross-referencing between them.

Often, individual requirements are not static throughout the project, but rather changed, in one or more steps. Requirement changes are often preceded by oral discussions, and hypothetical testing and consideration of proposals before formally agreed and documented in the specification. This is a natural process since prerequisites are often changed and knowledge is gained throughout the course of the project.

From an overall point of view, the studied project has so far been successful, and most of the central purposes of the project have been cared for. This should mainly be attributed to the continual co-operative work in the core team and to the efforts of the requirements specialists. Nevertheless, the follow-up of requirements and their fulfilment has shown to be more problematic to manage than the requirements specification itself. It is apparent that the priority given to the different requirements in the practical work situation does not adequately mirror the requirements specification or the emphasised central purposes, but rather mirrors the resources of the corresponding requirements specialist discipline, or focus of the approaching tollgate. Specifically, it can also be pointed out that requirements not promoted by requirements specialists or any other discipline seem to be implicitly suppressed.

The balance between functional properties, aesthetics, and cost is seen as a central factor to pay attention to when developing and selecting design solutions. At the same time, in the minds of all parties, balancing of performance and performance/cost ratio is a well-known difficulty, and a number of structured methods are fruitfully used to evaluate and select solutions in relation to strategic requirements. It is also evident that the daily work is central for stepwise development of a balanced solution. Still, there is an evident potential to improve the working practices for balancing requirements and solutions. For instance, requirements setting, late changes, and cost savings are sometimes made with limited consideration to overall system solutions, total property content, and overall performance/cost ratio.

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