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Requirements management in practice: findings from an empirical study 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. More specifically, the intention has been to identify and describe progress, changes, deviations, and compromises regarding the requirements and their fulfilment linked to the different phases of the product development. The logical reconstruction of the requirements management process is complemented with broad descriptions of associated phenomena, such as important events, organisational structures, competences, and attitudes. Findings are presented, analysed and discussed considering also factors underlying observed phenomena. Accompanying the empirical findings, the paper concludes with recommendations for constructive and efficient requirements management in practice.

Keywords Automotive engineering · Distributed product development · Empirical study · Requirements

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1 Introduction

Throughout the development of a new car model, thousands of requirements are established, communicated, transformed into solutions, followed up, and verified. 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, e.g. in terms of product, 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 could 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, project organisation, competence, and attitudes towards requirements and their fulfilment, are taken into account. Finally, the study aims to provide recommendations or guidelines for constructive and efficient requirements management with the focus on industrial application. Thus, the overall ambition with the study is to present a comprehensive empirical material, but not necessarily to provide a full theory on requirements management.

The main body of this paper is arranged as follows: Sect. 2 frames our theoretical and hypothetical starting points related to the studied context, and presents the studied development project. Section 3 thoroughly describes the research approach. In Sect. 4, findings are presented and discussed. Section 5 discusses the research approach and use of the results. In Sect. 6, we state our key conclusions and recommendations.

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 (Pahl and Beitz 1996). Furthermore, specifications are prescribed to be established early and kept in focus all through the development, e.g. as proposed by Pugh (1990). In Systems Engineering literature (e.g. Blanchard and Fabrycky 2005; Stevens et al. 1998), requirements and their management is perhaps an even more central issue. The V-model, see Fig. 1, is frequently used to present an overview of verification and validation activities associated with the development of a system.

During recent years, much research effort has been spent on development of computer support for distributed, co-operative development of complex products, involving requirements management. One example, presented by Feldmann et al. (2002), is a product model based IT tool supporting the stages of product design according to the VDI Guideline 2221. Commercial software products aimed to support requirements management in a distributed environment include, Teamcenter Systems Engineering (UGS 2006), Doors (Telelogic 2006), and RTM (Serena 2006).

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 (1992) reflectively describe how requirements were managed in a NASA project. Weber and Weisbrod (2003) share their experiences and challenges regarding Requirements Engineering in automotive development, after piloting associated processes, methods, and tools in various development projects within DaimlerChrysler. Their experiences and challenges mainly refer to the implementation and use of Requirements Engineering tools but also to the process as a whole. Besides, there exist empirical studies on design teams in industrial practice focusing other areas, such as communication flows in international product innovation teams (Moenaert et al. 2000), collaboration between main and sub-suppliers (Fagerström and Jackson 2002), teamwork (Baird et al. 2000), change management (Fricke et al. 2000), and “Set-based Concurrent Engineering” (Ward et al. 1995; Sobek II et al. 1999).

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 hypothetical starting points has been considered. These involve:

- Failure of the requirements specification to highlight the key issues for development, resulting in different interpretation by different parties.

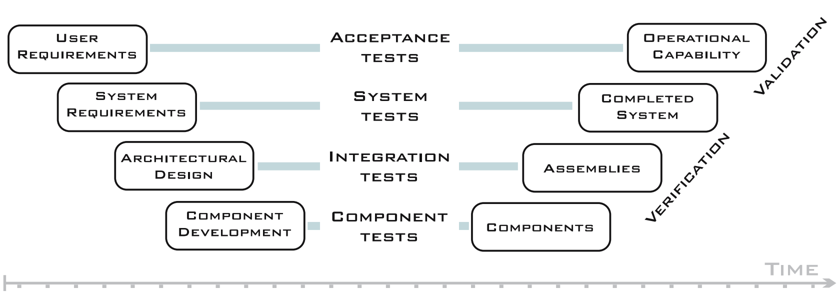


Fig. 1 V-model highlighting validation and verification activities (adapted from Stevens et al. 1998)

- Insufficient knowledge about requirements, or their context, limiting the holistic view needed to develop attractive solutions.
- Late introduction or changes of requirements and features, causing expensive changes, project delays, and affected product attribute balance.
- 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.
- Unclear roles, resulting in inefficient work-split and division of responsibilities.
- Communication problems, intra-company as well as extra-company, leading to inefficient requirements management.

In the more pragmatic sense, these hypothetical starting points have given direction for our data collection and guided our analysis, and will, consequently, be referred to in the paper.

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 geometrical boundaries and functional content of a car cockpit differ from case to case, but components usually included are load bearing structure, steering column, climate system, instrument panel, storage facilities, airbags and other safety systems, wiring, instruments, and controls. In the development project studied, these components are developed and assembled in the car as an integrated cockpit module, which is a philosophy often adopted in the automotive industry. 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.

The development of this cockpit was started in spring 1996, being originally an advanced engineering project[1] at a Swedish car manufacturer, and was gradually extended to become an international industrialisation project involving several car manufacturers and suppliers (Fig. 2). During the advanced engineering phase, systematic design methodology adapted from Hubka's theories (1987) was used for concept development. One of the authors played an active part in this concept development, at that time being a design engineer at the Swedish car manufacturer. Following this systematic design methodology, 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. Thus, the system supplier was already engaged during the concept phase, i.e. relatively early. Platform development activities, e.g. balancing of product synergies and brand uniqueness, 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 development and industrialisation project involving three brands in three countries with different cultures, see Fig. 2. 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. At that time, the concept was already more or less established as the main track for industrialisation for the three brands of the platform. 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. These kinds of activities have been carried out a number of times during the development project, more or less regularly. 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. Add to this management complexity due to each brand's matrix organisation, different

[1] In the actual case, advanced engineering means a strategic development project not closely bound to a specific car project's time plan, aimed at development and evaluation of conceptual and technical principles.

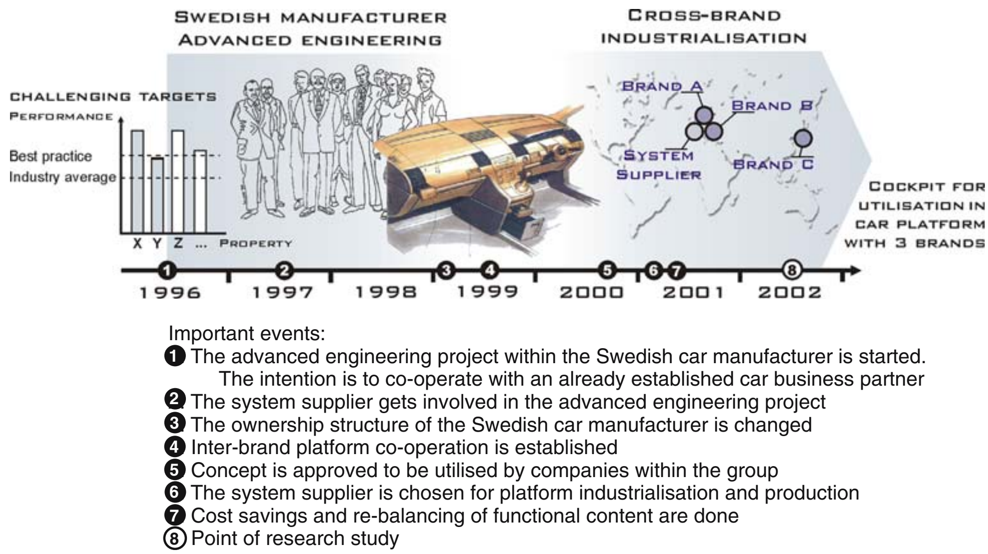


Fig. 2 The evolution of the project illustrated, focusing on important events

organisational structures, outsourcing to the system supplier, and dependence on parent company approval. It is easy to conclude, therefore, that the management structure of the project has been very complicated. So it has been a long and winding road, and the innovative cockpit concept originating in the advanced engineering project has been called into question several times throughout the complete development project, but has repeatedly shown its strengths and will remain the basis for the cross-brand cockpit industrialisation. The first products on the platform were launched in 2003. In 2002, the whole development, from the early concept phase to the current industrialisation, was 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

3.1 General approach and data collection sources

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 (of test series/beta prototype status) 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 addition, preliminary results have been presented in seminars; for testing acceptance of findings and for feedback. Figure 3 depicts the information sources.

The main purpose of the product study, which was done by visual inspection, was to discover the product status in relation to central requirements of the original specification. In addition, the product study provided the researchers with a basic understanding of the cockpit system, as well as ideas for interview topics. Documents studied include:

- initial and yearly assignment descriptions for the advanced engineering project,
- requirements specification used in the advanced engineering project,
- design prerequisites used in the industrialisation phase,
- platform requirements specification (for the three brands),
- concept sheets concisely summarising driving factors and solutions,
- all major project reports from both the car manufacturer and the system supplier describing status and results of different phases,
- validation plans showing test procedures and fulfilment of requirements, and
- descriptions of the prescribed product development processes.

The main purpose in selecting and studying the documents has been to pinpoint the requirements evolution and fulfilment throughout the different

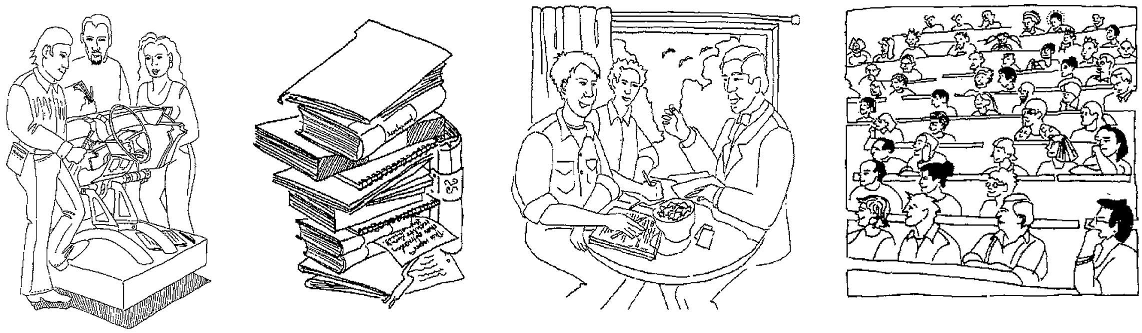


Fig. 3 Information sources: the physical product, documents, interviews, and seminars

development stages, as well as to identify prescribed document standards and procedures for requirements and their management.

However, the interviews constitute the most important information source. In total, 24 semi-structured, approximately 2-h interviews have been held (with 25 interviewees). The selection of interviewees was carried out following a heterogeneous, purposive sampling strategy. As described by Robson (1998) heterogeneous sampling means that there is a deliberate strategy to select individuals varying widely on the characteristics of interest, while purposive sampling means that a selection of typical or interesting individuals is made based on the researcher's judgement. 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. Thus, those interviewed include development engineers and project leaders of the core team actively involved in the development project, requirements engineers, line managers and specialists representing related disciplines. The latter includes different development departments and the purchasing section, and people developing the product development processes. Figure 4 illustrates the interview sample, mainly referring to the interviewees' area of expertise.

The interviewees have experience in product development ranging from 2 to 27 years. In this research study, the selection of respondents was facilitated by the fact that one of the authors had previously been involved in the studied development project.

3.2 Interview strategy

The interviews were done adopting a qualitative approach, basically, but with some elements related to an ideographic approach, as described by Westlander (2000). Based on the approach adopted, the interviews aimed to gather descriptions of the interviewee's views of how the requirements management process took place, in practice, as well as his or her current opinions of and attitudes towards requirements and their management. Thus, mainly qualitative information has been collected, but some complementary elements are in quantified form. This data, brought together with data from the product and document analyses, serves to create a broad empirical basis to support an overall description and analysis of the requirements management process in practice.

The overall structure of the interview guide used in the study follows a commonly used sequence. As formulated by Robson (1998), the general sequence is: Introduction–Warm-up–Main body of interview–Cool-off–Closure. In total, the interview guide comprises 49 questions, some of them multiple, organised in the nine main areas listed below. The areas 2–8 are closely linked to our hypothetical starting-points presented in Sect. 2.1.

1. Opening questions
2. Attitudes towards requirements and opinions on requirements management
3. The organisation and interpretation of the requirements specification
4. Change and (late) addition of requirements and prerequisites during the project
5. Fulfilment and follow-up of requirements
6. Design competence
7. Roles and responsibilities
8. Communication
9. Rounding off

The conversation themes are generally clearly defined, but in most cases the interviewee is free to answer using his or her own words. The questions have been formulated with the intention to facilitate a fruitful discussion, and not to be perceived as offending or negative. The interview guide was tested through pilot interviews with three individuals, after which

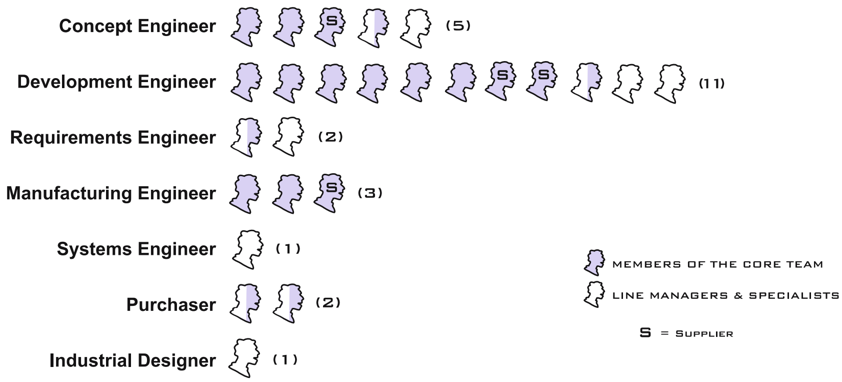


Fig. 4 The interview sample, referring to the interviewees' area of expertise (''Line Managers and Specialists'' concern individuals outside the core team but with insight into the studied development project)

minor changes were made. These three pilot interviews are included in the empirical material.

For each conversation theme, the interview guide includes both open and specific questions. Open questions give the interviewee an opportunity to spontaneously describe experiences, views and opinions in a personal manner and in his or her own words. An example of an open question used in the study is: ''What have been this project's most important purposes and goals?''. When the interviewee has exhausted the theme, specific questions (involving more standardised wording or definition) follow in order to bring forth additional information completing the description of the theme. An example of a specific question, following the open question presented above, is: ''To what degree, in your opinion, have these purposes and goals been fulfilled? Use the scale 1–10, where 10 means high fulfilment.''. When the intention has been to map out an overall picture of a process, multiple questions of the type ''What...Why...-When...?'', or ''How...When...Who...?'' have also been used. The belief behind these questions is that data collected can be used for logical reconstruction of a process according to certain theoretical thinking (see Westlander 1999, ''formal approach''). In contrast, when the intention has been to collect attitudes, an ''empathic approach'' (Westlander 1999) has been used, e.g. when asking: ''What do you feel about this project?''. Theoretically, this kind of question can give as many answers as there are individuals (Westlander 1999). Furthermore, the individual answers may vary considerably from time to time. Thus, the data collected by adopting an empathic approach is very qualitative and diverse, which complicates the analysis. Nevertheless, the approach provides a valuable unobtrusive measure of the actual situation.

3.3 Carrying out the interviews

The interviews were held in a relaxed atmosphere on site at the respective companies. The questions were put to interviewees, who were unprepared except for being pre-informed about the topic of the research study. The conversation was held in Swedish, with the Swedish-speaking respondents, and in English with respondents having English or French as their mother tongue. As a rule, a single respondent was interviewed by two of the researchers, of which usually both, always at least one, made notes simultaneously with the respondent's answers. In most cases, unlimited time was given for answering the questions, but if considerable digression followed an already very full answer the conversation was politely directed to the next theme. The respondent was always respected if choosing not to answer a question. In the event that the question was not clearly understood, it was repeated, if necessary with a different formulation. The sequence of the interview guide was always followed, but sometimes questions were skipped, e.g. when evidently covered by answers to previous questions. In case of limited time, questions were prioritised in order to obtain experiences related to the respondent's specific competence. This prioritisation was generally prepared by discussion between the researchers prior to each interview.

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 and phone calls have been used to resolve unclear interview responses, e.g. when making the data analysis.

3.4 Analysis of the collected data

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.

First, a general scanning of the interview data was made in order to pinpoint most significant findings. Then followed a more systematic analysis and reduction of the complete data material. The data from the document study has been used mainly to support a reconstruction of the more formal description of the requirements management process, but has also been compared with responses from the interviews in order to triangulate the findings during the analysis. The result of the product study has been used only to support the identification of the actual requirements fulfilment. Regarding the interview material, the data has been analysed mainly by comparing responses across the different interviewees. Throughout the analysis, our general intention has been to provide a rich and many-sided view of the requirements management process and its phenomena. In order to increase transparency, typical statements as well as opinions less frequently given by the respondents are used to emphasise and enrich descriptions of significant phenomena. As a rule, in connection to each topic, findings are related to the theory base, including prescribed approaches as well as observations in other empirical studies, and our hypothetical starting points.

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. In total, more than 300 people have attended these seminars; most of them having their background in the Swedish car industry, international truck industry, or academic product development research. Some of the interviewees, as well as some other people having insight into the specific development project studied, are among these seminar attendants. Through the seminars, important feedback has been provided to the researchers prior to final analysis and presentation of findings. More specifically, the seminars have given the opportunity to confirm the accuracy of the data collected, as well as to make sure that all relevant aspects are covered. Thus, the seminars can be stated to be part of the study's "construct validity" (cf. Yin 1994). In addition, the seminars have constituted a forum to scrutinize the trustworthiness of the study's general result; our interpretations and preliminary conclusions included. Furthermore, the draft written report has been provided to all interviewees, and two of them have made a full review.

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 hypothetical starting points earlier presented. The findings include descriptions of concrete requirements management issues, as well as interesting phenomena related to the overall development system and its individuals. 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. When appearing in the text, quotations illustrate typical phenomena or opinions. Figure 5 provides a mapping between the following finding sections and the empirical material used; showing how the different information sources contribute to the respective section.

A discussion concerning our research approach and the validity of the results will be presented further on, in Sect. 5.

4.1 The respondents' self reports on requirements

Requirements play a central part in product development, although their significance and role differs between small autonomous projects, where requirements are used as a means to define an initial purpose, and large development projects, where requirements are also used as a means to manage complex assignments. Whatever the case may be, everybody involved in product development is somehow affected by

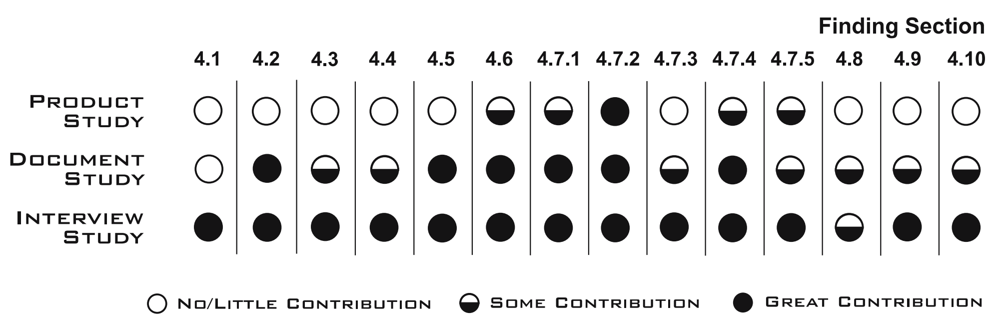


Fig. 5 The finding sections: contribution of different information sources (product, documents, and interviews)

requirements, whether writing an assignment description, performing the design of a system or component, or verifying the result. Consequently, the interviewees have given different perspectives on requirements, including strong product or process perspectives as well as more holistic and pragmatic ones. Since the product is the goal of the operations in the mind of most people dealing with product development, it is not surprising that the product perspective is most common among the respondents (e.g. related to product attributes, technologies, interfaces). The organisation and design of the development, manufacturing and assembly processes (e.g. tollgate systems, test and validation plans) are also mirrored in the individuals' perspective on requirements. However, among the respondents one can also notice a more holistic or pragmatic perspective on requirements, e.g. customer satisfaction with reference to the product's purpose, or requirement evolution throughout a project as a result of knowledge gained. All the above mentioned inherently affect the responses and views presented here.

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 half of the respondents reply *‘‘Yes’’* and the other half *‘‘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 (e.g. Pahl and Beitz 1996), or categorisation of requirements as demands and wishes (e.g. Cross 1994; Olsson 1995).

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. Thus, it is vital, as one of the respondents concludes, that the rationale behind each requirement is brought forward so that requirements can be critically assessed not only when created but throughout a project.

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, and that operations in general have become more target-oriented. As a result, prerequisites and development requirements have become more emphasised, rather than just requirements for the car in production. Furthermore, requirements specifications have become more unambiguous, more structured, and comprise more traceable requirements (from holistic requirements to systems and components, and vice versa). Also, subsequent activities, such as follow-up and balancing of requirements, have become more strictly managed. Thus, reflecting over the evolution, the processes for managing requirements in the automotive industry are approaching the ideal given in academic literature. However, one should remember that several product development procedures presented in literature are basically condensed descriptions of personal experience from work in industry, e.g. VDI Guideline 2221 (Pahl and Beitz 1996) or procedures evolved in government and industry, e.g. Systems Engineering (e.g. Stevens et al. 1998).

The Swedish car manufacturer has a well-established organisation, involving specialised competencies, dedicated to manage the setting, breakdown, follow-up, and verification 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 Fig. 6. Thus, the approach has similarities with Systems Engineering and the V-model shown in Fig. 1. Roles associated with each breakdown level provide for the supply and follow-up of corresponding requirements documents with different levels of abstraction and detail. The professions Functional attribute analyst and System attribute analyst, mentioned in Fig. 6, play an essential role in the analysis, authoring, promotion, and verification of requirements related to a specific vehicle attribute, e.g. crash safety. During very early phases, before having any formal requirements specification, e.g. in advanced engineering, a preliminary specification is used based on state-of-the-art technical knowledge and 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. We have observed that the requirements of the design prerequisites document are usually not neutral with respect to solutions in opposition to what is often recommended in academic literature (e.g. Hubka 1987). This can be explained by the fact that the majority of the requirements are not formulated until the solutions are well known, and that automotive development is characterised by evolution rather than revolution.

During the prestudy phase, platform requirements are also elaborated and agreed. This work is carried out by the car manufacturers in co-operation. The platform requirements specification focuses mainly on commonality and uniqueness issues on a general system level as well as on a specific component level.

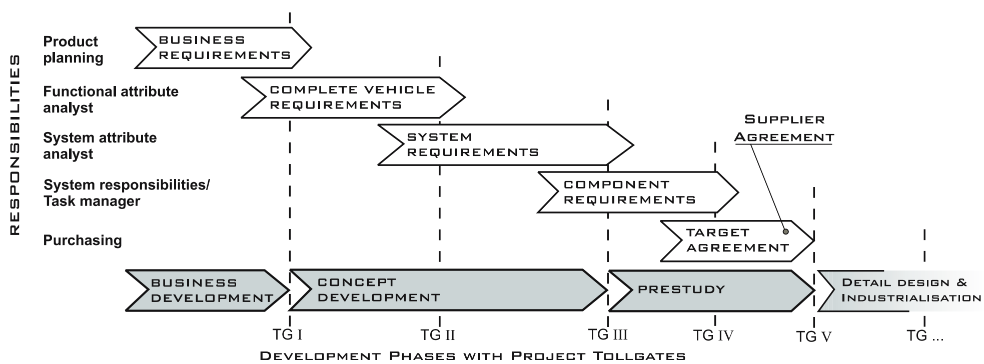
Manufacturing requirements are organised in a similar way as product requirements, but are mainly a responsibility of the manufacturing engineering discipline. The focus is on the car manufacturer's internal assembly process, and requirements deal with, e.g. geometrical constraints related to the assembly line, qualitative design guidelines based on experience, and assembly ergonomics. Management of requirements related to manufacturing of the components themselves is mainly a supplier responsibility.

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...''*

The French system supplier has an organised approach for reviewing the requirements received from the car manufacturer, involving all members of the project core team. First, quality engineering gets and reviews the requirements. Then, the requirements specification is split into smaller parts, which are dispatched to concerned competencies such as project leader, sales manager, system architect, product engineer, and production engineer. Internal reviews are held, with the

Fig. 6 Formal process for breakdown of requirements at the Swedish car manufacturer



different competencies present, in order to follow up the work of the team and to prepare for feedback to the car manufacturer. Regular meetings with the car manufacturer are held to provide feedback and have a dialogue. There is also a system of verification and validation plans, which are negotiated and agreed with the car manufacturer, e.g. regarding what has to be done and by whom.

4.3 Opinions on the design and content of 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 among the interviewees, 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. Reflecting on this, 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 (1995) who argue that a specification should be concise to be used actively.

Regarding the detail level to which requirements should be broken down there are considerably differing opinions, among the different respondents as well as in the mind of each individual. A too detailed break down of requirements may result in too many requirements, and may inhibit optimisation and creativity. A less detailed break down may better allow the utilisation of supplier competence, but may result in differing interpretation and misunderstandings. Thus, and supported through the interviews, the issue is a matter of how firmly it is desired to manage the development work, and trust to the development team or the supplier.

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 one 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 product content and system 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 (Stevens et al. 1998) 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 the studied project, some disputes between the car manufacturer and the system supplier have occurred regarding the content and interpretation of the requirements specification, mostly in connection to requirements' changes and job-split issues. This further emphasises the need for clear, crisply formulated requirements. On the other hand, thanks to close co-operative work, discrepancies and misunderstandings have usually been detected and solved quickly.

4.5 The team players' views on important purposes and goals for the project

To get an indication of the driving factors that are actually in the minds of the team members in the project, the interviewees were asked ''What have been this project's most important purposes and goals? Can you mention six?'' No suggestions were given, meaning that the respondents were free to answer in their own words. Consequently these answers overlap, making it difficult to reduce them to coherent sub-groups. Nonetheless, the answers indicate that the most important driving factors in the project are cost, performance X, weight, platform commonality, and aesthetics, see Fig. 7. We have also observed that the answers, with a few exceptions, match well the most central requirements stated in the specifications. In addition to the 15 presented in Fig. 7, a further 43 different answers were given, such as packaging efficiency, company knowledge enhancement, utilisation of computer aided engineering tools, profit, time keeping, and creating an innovative interior.

Thus, it is not only ''hard'' product-related drivers, such as weight, manufacturing and quality, that are said to be important purposes and goals, but also ''soft'' drivers, such as work methods, supplier involvement, and company knowledge enhancement. Accordingly, the members in the team carry a very wide range of driving factors, involving both hard and soft issues that mirror their daily work as well as affect the final result. One can note that the employees at the system supplier are much more focused on activities than on product related issues. A possible explanation is that the supplier is more focused on carrying out given assignments while the car manufacturer's success depends highly on the product as experienced by the end customers.

4.6 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 process. Based on the results of our studies, involving all information sources, 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:

- knowledge gained through the development work (e.g. through testing),
- requirements found to be conflicting,
- technical difficulties to meet a high specification,
- opportunities for function-sharing and synergies,
- unexpected demands for cost savings,
- new legal requirements, and
- unexpected competitor situations and customer preferences, resulting in changed market requirements.

These factors can be compared with the three main reasons for changing requirements, in a general sense, identified by Wenzel et al. (1997), cited by Fricke et al. (2000): *Technological Evolution*, *Competitors*, and *Customers*.

In Fig. 8 the evolution of six essential requirements related to product performance or function is reconstructed (based on all data sources, see Fig. 5) 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.

It is interesting to observe that there have been no noticeable changes of the performance requirements as a result of the platform co-operation. Interpreting the responses, this is explained by the fact that the requirements used in the advanced engineering project were generally high in comparison with the industry average.

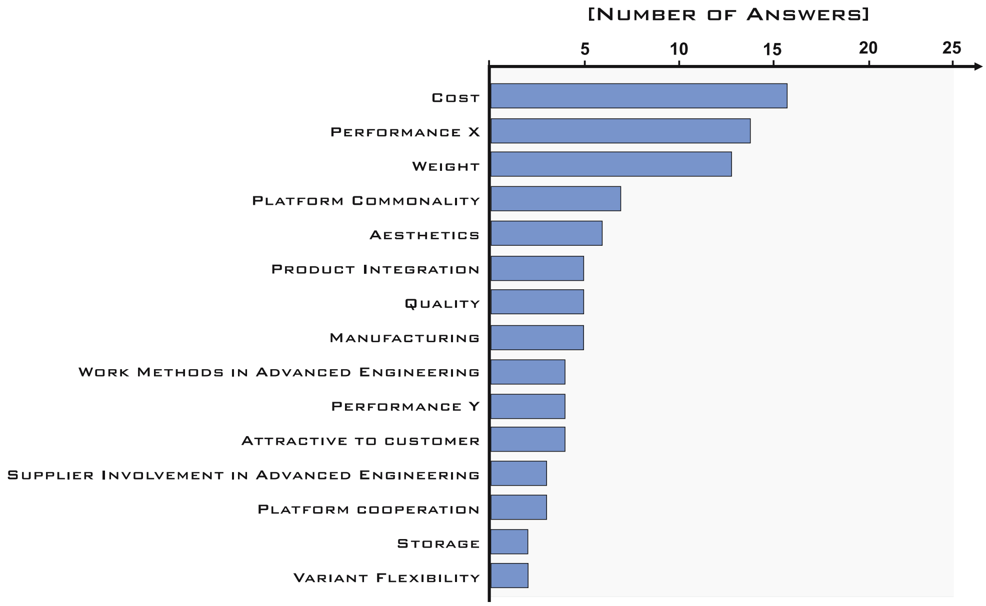


Fig. 7 Driving factors in the minds of the team members (performance *X* and *Y* are masked definitions related to core attributes of the brand)

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 product content and system 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.

Requirements for commonality have also been focused throughout the project. One observation is that the requirements related to commonality have changed character over time. During the early development phases, requirements emphasised the concept's provision for flexibility regarding product range using common components. The platform requirements specification established during the cross-brand platform development phase specifies, more specifically, common and unique requirements and components at detail or sub-system level. In the platform requirements specification there is also a general requirement on value commonality (refers to manufacturing and development costs).

4.7 Follow-up, balancing and fulfilment of requirements in the project

4.7.1 Process aspects

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 Sect. 4.2 and shown in Fig. 6, 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*

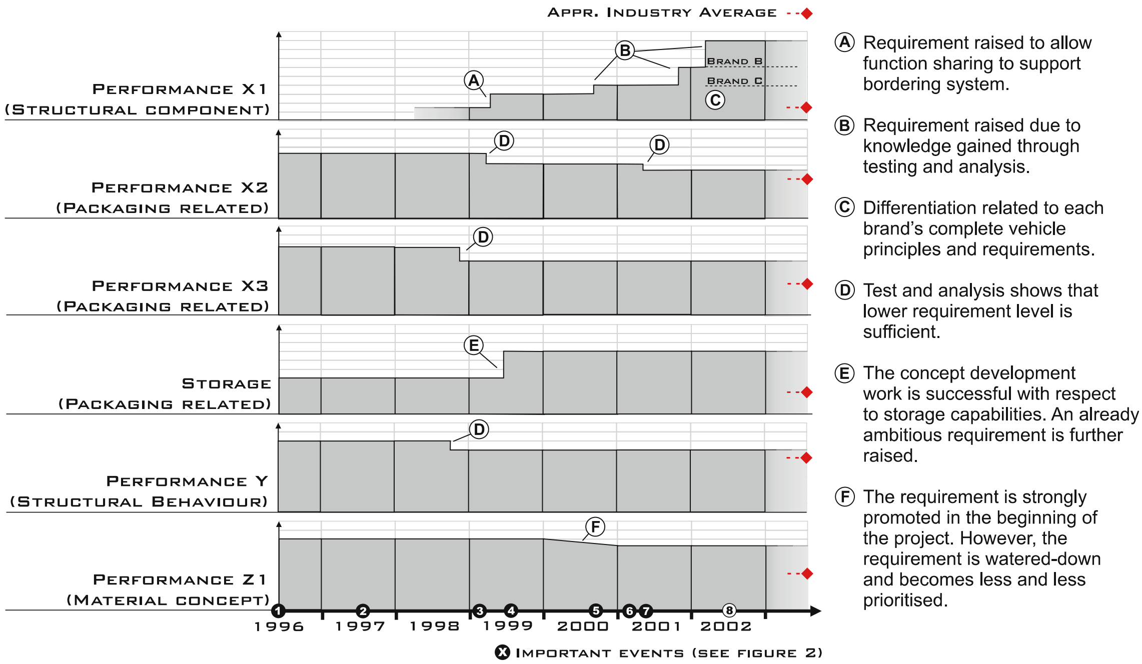


Fig. 8 The evolution of six essential product requirements (a high level in the graphs corresponds to a high product performance level)

and *System attribute analyst*, whose responsibilities are related to a specific vehicle attribute. In the studied project these requirement specialists, besides the members of the core team, have certainly played important roles in the follow-up of product requirements and their fulfilment. As a rule, though they vary, depending on attribute, sign-off processes in one or two steps have been used as a means to support the communication and follow-up of the requirements. At each sign-off, the requirement specialist and the task manager for a system or a subsystem formally agree on requirements related to the vehicle attribute in question. The fulfilment of the product requirements have been analysed using computer simulations or testing of physical objects, or both, either at the car manufacturer or at the system supplier. 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, with some exceptions, 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. A parallel phenomenon, indicated among the respondents, is that deviation reporting adopted as the principle to follow up requirements may result in issues falling between the stools. Deviation reporting is often used for follow up of requirements in the co-operative work between the car manufacturer and the system supplier and aims to save time by focusing only on the problems. However, since the same question about requirement fulfilment is not repeatedly asked, and there is thus no continual requirement follow-up, the risk is that issues are lost. In addition, one can hypothesise that focusing also on the achievements, not only on the deviations, would increase the team members' motivation.

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, available development competence, 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.

4.7.2 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 phenomena are apparent, see Fig. 9. 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 Fig. 9. In the following sections, each of the six requirements' fulfilment evolution, including design rationale, is described in more detail.

The packaging related requirements *performance X*2 and *X*3, 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. This unfavourable mechanism to overlook requirements in other design contexts has been studied by Chakrabarti (2003) during protocol and observation studies of individual designers.

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 the moment of the data collection the performance was 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 Z*1) 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

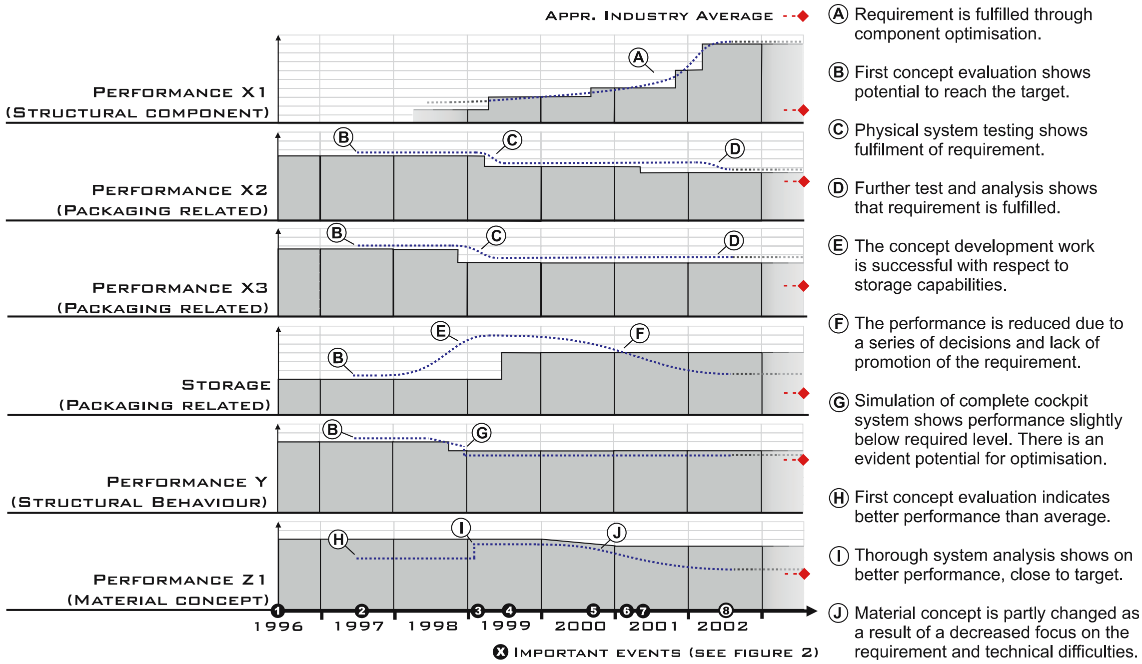


Fig. 9 The fulfilment evolution (*dotted line*) of six essential product requirements (a high level in the graphs corresponds to a high product performance level)

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 X*1 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 certainly 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. However, an important necessity for this is to have an organisation flexible enough to allow new ideas to be adopted and brought into the specification. Referring to literature, this design case including iterative knowledge enhancement exemplifies *opportunism*—a phenomenon that Maiden and Gizikis (2001) and Nguyen and Swatman (2003) find essential in requirements management.

4.7.3 Incorporation of manufacturing requirements

In general, and regardless of background, the interviewed team members think that manufacturing requirements have been managed in a good way, in the sense that requirements related to the car manufacturer's assembly process, the supplier's production process, materials, geographical locations, quality, cost, and resources have continually been considered. This favourable situation is attributed mostly to the early and continuous involvement of the system supplier as well as the car manufacturers' internal manufacturing engineering discipline. Considering the car manufacturer, a general observation is that manufacturing issues to a great extent are managed through experiences owned by manufacturing engineers involved in the project, and that manufacturing requirements are experience-based rather than specifying purposes and goals, and describing expected results. Another observation is that the team members at the car manufacturer seem to be less actively involved in the satisfaction of component manufacturing requirements as a result of the increased responsibility given to the system supplier. At least for the authors, the long-term effects of this are not clear, e.g. in terms of drained manufacturing competence at the car manufacturer, leading to difficulties to critically assess production processes in relation to desired product design.

4.7.4 Incorporation of commonality requirements

Basically the same cockpit concept is used in the three brands on the platform, involving several car types, which means that commonality has been successful in terms of concept principle. Thus, it can be stated that the early requirements emphasising the provision for flexibility regarding product range using common components have had the intended effect, although these requirements actually referred to a different platform scenario considering co-operation between the Swedish car manufacturer and its previous business partner. Indeed, later commonality requirements specifying common requirements and components on a detail level also facilitate commonality regarding the concept principle. However, not only have the specified requirements related to commonality facilitated concept commonality. In the platform project the Swedish car manufacturer has strongly promoted the concept, including justification of solution principles in relation to benefits and strategic issues. *"It was certainly a terrific focus on promoting the benefits—it's been very hard work"*, as formulated by one of the development engineers. The system supplier also took an active part in the promotion of the overall concept as well as commonality issues and has thus increased its chances of being selected to supply components to all three brands. In other words, the system supplier potentially had much to gain from commonality.

Comparing the actual cockpit configuration of the three first cars (three brands) on the platform, it appears that commonality at component level has not been fully adopted in the development project. This might be explained by the fact that the collaborative platform work took place late, i.e. after the actual concept development work. On the other hand, a view supported by information from the interviews is that the actual level of component commonality is well balanced considering the car brands' different driving factors and cost frames. However, there are examples of design differences at detail level that are very difficult to relate to core attributes of the brands, but rather to each brands' corporate standard requirement levels. One example is design differences regarding the climate unit due to the three car manufacturers' different standard requirements on foot space. This shows the importance of making joint efforts to define and agree commonality and uniqueness issues in relation to brand-specific goals.

Regarding a more strategic, or ideological, view on commonality, it was stated that the car manufacturers are in agreement about the use of common components, but not about the requirements. The philosophical question that then follows is to what extent it is possible to design common components for requirements that are different due to brand.

4.7.5 Balancing product performance versus cost

Attested by facts, 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. Actually, in the academic literature there are also few examples of methods considering these kinds of interrelationships. One example, though, is the design structure matrix (DSM), which can be used, essentially, for the analysis of complex interrelationships between components or interfaces of a design, e.g. as shown by Pimmler and Eppinger (1994) or by Sosa et al. (2000). However, in the development context we have studied, multi-attribute relationships between different systems should be considered. Thus, in practice, a DSM would not provide an efficient balancing support, as the matrices would have to be fed with a huge amount of information and consequently also be very complicated to handle.

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.

4.8 Between requirements and solutions

The basic perspective adopted in this paper, in conformity with prescribed procedures in literature and industry, is that product development is driven by requirements. However, as can be traced in the previous sections, solutions are not only justified by driving requirements. The underlying rationale for solutions is also a result of many other factors contributing to the composition of the final design, such as skills to conceive and design, individual participants' beliefs, desires and intentions, misunderstandings, and influential individuals' abuse of power. The rationale behind the present system solutions for the cockpit has partly been recounted in project documentation as a result of the daily work. However, to a great extent design rationale is tacit by nature, meaning that a lot of it is more or less consciously carried in the minds of the team members. Based on the interviews it is evident that the team members, with a very few exceptions, have a very good system understanding, e.g. of why system elements have been selected and designed the way they have.

Designing is far from a logical pattern of information processing and exchange, which in the light of incomplete and changing information rather proceeds under great uncertainty. Thus, many parts of the design must be carried along unresolved, and designers are forced to make assumptions about things such as initial requirements and inter-related systems. This becomes apparent since many of the respondents state that if prerequisites or requirements needed are not available, and cannot be given by responsible actors, assumptions have to be made. As stated by Coyne et al. (1990) designers appear not to resolve all inconsistency problems as they arise, but sustain many lines of reasoning, deferring a resolution of the problem until the moment when it is necessary to make a decision.

Thus, in this context designing is a socio-cultural process, in which different participants, with different competencies, responsibilities and interests harmonise their claims and proposals and finally agree about appropriate requirements and solutions.

4.9 The team players' views on the project result and the fulfilment of important purposes and goals for the project

As we stated in the introduction of this paper, the result of development activities, e.g. in terms of product, does not always mirror the driving factors for a project, and is then most likely to be regarded as less successful than originally expected. This might be true if the result is strictly compared with the requirement specification. However, considering the turbulent nature of a complex project it would not be surprising if team members consider a project to be successful and feel pride even if all requirements are not fulfilled. Therefore, besides logging the actual requirements fulfilment, we also wanted to capture the fulfilment of important purposes and goals through the eyes of the respondents.

Interviewing the team members it is clear that all involved feel proud of the achievements in the project. This is evident as the open question ''What do you feel about the project?'' typically results in answers such as ''*It is probably one of the projects I will stay very proud to have worked with*'' and ''*I will enjoy seeing this car on the road, a high job satisfaction*''. The interviews are also characterised by an enthusiasm and fighting spirit that have obviously driven the pioneering work that this project has been faced with. Words often used by the respondents when talking about the projects are; fun, inspiring, dynamic, challenging, and interesting.

When the respondents were asked to state the project's most important purposes and goals in their own words (presented in Sect. 4.5), they were also asked to estimate the fulfilment of the respective purpose or goal they mentioned. As responded, the interviewees think that most purposes and goals generally have a high fulfilment. Having analysed the empirical data, it is clear that the answers given correspond well with the actual high fulfilment status of the requirements in the project.

4.10 Supplier collaboration

Naturally, the car manufacturer and the suppliers have a common interest to bring forward a product that is commercially successful. Yet, at the same time, the parties are in a sense in competition with each other because they also need to contribute to their respective company's profit and sustainability. Since car manufacturers are closer to the end consumers, they are very dependent on the final product's attractiveness to customers and total cost, while suppliers' profit is more reliant on revenue related to contracts, and investments in knowledge, technologies and manufacturing capabilities. Consequently, the parties might have different preferences for design solutions and manufacturing processes. Having this in mind it is not surprising to see that respondents within the car manufacturer have observed that suppliers have a tendency to follow their ''normal specification'', i.e. that they passively oppose adopting solutions or specifications that might lead to changes in their development or manufacturing facilities; at least those changes that subsequently decrease return on investment.

Even if outsourcing of development projects, or parts of them, might facilitate better utilisation of supplier competence and implies shared development cost and risks, it is certainly associated with some delicate strategic as well as practical problems, e.g. related to requirements management. For instance, many of the respondents, both within the car manufacturer and at the system-supplier, stress the problem of communicating and cascading requirements, especially down to sub-suppliers. As described by one of the system supplier respondents, the real difficulty is how to take relevant chunks out of the requirement specification and dispatch them to concerned sub-suppliers. Furthermore, interviewees from the car manufacturer stress their concern about how system suppliers in general can adopt brand values and, based on a specification, develop a product with a specific product identity - an identity that not even experienced designers at the car manufacturer can really put their fingers on. As one respondent concludes, *''Every company has a brand DNA, something deeply embedded in the company culture. It's a kind of a feeling for problem solving and how to talk to one another that has been passed on from person to person. This influences the way problems are solved and thus how the product is designed''*. The potential for success of outsourcing activities is naturally dependent upon the degree of maturity and complexity of the product and the form for collaboration between the two parties, e.g. collaborative joint venture or outsourcing of a whole project.

Since product identity and brand uniqueness has become increasingly important with the flood of similar products on the market, one can speculate whether or not outsourcing of development projects is compatible with the requirement for product success. Perhaps, outsourcing can be seen as a fruitful business in the short term, since there are skilled people available with a good system understanding that can specify relevant requirements. However, as this system understanding has been gained through years of personal engagement in development activities, one can speculate about the long-term effects when this knowledge is drained at the car manufacturer.

Apparent through the study is that the collaboration in practice between the Swedish car manufacturer and the French system supplier, including a formal as well as an informal requirements dialogue, has been continual, close, and in many ways fruitful. In this context, a specific request raised by supplier respondents is that the car manufacturers should respond more quickly to questions from the supplier. The system supplier has spent substantial effort on gathering and organising all requirements, initially from the Swedish car manufacturer and later on from all three brands. Maybe not evident to the project parties respectively, but evident through this study, is that the system supplier has played a central role in the negotiation of contradictions, and development of satisfying solutions in the cross-brand collaboration.

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 development 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 (Sect. 3).

A specific difficulty important to consider is the reconstruction of events that took place several years ago. These reconstructions have been facilitated because one of the authors played an active role in the early phases of the studied development project, which supports a relevant interpretation of responses and documentation. Furthermore, the respondents cover the different phases of the project, and some of them have been involved throughout the whole project.

Results of qualitative case studies can be argued to lead to generalisation by *recognition* (Svensson et al. 2002). 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. Among other things, the attendees at the industrial seminars commonly acknowledged the pattern of requirements changes over time, and associated causes, as described in Sect. 4.6. 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.

However, in a single case study *transferability* (cf. Guba and Lincoln 1989) is just as important as generalisation. Therefore, we have provided a rich, many-sided description of the study and its results, so that the experiences revealed can be transferred to secondary observers and researchers that may want to apply the findings in other settings. Thus, our intention has not solely been to provide generalisations, but also to present experiences, and make it possible for external observers to make their own generalisations.

6 Conclusions and recommendations

This paper contributes with experiences from current practice on managing requirements in the automotive industry. Experiences range from administrative to operative aspects of requirements, from the company-wide to the individual level. Administrative aspects of complex requirements management are well covered in the Requirements and Systems Engineering community (Blanchard and Fabrycky 2005; Hull et al. 2005; Kotonya and Sommerville 1998; Robertson and Robertson 1999; Stevens et al. 1998). However, it does not encourage the role of requirements as innovation drivers and mediating objects in multi-disciplinary teamwork, thus having a rather formal perspective on requirements. Engineering Design methodology (Cross 1994; Hubka 1987; Pahl and Beitz 1996; Pugh 1990; Roozenburg and Eekels 1995; Ulrich and Eppinger 2003) indeed promotes the generation of requirements driving value and associated product solutions. However, it lacks attention on the complexity of large development organisations and projects. While considering these perspectives in literature, this paper complements the subject area with the diversified picture of real-life management of requirements. In the following we state the main conclusions of the study.

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.

In the complex development environment studied, a continual, strong focus on requirements is seen as essential for the creation of good products. At the same time, a common consideration is that too forceful and formalistic striving to fulfil them might result in sub-optimisation or project stagnation, since requirements in practice are often incomplete or conflicting.

The requirements specification used in the industrial 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 interviewed 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.

Outsourcing of design and production inherently accentuates the need for managing requirements, and clearly defining and communicating brand core values. However, based on the case studied, it is clear that providing a requirements specification fully encompassing project intent and brand identity is not an easy issue. Whether this mostly depends on the car manufacturer's ability to formulate requirements or the supplier's interpretation and prioritisation of the requirements is difficult to tell. Nevertheless, the study shows that suppliers have a tendency to follow their ''normal specification'', i.e. that they make decisions in line with their own preferences. Thus, there is a risk that the car manufacturer's intent is watered down. This risk can, naturally, be alleviated by organising a close collaboration.

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. Weber and Weisbrod (2003) share this view in stating *''Change and discussions about change are part of daily project life—and there's no way to change that''*. The insights regarding the requirements specification and the evolution of individual requirements lead to the following recommendations:

Recommendation: Emphasise a set of key issues, approximately ten, in order to provide a shared cognitive map for the development, as well as to facilitate subsequent evaluation activities.
Recommendation: Elaborate a concise, over-arching cross-system requirements specification providing a summary of most important requirements.
Recommendation: Clarify the individual requirements. Clarify the context and underlying intent of each requirement, define interfaces, specify verification method, and prioritise or assign weightings.
Recommendation: Establish requirements early but be open-minded to changes of requirements.

Most of the central purposes and high stated requirements 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 both more problematic to manage and less sophisticatedly organised 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, or not even covered by specific attribute areas, seem to be implicitly suppressed. Another observation is that deviation reporting as the principle to follow up requirements may result in issues falling between two stools. Reflecting on the observations concerning follow up and fulfilment of requirements, the following recommendations can be formulated:

Recommendation: Approach a more continual cross-requirement follow up, providing all involved with a current overview of all requirements' fulfilment status, with focus on the key issues for the development. Pay attention to progress and good ideas, in order to motivate the people involved.

Recommendation: Ensure that the key issues for the development project are well rooted in management and organisation.

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. Thus, with regards in the working practices for balancing, the following recommendations can be given:

Recommendation: Emphasise the importance of making decisions with regard to overall performance and overall performance/cost ratio.
Recommendation: 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.

During the platform collaboration phase, the project organisation and management structure have been very complicated, involving international development activities on a platform with three brands and many variants. A lot of team members feel that substantial energy has been spent on communication with different parties in the platform work, and even to the degree that the actual development work has suffered.

Commonality at component level has not been fully adopted in the development project. One explanation is that the collaborative platform work took place late, i.e. after the actual concept development work. Another view is that the actual level of component commonality is well balanced, considering the car brands' different driving factors and cost frames. However, there are examples of design differences at detail level that are very difficult to relate to core attributes of the brands, but rather to each brand's corporate standard requirement levels and solution preferences. These findings lead to the following recommendations:

Recommendation: Consider a co-located, cross-disciplinary team for the inter-brand platform development activities also, in order to facilitate an efficient collaborative work.
Recommendation: Spend early, collaborative effort on defining and agreeing commonality and uniqueness issues in relation to brand-specific goals.

The issues presented above, conclude our major generalisations emerged from the empirical material. In this view, recommendations may be considered as prescriptions for constructive Requirements Management, but also as opportunities for future research studies. The recommendations given reflect a perspective focusing on the role of requirements in collaborative development work, which complements the formalised process views typically found in Systems Engineering and Requirements Engineering literature.

Reflecting on the insights gained through this study in relation to our hypothetical starting points presented in Sect. 2.1, we can conclude that most of the starting points, as presented, touch upon important problems in industrial practice. However, the view on the subject matter in general and the hypothetical starting points in particular has certainly turned out to be more multi-faceted and nested. It should be noted, in particular, that unclear roles were hypothesised to cause problems. This has not gained any support through the study.

Beyond the conclusions and recommendations presented, the study with its open approach resulted in some accompanying insights not directly related to the main scope and hypothetical starting points, but nevertheless interesting to consider. First, a perfect requirements specification does not guarantee a perfect product. A requirements specification can never—-fully—cover all aspects of an envisaged product, and a strong focus on requirements does not guarantee a successful search for solutions. Second, informal requirements management, such as inter-personal requirements dialogue, is essential. Finally, being passionate about the product overcomes many problems. Thus, product development processes and organisations do not solely determine the ability to design attractive products.

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