Issues Related to Development of E/E Product Line Architectures in Heavy Vehicles

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Abstract

The amount of electronics in vehicles is growing quickly, thus systems are becoming increasingly complex which makes the engineering of these software intensive systems more and more difficult. In the automotive industry the use of product line architectures enables a set of vehicles to share architecture to decrease cost and increase quality. In this study we investigate key issues related to real-world decisions regarding electrical and electronic product line architecture for heavy vehicles. To extract key issues a multiple exploratory case study at two heavy vehicle manufacturers was performed. We used semi-formal interviews complemented with a survey to validate the results. The contribution of this study is 14 issues that reflect the situation at the two companies. Many of the identified issues relate to non technical areas such as organization, process, methods and tools, and management. Moreover, possible actions to deal with these issues are discussed.

1. Introduction

The automotive industry has in recent years witnessed a dramatic increase in functionality based on electrical and electronic components. According to some sources, 80% of the innovations in a vehicle come from electronics [18]. Many of the advances seen in the automotive industry, for instance in areas such as safety, emission control, comfort, and quality, would have been impossible without the use of advanced computer-based systems. Also, electronics can be used to reduce cost, when expensive mechanical components are replaced by cheaper electronic controllers. However, there are many challenges related to developing these systems. In this paper, we present a case study that tries to establish how two different heavy vehicle manufacturers deal with the development of the overall electrical and electronic (E/E) system architecture, and what important issues remain to be solved.

1.1. Context description

Although the electronics has a great potential to improve vehicles, the systems are becoming increasingly complex and that makes the engineering of these advanced computer-based systems more and more difficult. The functions are in many cases safety critical, requiring special care to handle any circumstances that may possibly occur during operation. At the same time, the system has a very long life time where only sporadic maintenance can be assumed. The products are mass-produced, so assembly must also be very efficient. Due to the fact that almost all heavy vehicles are sold business to business the customer puts extra consideration in the overall profitability of the product, instead of just the cost of purchasing the vehicle. Quality attributes such as availability and maintainability are important factors in reaching profitability for this kind of products.

Due to varying customer demands, but also due to different legal requirements in the countries in which the products are being sold, many variants of the product must be designed and verified. To handle this, and to be able to have reasonable production volumes of each system, the Original Equipment Manufacturers (OEMs) usually employ a platform strategy in which many components are common across a range of products. A platform is normally refined over many years, and each vehicle therefore has to cope with an extensive amount of legacy both in components and in the overall structure.

With this multiplicity of products and variants, the architecture is becoming very important and is a source of increasing interest for the OEMs. An architecture can be defined as the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution [2]. An automotive electronic system architecture can be described in many ways using different views. A common view used is the physical view showing where the different Electronic Control Units, ECUs, are physically placed and also shows how they are connected to each other.
via different networks with protocols such as CAN, Flexray, MOST etc.

Another view that is important is the logical view. The logical view describes logical relationships and how different components depend on each other logically. The logical view is independent of the physical view. However there might be physical limitations that will favor a different logical solution.

A view that is more unique for an automotive E/E architecture compared to general software architecture is the electrical view. This view shows the electrical distribution in form of cabling, fuses and power generation and storage.

Typically, the definition of the architecture is done early in the development phase, and is a prerequisite for the detailed system design. Therefore, architecture development is a key activity in which many important decisions are made directly or indirectly.

Many of the vehicle manufacturers are part of larger, multi-brand corporations. This means that additional complexity is generated by sharing platforms, architectures, and systems across several brands, while still maintaining the uniqueness of each brand. Also, much of the system development is done by suppliers, and the main responsibility of the OEM is providing requirements and later integrating the different systems together. This further adds challenges to the development.

It should also be mentioned that the OEMs are very large organizations, in which thousands of engineers are involved in the development of a new vehicle. The suppliers are just as large or sometimes even larger than the OEM, meaning that even more people participate in the complete project. Since the architecture is a basis for integration activities, it is a place where many interests meet. Therefore, organizational and management issues are closely related to the architecture development.

1.2. Research question

The purpose of this study is to get a deeper understanding of how decisions are made when developing the electronic system of a vehicle. In particular, we would like to improve the knowledge about factors involved in a real-world situation, in order to be able to later provide solutions that are realistic and effective.

The concrete research question we address is therefore as follows:

What are the key issues affecting real-world decisions regarding a heavy vehicle’s electrical and electronic system architecture?

With real-world we mean not only an industrial setting, but also what the people in that industrial setting consider to be the most important issues. Hence, it is how people perceive the current situation at that particular company we focus in this study.

Naturally, the answer to this research question must be sought at the companies carrying out development of electronic architectures. Also, it cannot be assumed that only technical issues are related to this question, but also organization and management, as well as processes, methods, and tools must be considered.

1.3. Related work

The connection between the architecture and business objectives is often hard to find. However, changing the business objectives will influence areas like organization and process. It is therefore important to understand these dependencies between business objectives, architecture, organization, and processes [20]. A method to visualize these dependencies are described in [17]. The work is related to what Van der Linden et al. discusses in [28] and in a different context in [11].

To assess an architectural approach or aid in selecting a specific architecture over another, a number of methods exist. The problem with most of these methods is that they only consider technical aspects. Other considerations such as organization, cultural issues and the political situation at the particular company are usually ignored even if it is stated in [10] that it is even harder to deal with these non technical factors.

To evaluate a software architecture and analyze how well it suits the business drivers the Architectural Trade-off Analysis Method (ATAM) [15] can be used. It has been developed for software architectures and only consider one architecture. Larses suggests in [16] a combination of key-figure analysis, similar to balanced scorecard [13], Design Structure Matrix (DSM) [24] and qualitative reasoning resulting in a model that aids in designing the architecture. Another method to evaluate an architecture is the Architectural Evaluation Method (AEM) [19] in which requirements are analyzed to establish quality goals. This method is based on the ISO 9126-1 quality model [1]. The methods described above focus only on technical parameters. How to predict cost and business value for different architectures is discussed in [3] where cost is added to existing UML models and together with risk analysis and probability distributions Monte Carlo simulations are used to analyze the risk of not reaching the cost targets.

Even though many of these methods relate to industrial problems, few are used actively in the automotive industry today. There is also no or little documentation that these methods really solve today’s issues with E/E system architecture development. We believe that there is a need to understand what the real issues are when developing E/E system architectures, before developing a new method or model.

Our approach is therefore to investigate how the current situation and what the real issues are, and as a second step
focus on how to solve these issues. Different issues can have different solutions, where some may require new methods and models, and others could require a process change.

The contribution of this paper is therefore a number of issues that reflect the situation at the two automotive companies. Many of the identified issues relate to non technical areas such as organization, process, methods and tools, and management. Moreover, possible actions to deal with these issues are discussed. Although many of the issues and actions have been identified separately in various papers for different industries, we provide a current state of what the key issues in the automotive industry are.

Further references that are related to specific findings of this study are described in Section 3.

1.4. Overview of the paper

In the next section, we provide more details about the study, including the methodology used to answer the research question. Then in Section 3, the results of the study are presented and analyzed. In Section 4, the validity of the results are discussed. Possible actions concerning how to deal with the issues found are presented in Section 5. Finally, in Section 6, the conclusions are summarized and some directions for future research are proposed.

2. Methodology

The research question was addressed with an exploratory multiple case study. Exploratory studies reveal answers to questions based on what, how, and why. As our primary source of information we used semi-structured interviews. Semi-structured interviews have predetermined questions, but the order can vary based on the interviewer’s perception of what seems most appropriate [21]. Additional questions can also be constructed during the interview and it is also possible to remove questions that seem inappropriate.

2.1. Volvo 3P

One of the two companies involved in this study is Volvo 3P (V3P). V3P is a division within the Volvo Group responsible for product planning, product development, purchasing, and product range management for the three truck brands that are owned by the Volvo Group (Mack Trucks, Renault Trucks and Volvo Trucks). The development is focused to Gothenburg, Sweden but some activities are done in the United States and France. In total there are around 3,000 employees at V3P and the sales volume is approximately 220,000 trucks per year. The E/E department involves roughly 600 employees.

2.2. Volvo Construction Equipment

Volvo Construction Equipment (VCE) develops and manufactures all kinds of construction equipment such as; wheel loaders, excavators, articulated haulers, and graders. Responsible for the E/E system development is the component division of VCE. At VCE around 16,000 people are employed and approximately 140 are directly involved with E/E development.

Although both VCE and V3P are part of the Volvo Group they have limited cooperation and have their own business strategies. Further VCE has different legal requirements than V3P since VCE is to 90% a manufacturer of off-road machinery. Furthermore VCE has more product variants and at the same time lower sales volumes than V3P.

2.3. Planning and Preparation

The unit of analysis [31] for the case study was the E/E development at the different companies. At VCE eleven people were selected, and at V3P ten. All persons were selected by a contact in the company with extensive knowledge about each organization and therefore suitable to choose people with different roles within the company. The people interviewed included a project manager, a technical leader, a senior technical advisor, a system architect, a software architect, a senior manager, and a technical expert. Both companies have a matrix organization and roles from both the line and project organizations were included. We believe that this selection covers all major aspects of the architecture development. After the selection was made, invitations were sent out and interviews booked. None of the interviewees have any strong formal relationship to the authors or the different contacts at each company, which reduces the risk to get insincere answers.

2.4. Interviews

All interviews were semi-formal and questions were asked in such a way that the respondent was encouraged to talk about what they thought important. An example of a question asked was “How do you make architectural decisions today?”. Questions were added based on the answers from the respondents, and there were very large differences between different interviews regarding what topics were discussed and how much time was spent on each area. No recording devices were used to further ensure that the respondent spoke as freely as possible. Two researchers were present at all interviews, one taking notes and the other one asking most of the questions. All interviews lasted between 70 and 120 minutes and the average time for interviews was 100 minutes. All notes were transcribed directly after each interview to avoid any misinterpretation of the notes made.

The interviews were anonymous and no names were printed on the transcripts. All names of respondents were kept in a separate file to facilitate traceability in case the data needed to be complemented in any way.
2.5. Data Analysis

The data was extracted from the transcribed documents by categorizing data into a spreadsheet. The result from the data analysis was a long list of issues and factual statements. Similar issues were grouped together and a high level issue was constructed based on the low level issues. Each high level issue was constructed based on opinions from at least two respondents. A chain of evidence was upheld by a case study database as described by Yin in [31]. All data analysis was done by two researchers together enabling a discussion about how to interpret the data.

2.6. Validation

To validate that all identified issues were relevant a survey was conducted. Each respondent received a letter describing each issue. The respondent then placed a mark on a line to indicate how well the described issue matched their own opinion. The line ranged from "I do not agree at all" to "I agree entirely" and was 100 mm long. The reason for using a continuous scale is that we intend to collect survey data from other companies and with a continuous scale more powerful analysis methods can be used [22]. If the respondent considered that he or she had insufficient knowledge about an issue, the option "No opinion" could be marked. An example describing how the survey was designed is shown in Figure 1.

![Survey Design Example](image)

**Figure 1. Example of survey design.**

The survey used for validation can also be used to investigate if a respondent thinks an issue is important but did not state that clearly during the interview. Out of 20 surveys sent out 17 interviewees answered.

3. Results

In this section, the results of the case study are presented. First, we will list the issues that were elicited from the interviews, and discuss their meaning. Then, in the second subsection, the results of the follow-up survey sent to the respondents are presented.

It is important to note that what we measure is the subjective understanding of the situation of the company, as perceived by people in the organization with extensive knowledge about the architecture development. However, we believe there are good reasons to assume that this correlates well with the company’s actual performance, even though we cannot show this formally.

3.1. Identified issues

Based on the interviews, a number of statements were collected, grouped, and categorized. After abstracting from similar statements, a total of 14 issues were identified. These were all issues that were mentioned by at least two different respondents. Below each of the 14 issues are described.

**Issue 1. Several brands and products share the same architecture but have different priority order between, for example, quality and cost.**

Coordination of different brands and products is a complex problem. Brands and products that share an architecture have different priorities. Some brands focus more on cost and want to choose the cheapest alternative while others see more to the value that is created. This creates complications and thoughts around how much can be shared without the brands losing their identity. This issue was found at both companies. In [25] there is a discussion about brand identity and commonality but more from a functional perspective.

**Issue 2. There is a lack of process for architecture development.**

There is not a clear and documented process for how the E/E architecture is developed. This could be related to the fact that it is hard for management to see any real benefits from a structured architectural work. Also the architecture is seldom connected to customer needs which make it harder to motivate architectural development. This issue was also found at both companies. In another interview performed by Graaf [9] focusing on consumer electronics, the same issue was identified. Without an architectural process there is a big risk that the architecture is not documented properly which is a prerequisite to be successful in a product line architecture [4].

**Issue 3. There is a lack of understanding of the electrical system and software at the management level.**

There is generally a lack of understanding of the electrical system and software in the organization outside the E/E department. Possibly, this is due to the fact that many managers and other staff have a mechanical background. The understanding improves over time, but only slowly. Historically both companies have strong roots in development and manufacturing of mechanical products and as some interviewees stated “we are still a nuts and bolts company”. This issue was more predominant at VCE then at V3P. A reason for this could be that V3P has put a lot of effort into trying to educate management in software and systems engineering. This issue is supported by [9] stating that systems engineering is mostly driven from a mechanical and electronic point of view and seldom from a software perspective. In our case the systems engineering
was driven from a mechanical view and not considering either software or electronics.

**Issue 4. There is no clear process for handling requirements.**

There is no clear process for how requirements should be collected. It is quite common to come up with a pure "wish list" and more effort should be made to investigate each requirement instead of relying on gut feeling. Informal contacts are an important part of working with requirements today. This issue was found at both companies. Another study [8] confirms that this issue is valid outside the automotive industry and that there is a specific need for clear prioritization of requirements.

**Issue 5. The cooperation between product development and product planning needs to be improved.**

The interface between product development and product planning is not clear. Product planning is spread out and is uncoordinated and at the same time the communication from the electronics department needs to be more coordinated. This issue was only found at V3P, and this could be heavily dependent on the background of the interviewees. Many of the interviewees at VCE do not have any direct contact with product planning. In [27] the importance of cooperation between different departments are discussed.

**Issue 6. There is no method or model for measuring and follow up of quality problems during development.**

Lack of quality is not identified until the product reaches the market. Today, the actual quality achieved is not seen until late in the development process. For example, it is unclear how much a quality issue costs compared to choosing a more reliable and expensive component from the beginning. This issue was also only found at V3P.

**Issue 7. There is a lack of method or model to evaluate the business value when choosing the architecture.**

The connection between customer benefit and architectural decisions is hard to make, and the understanding of the relation between the architecture and the business is poor. A consequence is that many decisions are based on short-term cost requirements rather than long term strategic trends. Many respondents indicated that this may be due to the fact that each vehicle project must carry its own cost, but sometimes an investment in the architecture does not give any benefits until later in the lifetime of the platform. A better model for sharing this kind of investment between vehicle projects is needed. The consequence of such event-driven development is that a cheaper product cost can result in a complex system that is costly to maintain in the long run. This issue was only found at VCE. In [5] they state that there is a need for such model for product line architectures but none existing yet. This issue is probably valid in many domains although it might not be possible to create a model that satisfies the need for many domains. For example in [7] three approaches to value based software reuse is suggested.

**Issue 8. It is unclear how to prioritize between time, cost and quality.**

The official position at the companies is that quality is the most important factor but in reality it is usually time. This is due to a decision for the start of production date early in the development process. The start of production date is often based on new legal requirements which mean that if these deadlines cannot be met the number of sold units will be zero until these regulations are fulfilled. This issue concerns prioritization of the overall vehicle project while issue 1 is about trade-offs in the architecture.

**Issue 9. The complexity in the organization as well as the product has increased which has led to a situation where the existing processes are insufficient.**

Clear processes and documentation is particularly important in a large organization and these areas have not been adapted in the same pace as the organization has grown. Both organizations have grown extensively during the past years, both organically and by purchasing other companies. Especially the E/E department at the different companies has grown and new requirements for incorporating different brands and products in the same E/E platform have arise.

**Issue 10. Decisions are usually poorly motivated and it is hard to reach consensus and acceptance in a decision.**

Decisions are often based on gut feeling and poorly motivated. When a decision finally has been made it is hard to get people to accept them. This sometimes leads to decisions being brought up again for discussion. This could be a trust issue based on unsuccessful projects in the past. The issue was found in both companies.

**Issue 11. Decisions are easily made that suit one’s own project, team or component even though it leads to a poorer overall solution.**

Sub-optimizations are common and sometimes lead to a more complex overall solution than necessary. Optimization is made within one’s own project or team and does not consider the potential of a favorable overall optimization. Each project is supposed to carry its own cost and this means that no one is prepared to compromise in favor of commonality. Everyone thinks that commonality is good as long as "my project" doesn’t have to adapt in any way. This relates to Conway’s law [6] from 1968 that says: "Any organization which designs a system will inevitably produce a design whose structure is a copy of
the organization’s communication structure”. This issue was only found at VCE. VCE has an outspoken strategy that they should enhance commonality as much as possible. A problem is that there are no clear directions from top management how to achieve this.

**Issue 12. Advanced engineering projects have low priority and to increase the priority they are merged into development projects to early.**

Too little effort is put into advanced engineering projects or early concept and technology development. The projects are included too early in a delivery project to increase the attention and priority of the project. This is due to the fact that many resources are spent in the end of the delivery project making the advanced engineering projects short on resources. This severely increases the uncertainty in the delivery project. This issue was found at VCE. A more structured way of dealing with advanced engineering projects and stricter demands about when an advanced engineering project should be allowed in a vehicle project is needed and also it would be beneficial to try to move from back load to front load development. A problem is that legal requirements might force an advanced engineering project to be included earlier than what is preferable. One reason that the organization usually ends up in this situation might be that old development projects cannot keep their deadlines and are therefore utilizing resources that were allocated for advanced engineering projects. This issues with a possible solution is discussed in [26].

**Issue 13. Processes and methods are less valued then knowledge and competence of individuals.**

Today the development is highly dependent on individuals and the company rely on their knowledge. It is far from all projects that write white books 1 and even if a white book is written, it is seldom used as input to the next project. Information follows individuals and this leads to “hero based” development. It is of course important to know what knowledge and competence is available inside the company but it is dangerous to rely on that this competence can replace processes and methods. This issue was only found at VCE.

**Issue 14. Prestige and rivalry complicates cooperation between different departments and business units.**

There is a mismatch between some business units. This is to a large extent caused by the lack of clear guidelines from management what each business unit is responsible for. This rivalry and prestige is even clearer when it comes to higher management. This issue was found at VCE and it is in particular between two divisions that these problems arise. In [12] an interview study from an e-commerce software developer a similar issue was found.

### 3.2. Survey

The survey served two purposes: firstly to validate that all issues were correctly understood and secondly to investigate whether a respondent thinks an issue was important but did not state that clearly during the interview. Since the respondents marked their opinion on a scale of 100 mm all answers range from 0 to 100. Only one respondent used the “No Opinion” alternative on one question. A boxplot with outliers and distribution is shown in Figure 2.

The survey shows that for most issues the respondents agree, but there was disagreement in some cases. For example in Issue 6, that states; “There is no method or model for measuring and follow up of quality problems during development”, the answers differ a lot. One explanation of this could be that respondents belong to different groups and that the respondents interpreted the statement differently. A reason for the variance could be that the data is from two different companies but further analysis shows that the reason more likely is due to different roles within each company.

### 4. Validity

An important aspect in case studies and interview studies is to ensure the validity. In the literature on research methodology, several different categories of validity are discussed. We mainly base our analysis on [31], but also complement it with more detailed guidelines from [30].

#### 4.1. Construct validity

The construct validity is about ensuring that the construction of the study actually relates to the problem stated in the research question, and that the chosen sources of information are relevant.

A specific threat to construct validity is the use of unclear terms, and in this study the term architecture is a good example. We did not present the respondents with a clear definition of what we mean by architecture, but instead asked them what they mean by it. It is possible that some respondents answered the questions differently depending on their view of what an architecture is, but since we did not find any radically different opinions this threat is reduced.

Another possible threat is that the respondents guess what hypothesis the researchers had, and adapt their answers accordingly, for instance by exaggerating their opinions in an attempt to try to influence the outcome of the study. We tried to reduce this threat by using open ended questions in the interviews.

A possible threat is also that respondents may be hesitant to express their views if they could later be affected by

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1In the white book project drawbacks and success are summarized. This document should always be used as input to the next project according to the companies development process.
their responses. The respondents did however not have any formal dependency on the researchers which also limits this threat. By guaranteeing anonymity, this risk is also reduced.

4.2. Internal and conclusion validity

Internal and conclusion validity concern the possibility to ensure that the actual conclusions drawn are true. In [31], it is stated that "internal validity is only a concern for causal (or explanatory) case studies". Our case study is explorative, and hence less sensitive to this threat. However, there are still issues that can be relevant to examine.

One has to do with the selection of respondents. The group used in the study is rather homogeneous in terms of personal characteristics. We tried to make a representative selection by ensuring that the participants had different roles in the organization.

With a fairly small sample, there is a risk that a certain individual with a strong opinion can influence the result very much. We took two measures to try to compensate for this risk. The first was to only include issues that were mentioned by at least two persons. The other was to validate the identified issues with the survey.

On the other hand, the filtering of issues can lead to the opposite risk that we missed some valid conclusions. It could be that an issue is very important to the organization as a whole, but was not mentioned by more than one person. Therefore, based on this study we can only claim that we have found a number of important issues, but not that we have found all issues or even all the most important ones.

The issue of mortality (i.e., individuals who declined to participate) was not a major one in this study. Of the 22 people initially contacted, only two were not able to be interviewed, due to scheduling difficulties. 17 out of the 20 that were interviewed also completed the survey.

Another risk is related to "fishing", i.e., that the researchers consciously or unconsciously search for certain kinds of information. We tried to avoid this by using open-ended questions in the interviews, and by finishing each interview by asking the respondent whether there was anything else that should be discussed.

In a survey, it is important to ensure that the instrument used is easy to understand for the respondents and does not cause any confusion in the interpretation. To reduce this risk, the survey was similar to one used in an earlier study, presented in [29], with similar context.

4.3. External validity

External validity concerns how the results can be generalized. This is a specific concern for a case study, where it always can be discussed to what extent the observations are particular to a certain environment, or whether they are examples of general phenomenon.

The primary type of external validity is whether the conclusions can be generalized to a different organization, either within the same industry or in a different industry. Based on the literature we can say that many of the issues are valid for other domains as well.

4.4. Reliability

Reliability relates to the ability of others to replicate the study and arrive at the same results. A basis for replication is to have a well documented study design and a well structured data collection, and we believe that this is the case for the study presented here. Assuming that the study were replicated and resulted in roughly the same transcripts of the interviews, it would still not guarantee that the resulting issues would be the same. There are different ways of
interpreting the textual material, and in some cases there could be several ways of relating different statements to each other resulting in a different set of abstractions. We tried to reduce this risk by doing the analysis by having two people work together and discuss the structuring in detail. We therefore believe that a replicated study would come up with very similar issues, even though the exact wording or structuring could differ.

Another question is if we would get the same results in the same organization if we did the study at a different time. There are several possible reasons why the outcome could become different. One is that people tend to be heavily influenced by the latest events, and it was clear in the interviews that a few respondents were relating to a very recent vehicle project where there had been some architectural changes and turbulence.

Also, it is expected that the organization will take notice of the issues identified, and try to improve them. Thus, the study itself may influence the study object in such a way that a replication at a later period in time is hard to fully accomplish.

5. Suggested Actions

In this section we show how the issues we have identified could be addressed by the companies in the future. Issues are grouped together and we try to identify where the studied OEMs are in the action tree shown in Figure 3. In the figure, we have marked A-E where different issues are located. The figure further shows possible ways to take from where the organization is at the moment. It is possible for the organization to move both ways in this tree. For example the issues concerning Group B, as described below, where management needs to be educated to understand how software and electronics are developed. It could be that a reorganization takes place where a large part of the current management is replaced, causing Group B to move either up or down the tree.

Based on the study we propose both companies to take the following actions:

A: Clarify responsibilities in the organization. Issues that relate to this group are issue 11 and 14. Both these issues could be solved by clarifying who is responsible for what and also focus less in the individual projects, and more on the overall business. Instead of trying to do what is best for the company, everyone prioritizes the success of their own project and is secondarily concerned about the success of the company. To resolve this, clear guidelines from management are needed, both about responsibilities and authorities. A barrier for this is the complex interdependencies between different parts both in the organization and in the system, as described in Conway’s law [6].

B: Educate management. The only issue directly connected to this group is issue 3. Also if we can increase the understanding from management on how software and electronics are developed all issues will be easier to take care of. There are some ongoing activities in this area, but we recommend that they should be
escalated. A possible barrier for succeeding with implementing this action is that the addition of software and electronics increases the complexity of the overall systems. In [23] it is shown that the learning cycle of managers’ breaks down in complex environments. A reason for this is the time lag between cause and effect.

C: **Increase the use of structured decision making.** Issues 6, 7, 10, 13 and possibly 1 are connected to this group. There is a need for a model or method that can be used to calculate the business value of architectural decisions. The problem is that the customer does not see any value of a new architecture although an architecture can limit to what extent new features can be added. Also decisions in general concerning the E/E system have to be improved. We suggest that a business value model is developed and an increased use of structured decision making. Creating academic models is one thing, but creating models that will work in industry usually something else. We believe that the goal of these models has to be effectiveness and efficiency rather than focusing on optimal decisions. A problem with such model is that it is still hard to value quality attributes against for example cost and time to market. What is the actual benefit by for example achieving flexibility in our system? The models we are seeking is models that can provide some value driven evaluation of quality attributes in the architecture. An attempt to achieve such model is the Cost Benefit Analysis Method (CBAM) [14], but the method does not appear to have gained any significant impact in the automotive industry.

D: **Improve the architecture development process.** This group concerns primarily issue 2, 4, 9 and possibly 14. There are some fundamental processes that are missing. For example there is formally no process for architectural development at any of the companies. The need for new processes has increased as both organizations have grown a lot in the last years. We suggest that a process for architectural development is developed. Complications for improving the architectural process could be the lack of understanding of the E/E system from management on why this is important and hence lack of willingness to contribute resources. This process will most likely include the use of methods for structured decision making as described in Action C. It should also describe when in time the organization will deliver according to their responsibilities (Action A).

E: **Clarify development strategies.** Issue 8 and 12 relate to this group. Today it is unclear how to prioritize between, time, cost and quality. Also the advanced engineering needs to be more separated from actual vehicle projects. We suggest that advanced engineering projects are prioritized and also that the consequences of removing resources and moving advanced engineering projects into vehicle projects too early are clearly shown. A barrier could be that there is a tradition in these companies to prioritize work with earliest deadline first. A possible way to cope with front-loading of projects is suggested in [26].

The only issue that is not included in the suggested actions described above is issue 5. It is not directly connected to the scope of this study and the problem is not directly connected to the E/E system development. However, if the background to this issue is that product planning does not understand how to communicate requirements to the E/E department it could be part of group B.

### 6. Conclusion & Discussion

The complexity of automotive electrical and electronic systems is increasing rapidly. This makes the engineering of these advanced computer-based systems more and more difficult. In particular, finding a good architecture is a prerequisite for successful design.

In this case study we have identified and validated 14 issues that are related to real-world decisions regarding heavy vehicles’ electrical and electronic system architecture. We have shown that these issues are relevant but we cannot say that this is an exclusive set of issues when developing electronic and electrical system architecture. We believe that the method used is well suited for this type of research.

Many of the identified issues are not just technical issues but they also relate to management and organization. The results have been validated by a survey and we can be certain that we have found issues that reflect the situation at the studied OEM. Also we believe that the results are general for the automotive domain. We believe the results of our work is common within the automotive industry because of informal meetings with personnel of our competitors and another study at a different OEM described in [29].

### 6.1. Future Work

To continue the investigation of issues that are related to electrical and electronic system development we will continue with a comparison of issues collected at three different automotive OEMs. It would also be interesting to see how different roles relate to the different issues, i.e. it is most likely that a manager and a programmer will not have the same opinion about what actually is an issue. This study mostly enlightens the problems that exist today, and as a natural next step we will start to sort out how to solve these issues.
7. Acknowledgement

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