A Case Study of Issues Related to Automotive E/E System Architecture Development

Peter Wallin
Mälardalen University
Dept. of Computer Science and Electronics
P.O Box 883
SE-721 23 Västerås, Sweden
peter.wallin@mdh.se

Jakob Axelsson
Volvo Car Corporation
SE-405 31 Gothenburg, Sweden
jakob.axelsson@mdh.se

Abstract

The use of electronics in vehicles is increasing quickly and the systems are becoming increasingly complex. 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 study we investigate key issues related to real-world decisions regarding a car's electrical and electronic system architecture. To extract the key issues an exploratory case study was performed at a car manufacturer. We used semi-formal interviews complemented with a survey to validate the results. The contribution of this paper is twelve issues that reflect the situation at a car manufacturer. Also, possible actions to deal with these issues are provided.

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 innovation in a car in the premium segment comes from the electronics [7]. 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 control 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 an automotive manufacturer deals 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. Some vehicles are also consumer products, which means that the price must be kept low.

Due to varying customer demands, but also due to different legal requirements in the countries in which the product is 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. The platform is 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 from 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]. 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, and 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 integrate 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, meaning that even more people participate in the complete project. Since the architecture is an integration activity, 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 car's electrical and electronic system architecture?

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

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. To evaluate a software architecture and analyze how well it suits the business drivers ATAM [5] and CBAM [4] can be used. Both methods has been developed by the Software Engineering Institute at Carnegie Mellon. ATAM and CBAM has been developed for software architectures and only considers one architecture. Larses suggest a combination of keyfigure analysis, Design Structure Matrix (DSM) and qualitative reasoning. This model aids in designing the architecture and is described in [6]. Another method to evaluate an architecture is the Architectural Evaluation Method (AEM) 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 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, some could require a process change.

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 single 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 interviewert's perception of what seems most appropriate [9]. Additional questions can also be constructed during the interview and it is also possible to remove questions that seem inappropriate. Two persons were always present at the interviews, one mostly taking notes and the other one asking questions. We chose not to use any recording devices due to the risk of limiting the respondent's openness.

2.1. The case at Volvo Cars

A suitable case study environment was found at Volvo Car Corporation (VCC), which is a partner together with two other OEMs in the research project in which this study was carried out. The company has its headquarters, including product development and many other functions, in Gothenburg, Sweden. The company is a producer of premium cars, with special focus on safety, environment, and quality. It has approximately 25,000 employees and manufactures and sells close to 500,000 vehicles each year worldwide. It has been a subsidiary of the Ford Motor Company (FMC) since 1999, and has close co-operation primarily with Ford of Europe in Germany and Jaguar-Land Rover in the UK. For these brands, VCC has a leading responsibility for the E/E architecture.

2.2. Planning and Preparations

The unit of analysis [11] for the case study was the E/E department within the Research & Development organization. At VCC seven people were selected by the second author of the paper, who is familiar with the organization. The people interviewed include a senior manager responsible for concept studies of E/E systems, a senior technical advisor working with strategies, a project manager for the E/E system in a vehicle project, a line manager responsible for some aspects of the system architecture, a technical leader responsible for key systems and functions in the architecture, and two engineers that develop functions and systems that utilize the architecture. We believe that this selection covers many aspects of the architecture development. After the selection was made and invitations were sent out, all contacts with the interviewees were handled by the first author, who has no relation to the company. None of the interviewees have any strong formal dependency to the authors and which reduces the risk to get insincere answers.

2.3. Interviews

All questions were semi-formal and 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. As mentioned above no recording devices were used to further ensure that the respondent spoke as freely as possible. Two researcher were present at all interviews, one taking notes and the other one asking most of the questions. All interviews lasted between 50 minutes up to 100 minutes and all notes was 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 be able to trace backwards in case the data needed to be complemented in any way.
Since the first language for all respondents is Swedish all interviews were also held in Swedish in order not to limit the answers.

2.4. 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 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 [11]. All data analysis was done by two researchers together enabling a discussion about how to interpret the data.

2.5. Validation

To validate that all identified issues were relevant we made a survey. 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. An example describing how the survey was designed is shown in Figure 1.

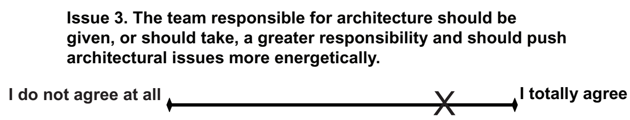

Figure 1. Example of survey design.

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. All surveys were totally anonymous making it impossible to draw any conclusions about how different groups or roles answers differently. All seven interviewees answered the survey suggesting that they see these issues as relevant.

3. Results

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

Table 1. Mapping of issues to high level attributes

Issue	Architecture	Organization	Process, Methods & Tools	Management & Business
1. Several car brands share the same architecture but have different priority order between, for example, quality and cost	X			X
2. There is a lack of clear strategy for what development should be done in-house and what should be done at external suppliers		X		X
3. The team responsible for architecture should be given, or should take, a greater responsibility and should push architectural issues more energetically	X	X		X
4. History has a large influence on architectural decisions, and is reflected both in choice of technology and in the organization	X	X	X	
5. There is a lack of clear long-term architectural strategy	X			X
6. There is a lack of method or model to evaluate the business value when choosing the architecture	X		X	
7. Architecture decisions are often made based on experience and gut feeling	X		X	
8. The modeling tools used today demand resources and provide little value			X	X
9. Decisions are easily made that suit one's own team or component		X		
10. There is a lack of process for architecture development	X		X	
11. Technical parameters are regarded as less important than cost when selecting components or suppliers			X	
12. There is a lack of understanding of the electrical system and software at the management level				X

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 12 issues were identified. These were all issues that were mentioned by at least two different respondents. An overview of these issues and to what area they relate are shown in Table 1. The issues were the following ones (where the issue titles are the ones used in the survey, but have been translated from Swedish):

Issue 1. Several car brands share the same architecture but have different priority order between, for example, quality and cost.
The co-ordination of similar brands is a complex problem, and brands that share an architecture may have different

priorities. In the case of Volvo Cars, the relation to Ford appears to be complicated. Volvo as a premium brand is driven more by the value of the product, whereas Ford as a mass-market brand is more focused on reducing cost. This leads to complications and thoughts on what can really be shared without each brand losing its identity.

Issue 2. There is a lack of clear strategy for what development should be done in-house and what should be done at external suppliers.
There are different opinions on how much influence a supplier should have. Sometimes the competence of a supplier is not fully used. On the other hand, with too much involvement the OEM will become tied to a certain supplier which makes it harder to switch to a new partner should the need arise. There are different strategies within the Ford Motor Company. The Ford brand often uses system suppliers whereas Volvo prefers to specify the details and design certain parts of the system themselves. Many suppliers try to move up the value chain by taking a larger responsibility for the integration which also can create tension.

Issue 3. The team responsible for architecture should be given, or should take, a greater responsibility and should push architectural issues more energetically.
It is not clear who is responsible for driving changes in the architecture. Many decisions are made bottom-up. The decisions are only made once a problem is present and there is a tendency to act reactively rather than proactively. Some respondents hinted that this situation may be due to the current organization, where certain aspects of the architecture are the formal responsibility of one team, and other aspects belong to another team.

Issue 4. History has a large influence on architectural decisions, and is reflected both in choice of technology and in the organization.
It is easy to get stuck in a historic pattern of reasoning when making architectural decisions, both in terms of organization and technology. There is a resistance to change and a tendency to "do as we have always done it". This is reflected in the fact that the current E/E architecture was fundamentally designed in the mid 1990s, and several of the persons involved in developing it are still part of the organization. Some respondents ask for an architecture that is more driven by current needs than by this legacy.

Issue 5. There is a lack of clear long-term architectural strategy.
There is a lack of clear strategy for how the architecture should look in the future. A consequence of this is that new solutions sometimes are developed under stress with a result that does not appear satisfactory. Some respondents mentioned examples of attempts to cut cost on components leading to overload on networks and a late restructuring of the network topology.

Issue 6. 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. One respondent 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 consequences 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.

Issue 7. Architecture decisions are often made based on experience and gut feeling.
Experience is important when it comes to understanding the architecture. Today, architectural decisions are often made by experienced individuals based on gut feeling. There is a lack of a structured method for making these decisions. It is not clearly stated in the interviews that this results in poor architectures, but nevertheless some respondents ask for better arguments and statistics as a basis for making these decisions.

Issue 8. The modeling tools used today demand resources and provide little value.
Many aspects are missed with the tools currently used in the organization. The tools focus on the functionality, but non-functional properties related to hardware or timing are not easily captured. The use of tools is thus considered to create extra work instead of making the job easier. One respondent also mentions that the tools have not been "marketed" enough in the organization, and many users have not been convinced about their benefits. (A description of the tools used at Volvo Cars for E/E development can be found in [8].)

Issue 9. Decisions are easily made that suit one's own team or component.
Sub-optimizations are common and the result is a more complex overall solution than is necessary. Each team optimizes for their needs and the cross-team improvements are not discovered. "Nobody is here to build a car, everybody is here to build their system", one respondent stated. He

connects this situation to a reorganization a few years back, when the vehicle projects were deemphasized and the line organization was given more responsibility. The driver for this change was to improve commonality across vehicle lines.

Issue 10. 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. One respondent claimed that the process does not exist, another that it exists but is not well known within the organization.

Issue 11. Technical parameters are regarded as less important than cost when selecting components or suppliers.
The price strongly drives the choice of component. The purchasing department choose the supplier and sometimes technical parameters are traded for a lower price. This can sometimes lead to lower quality and hardware problems for modules mounted in a harsh environment. "You get what you pay for", as one respondent stated. On the other hand, the price is a very tangible parameter, whereas quality issues are often speculative at the time when the supplier choice is made.

Issue 12. 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.

3.2. Survey

The survey served two purposes: firstly to validate that all issues were correctly understood and secondly to investigate whether a respondent think 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. 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 8, that states; "the modeling tools are resource demanding and provide little value", the answers differs a lot. One explanation of this could be that respondents belong to different groups. Due to the fact that all surveys were completely anonymous we cannot draw any conclusions about who provided deviant replies.

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 [11], but also complement it with more detailed guidelines from [10]. This section primarily concerns readers with extra interest in validity, and can therefore be skipped if no such interest exists.

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 this concept. On the other hand, VCC uses the term extensively in their internal work, and if it were the case that employees view of architecture radically differs, that would be an issue in its own right. However, even though there are some variations in the view on architecture, we did not find any radically different opinions, which reduces this threat to validity.

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.

The analysis could also be influenced by the experimenter's expectations. The second author is employed by VCC and has a long experience in the domain, and therefore he did not participate in the interviews to reduce the risk of influencing the respondents.

A possible threat is also that respondents may be hesitant to express their views if they could later be affected by 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 [11], it is stated that "internal validity is only a concern for causal (or explanatory) case studies". Our case study is ex-

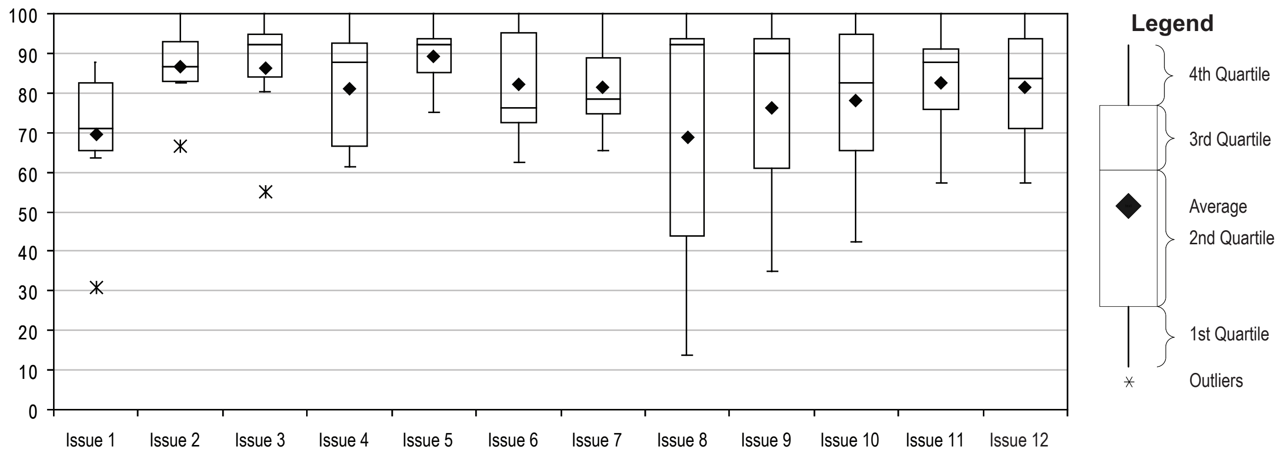

Figure 2. Boxplot showing responses to the survey.

plorative, 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, and also quite small. On the other hand, the full population (the E/E department at VCC) is also rather homogeneous and there is a limited number of persons that are closely involved in the architecture work. We tried to make a representative selection by ensuring that the participants had different roles in the organization.

With a 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 eight people initially contacted, only one was not able to be interviewed, due to scheduling difficulties, and all seven who 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 having as open questions as possible in the interviews, and by finishing each interview by asking if the respondent felt that there was anything else that should be brought up.

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 tested on three independent persons before sending it to the final respondents.

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 an different industry. We cannot with certainty say that this is the case, and to enable us to draw such conclusions further studies are needed.

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 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.

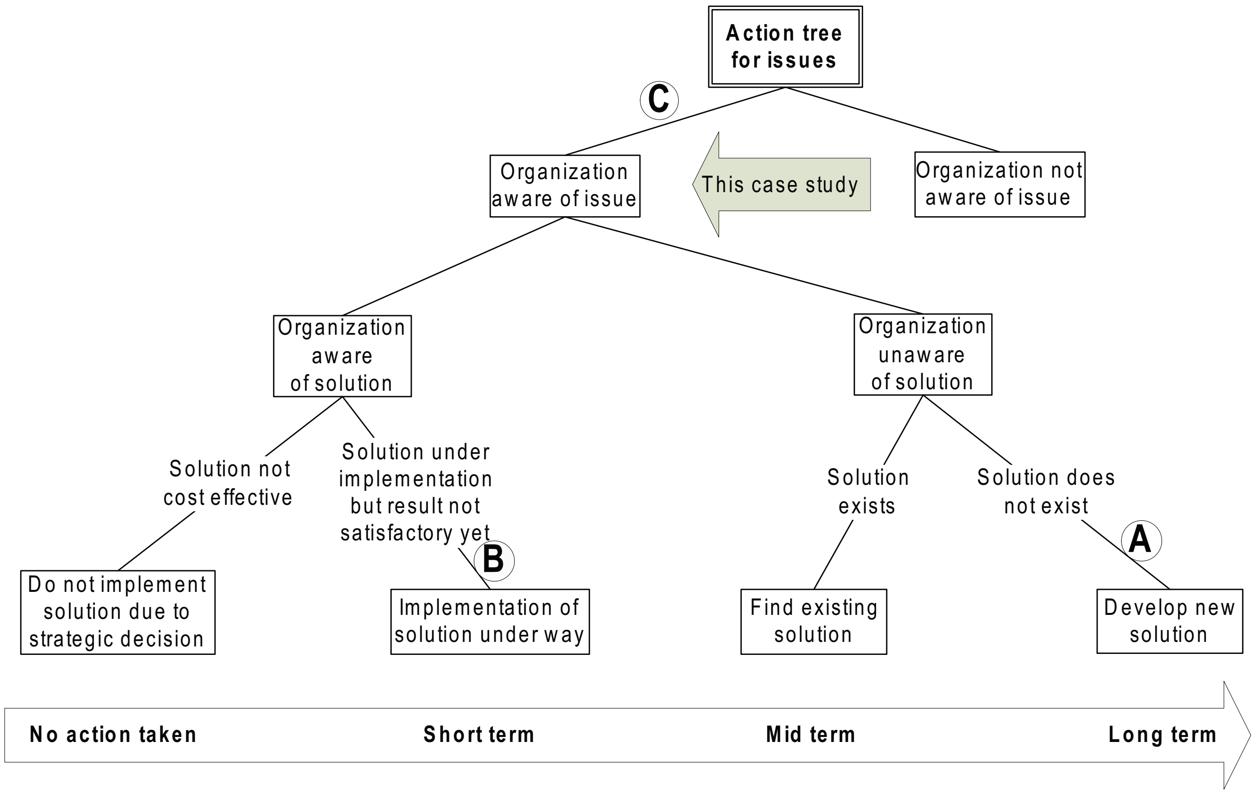

Figure 3. Possible actions for identified issues

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.

VCC has been going through a process of stepwise closer integration within Ford Motor Company over a number of years, and that has created a lot of work and discussion internally. At the time of the study, there were speculations in the press that Ford might consider selling VCC, and that could also have influenced the mindset of the participants. It is hard to judge the effects of such factors, but it is clear that a case study always measures a certain state of affairs, and over time reality changes so that a renewed study will give a slightly different result.

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 can be addressed. Issues are grouped together and we try to identify where the studied OEM are in the action tree shown in Figure 3. In the figure, we have marked by A, B and C 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 up the tree.

A: **Architectural business value model.** This group primarily concern issues 6, 7 and 8 but secondarily also issues 3, 4 and 11. This is related to the need for a method or model to see the business value of an architectural decision. At Volvo Cars they are aware of the problem but do not know how to tackle the problem yet. We recommend that more research is put into this area to develop better models for business evaluation.

B: **Educate management.** The only issue directly connected to this group is issue 12. 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.

C: **Clarify architectural responsibilities.** Issues related to this group is first of all 3 and 10. Indirectly issue 5 and 9 can be related to this group. A process for architectural development is needed and different responsibilities must be made much clearer than today. We recommend that a process describing different responsibilities is developed. Further, more responsibility should be given to the architecture group.

Issue 1 and 2 cannot be solved within the electrical and electronic department and must be handled on a global company level.

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 twelve issues that are related to real-world decisions regarding a car's 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.

Many of the identified issues are not just technical issues but they also relate to management and organization. The result has 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 result are general for the automotive domain. We base this last finding on informal meetings with other OEMs but further studies are needed to conclude whether these issues can be generalized to other OEMs or not.

6.1. Future Work

To continue the investigation of issues that are related to electrical and electronic system development we will continue with interviews at other automotive OEM's. Interviews have already started at an OEM developing trucks and will continue at an OEM developing construction equipment. This will hopefully give us the ability to generalize the result and get an exclusive set of issues that are related to electrical and electronic system development.

7. Acknowledgement

The authors would like to thank the E/E department at Volvo Cars and in particular all persons that participated in the interviews, making this study possible. Also a special thanks goes to Ana Magazinovic at Chalmers University of Technology who helped with taking notes and discussions about the context of this study.

References

[1] *ISO/IEC 9126-1:2001, Software engineering - Product quality.*

[2] *IEEE 1471-2000, Recommended Practice for Architectural Description of Software-Intensive Systems.* 2000.

[3] J. Axelsson. Cost models with explicit uncertainties for elextronic architecture trade-off and risk analysis. In *INCOSE 2006 Annual International Symposium on Systems Engineering*, Orlando, USA, July 2006.

[4] R. Kazman, J. Asundi, and M. Klein. Making architecture design decisions: An economic approach. Technical report, Carnegie Mellon Software Engineering Institute, CMU/SEI-2002-TR-035.

[5] R. Kazman, M. Klein, and P. Clements. ATAM: Method for architecture evaluation. Technical report, Carnegie Mellon Software Engineering Institute, CMU/SEI-2000-TR-004.

[6] O. Larses. *Architecting and modeling of automotive embedded systems.* PhD thesis, Royal Institute of Technology, 2005.

[7] G. Leen and D. Heffernan. Expanding automotive electronic system. In *IEEE Computer*, volume 35, pages 88–93, 2002.

[8] M. Rhodin, L. Ljungberg, and U. Eklund. A method for model based automotive software development. In *2th Euromicro Conference on Real-Time Systems, Stockholm, 2002*, pages 15–18, 2002.

[9] C. Robson. *Real World Research.* Blackwell publishing, second edition, 2002.

[10] C. Wohlin, P. Runeson, M. Höst, M. Ohlsson, B. Regnell, and A. Wesslén. *Experimentation in Software Engineering: An Introduction.* Springer, 2000.

[11] R. K. Yin. *Case Study Research, Design and Methods.* SAGE Publications, Thousands Oak, California, 1986.