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Software Product Development: Manufacturer – Supplier Cooperation

Master of Science Thesis in Software Engineering and Technology

NARUEMOL SRIBUAPHUAN

Chalmers University of Technology
University of Gothenburg
Department of Computer Science and Engineering
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NARUEMOL SRIBUAPHUAN

Examiner: DR. TONY GORSCHEK
School of Engineering
Blekinge Institute of Technology

Chalmers University of Technology
University of Gothenburg
Department of Computer Science and Engineering
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Department of Computer Science and Engineering
Göteborg, Sweden, June 2010

Abstract

Automotive software embedded in an electronic control unit (ECU) is mostly outsourced to the suppliers. An automotive manufacturer specifies functional requirements and takes role as a system integrator merging a large number of software components acquiring from different suppliers. The growing number of ECUs in a vehicle results in the manufacturer having a lot of interactions with a number of suppliers. Therefore there is a need of an effective mechanism to collaborate with the suppliers during software development.

In this thesis, a case study at an automotive OEM is conducted with the purpose to investigate the current state of the practice of how the practitioners develop a new software product together with suppliers. In addition, it also seeks to identify areas of challenges the practitioners encounter during the development effort.

The case study employs a framework for lightweight software process improvement as research techniques. The case study incorporates the study of interviews and documentation from multiple data sources allowing triangulation of findings.

The results show that, to develop a software-intensive system with the supplier, it is crucial to take into consideration not only the engineering process but also the aspect of management strategies. Moreover, it is this area that the practitioners have identified as the most important one to improve to achieve a successful OEM-supplier cooperation.

Acknowledgements

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To all people that have participated in this thesis. Without them, this thesis might not have been successfully executed. I sincerely appreciate their time, cooperation and information they have contributed to the thesis.

To my parents, for their comfort, care and love. They are my guiding stars holding me up when I feel down and discouraged. To my siblings, for all the jokes they have told me when I was depressed and upset. To my friends, for cheering me up with food and cakes.

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Contents

1. Introduction

Todays competition forces a manufacturer to frequently launch product innovations with lower cost yet meet or even exceed customer expectations. Strategically introducing suppliers early into product development is proven to be a successful technique to overcome this challenge. The benefits brought with this concept include reducing development time, sharing development cost and resources with the supplier, enabling product innovation and increasing product quality [Ragatz et al., 2002; Callahan & Moretton, 2001; van Echtelt et al., 2008; Petersen et al., 2005]. The supplier can contribute to product development from providing a simple consultation on product design to taking a full responsibility on components they supply.

The automotive industry is one of the manufacturing sectors whose competitive advantages are retained by the light of early supplier involvement [Wasti & Liker, 1997; Fourcade & Midler, 2005; Ro et al., 2008]. While material suppliers play the key roles in this phenomenon, the emerging field of automotive software engineering has rapidly been drawing attention. For the past years, the challenges in the automotive industry has been shifting from mechanical to mechatronic solutions. Instead of offering a hardware-controlled unit, a car manufacturer addresses the customer needs through software-controlled systems. Car's functionality such as cruise control, audio, and safety features is controlled by software-intensive systems or ECUs (Electronic Control Units). It has been revealed in [Salzmann & Stauner, 2004] that there are up to 50 ECUs in BMW 7 Series. The features of a vehicle are driven by market requirements whose expectations are continuously increased in terms of complexity. This is unavoidably resulting in the growing number of ECUs in order to create a car that meets the market ever increasing needs. Obviously, instead of developing them inhouse, these ECUs are outsourced to third party suppliers [Salzmann & Stauner, 2004; Natale, 2008; Heumesser & Houdek, 2004]. The automotive manufacturer (OEM) is thus dealing with a number of suppliers during a product development cycle, and these suppliers are free to choose process, tool and platform to develop their products [Natale, 2008]. This makes it impossible for the OEM to modify the component in the case of failures or incompatibility during product integration. As the OEM focuses on subsystem-integration activities [Heumesser & Houdek, 2004], the knowledge of supplier's development status and progress is crucial for project management.

The supplier cooperation, according to [McIvor & Humphreys, 2004], takes place very early at the beginning of the product development project - concept product designs. Once a conceptual model is created, the OEM creates a preliminary product specifications, which is on a very high abstraction level, and sends to potential solution providers. This is to initiate a dialog between the OEM and the key suppliers asking for the interest of joint-development effort. The subsequent step of this action is then to call for tenders, select an appropriate supplier and consequently sign a contract [Heumesser & Houdek, 2004]. This generally means that the OEM and the supplier have agreed on the development effort before the detailed product specification is available. The preliminary specification, more often than not, is evolving during the development lifetime. The detailed specification of the vehicle is created during product development, therefore the evolution of the specification should be well-managed [Heumesser & Houdek, 2004]. It is also important to mention that stakeholders involving in this product development are not collocated in the same development site, instead they are spreading over continents.

The OEM is then in the need of an effective method to manage the cooperation with its suppliers, which is still the remaining challenge [Fabbrini et al., 2008]. To respond to the increasing complexity of functionality and the number of suppliers, the cooperation between the automotive OEM and associated software suppliers needs to be scrutinized. In this thesis, a case study is conducted in order to understand such a cooperation in the practice state. The study investigates how the practitioners at an automotive OEM work together with their suppliers who provide software-intensive system during new product development. It also seeks to identify issues posed by the OEM-supplier cooperation. These issues are then prioritized, and their dependencies are identified. In addition, literature is reviewed to propose suggestions for the prioritized issues to improve the OEM-supplier cooperation.

1.1 Disposition

The rest of the document discusses five main topics: background of automotive software engineering and early supplier involvement, research methodology employed within this thesis, results and findings after applying research methods, analysis and discussion of the findings and conclusions.

1.1.1 Background

This section gives a brief overview of software development in the domain of automotive software engineering. It contains detailed discussion about characteristics and challenges emerging within this variant of software engineering. Together with background knowledge of automotive software development, this section also talks about a business strategy to introduce a supplier into a product development cycle. It provides the reader a comprehensive view of different models to involve a supplier in new product development as well as benefits and challenges carried by this concept.

1.1.2 Research Methodology

This section discusses in details how this piece of study is designed, planned and conducted. It highlights the research questions, research approach, techniques used for data collection and analysis as well as research context and the types of validity this study is trying to pursue. The section contains the detailed description about how different instruments employed in this study is developed. It also presents the relation between the research questions and the techniques employed to address each of the questions.

1.1.3 Results and Findings

This section shows the results and findings of the thesis. It presents raw data gathered along with other results yielded from the execution of different research methods.

1.1.4 Analysis

In this section, the analysis of the results and findings is discussed. Primarily, it aims to answer the research questions.

1.1.5 Conclusion

This section concludes the thesis by summarizing the methods, findings and analysis, and explains again in a brief manner.

2. Background

This section provides the background knowledge of main topics related to this thesis. It first discusses how software in the automotive domain is developed by focusing on the development characteristics and strategies emerged to tackle domain-related problems. The latter part of this section then discusses about involving supplier in new product development.

2.1 Automotive Software Engineering

An automotive OEM's responsibility has shifted from an assembler of unconnected parts to an integrator of highly interacting systems. The automotive development, in the past, was that the OEM assembled parts of a vehicle such as gearbox, steering or breaking system that were produced by a chain of suppliers [Broy et al., 2007]. These components, which were traditionally independent and unrelated, contained small pieces of unconnected software that was installed on a single controller or an ECU. With the industrial software revolution, mechanical and hydraulic solutions are no longer considered as the innovations in the automotive industry [Salzmann & Stauner, 2004]. This is simply because software enables the implementation of vehicle functionality deemed impossible by only a mesh mechanism [Broy et al., 2007]. The amount of software has evolved from zero to tens of millions lines of codes within a few decades [Broy et al., 2007]. This amount of software realizes nearly 300 functions deployed over a number of ECUs. A feature such as locking and unlocking car doors in the central locking system is a result of integrating a number of functions such as safety functions (automatic locking at a minimum speed or unlocking in the case of crash) or HMI functions (signaling the locking/unlocking through instrument cluster or light system) [Broy et al., 2007]. These functions are realized by a number of subsystems and their associated ECUs which are distributed according to the mechanical breakdown of a vehicle. Therefore, the OEM has to understand how the separated software components deployed on different ECUs interact to implement a distinct user function [Broy et al., 2007]. The OEM is now taking a responsibility to integrate the vehicle subsystems.

Software innovation plays a key role in retaining the competitive advantages for an automotive OEM. With high market demands, a number of vehicle functions and corresponding software grow rapidly. In fact, the binary code is expected to reach the size of one gigabyte in a few years from now [Broy et al., 2007]. A traditional method to develop embedded software does not seem to be applicable for a system this size. Besides the increasing size of the software, there are however a number of attributes that differentiates automotive software from other domains, which are summarized in the following section.

2.1.1 Automotive Software Profile

Automotive software has been observed that it possesses some characteristics that differentiate its domain from the others as the following:

1. Various application domains
   Automotive software has a great variety of applications integrated into a vehicle, for example entertainment such as audio, HMI such as climate control and seat adjusting or safety-related such as braking system and engine control. The application area, according to [Broy et al., 2007], can be clustered as:

   - Multimedia and telematics: data processing software such as infotainment including interfaces with other soft real-time software and client software that interacts with the vehicle such as mobiles and laptops [Salzmann & Stauner, 2004].
   - Body/comfort software: a control program that is a discrete event and reactive such as seat adjusting or windshield wiper.
   - Safety critical software: hard real-time safety- and security related software where a malfunction could harm human beings such as anti-lock braking systems (ABS) and electronic stability program (ESP).
   - Power train and chassis control: hard real-time software controlling mission critical algorithms such as those in an engine or a transmission [Salzmann & Stauner, 2004].
   - Infrastructure software: software for centrally managing data and IT system in a vehicle.

2. System integration focused
   A distinct vehicle function is realized by the interaction of many subsystems. As an example aforementioned, the central locking system is a result of the interplay of components belonging to a number of subsystems distributed across the vehicle infrastructure. To realize a cohesive functionality, this involves a network of drivetrain, body control, safety control and multimedia to implement locking/unlocking functionality. The central locking system interacts with the physical locks, a remote key, comfort functions, crash notification, safety control and security device. To correctly response to user scenarios, the OEM thus emphasizes on the integration of the distributed subsystems that are independently developed by the suppliers [Salzmann & Stauner, 2004; Broy et al., 2007]. The OEM specifies the functional requirements of a subsystem, while the supplier is responsible for realizing the subsystem according to the OEM's requirements. The

requirements are however not precisely specified in terms of design, architecture and the interaction between subsystems [Broy et al., 2007]. Upon the delivery of the subsystem, the OEM receives a black-box specification of a subsystem which is subject to integrate to one another. Therefore the exact implementation is unknown, or even the specification itself maybe not equivalent to the actual implementation. This poses a big challenge to the OEM during the integration phase such as to localize errors [Salzmann & Stauner, 2004].

3. Collaboration-based development
The development of an automotive product is, to a great extent, depending on how effective the OEM cooperates with the suppliers. Since the OEM only develops some certain core components, the majority of the subsystems are outsourced to third party suppliers. This comes with some certain advantages such as specialized knowledge. A supplier might produce the same system to other OEMs, which besides a specialized know-how, the lower cost of development can be in favor. However, unlike outsourcing in a software for business, the suppliers in the automotive industry are free to choose development method, platform and architecture. As mentioned, the OEM specifies functional requirements and receives the systems acquired from many different suppliers. Therefore, the OEM needs to have an effective supplier management and collaboration mechanism [Heumesser & Houdek, 2004].

4. Variants
The distinction of market demands requires automotive software to be customized addressing specific needs. A certain model selling in European market is not identical to those marketing in Asian countries. There can be up to 3,488 unique applications by instantiating different algorithms and their variants of a power train control [Broy et al., 2007]. The automotive software is then possessing a huge amount of software variants, all of which must be taken care by the OEM in terms of technical methodology and economic aspect.

2.1.2 Automotive Software Development Strategies

Automotive applications work through the feature interaction of various application domains such as drive-by-wire, power train control, passenger comfort, multimedia and *etc.* These features are the functionality of distributed subsystems that are developed by independent suppliers [Salzmann & Stauner, 2004; Natale, 2008; Heumesser & Houdek, 2004]. One of the benefits of outsourcing the development is that the development cost per unit is usually cheaper since the supplier produces the same kind of system for other OEMs as well. Furthermore, the supplier is the one who is specialized to the domain, therefore the OEM can make use of the supplier's know-how for competitive advantages. As a result of distributed development, the OEM is then focusing on system integration of a number of subsystems, therefore the automotive development is depending on the collaboration between the OEM and the suppliers. With the discussed profile, the automotive software is then one domain of software engineering that needs tools, processes and methods that are tailored to the emerging software development and applications to be able to solve existing domain-specific problems and support future challenges [Salzmann & Stauner, 2004; Grimm, 2003; Fabbrini et al., 2008].

As a response to the challenges, there are several countermeasures adopted within the automotive industry. The strategies/technologies can be classified into two families which are product-based and process-based [Fabbrini et al., 2008].

1. Product-based countermeasures

    - AUTOSAR (Automotive Open System Architecture): the software infrastructure initiated by a collaborative effort of automotive manufacturers, suppliers and tool developers. It is an open and standardized software architecture, whose intention is to establish a common software infrastructure for all vehicle domains. The idea is based on common and standardized interfaces for the different layers of the software architecture [Fabbrini et al., 2008; AUT, 2009].
    - MISRA (Motor Industry Software Reliability Association): this initiative aims to advocate the best practices to develop safety-related automotive systems. It is jointly developed by automotive manufacturers, component suppliers and engineering consultancies.
    - Product Lines: a systematic reuse of software assets to develop a set of software families. These products share a common reference architecture and other reusable core artifacts. Deriving new products from the reference architecture should eliminate rework and enforce a systematic approach to variability which facilitates the creation of new products with minimal effort [Pohl et al., 2004]. Software product line has been widely adopted in the automotive industry, especially by the software suppliers because they supply components to many OEMs [Fabbrini et al., 2008].

2. Process-based countermeasures
   International standards for software process assessment such as CMMI [SEI, 2006] and SPICE [SPICE, 2006] are utilized as the means to assess the capability of suppliers' software development process. To avoid a supplier facing different software assessment model from different manufacturers, there has been a common trend in European manufacturers in using Automotive SPICE to determine a target capability profile that a supplier shall accomplish in order to succeed in supplier selection. This is a mechanism employed in order to increase quality of the acquired system. However, there is also other benefits binding with employing Automotive SPICE such as improved supplier selection and monitoring, improved relationship and possibility to identify improvement areas [Fabbrini et al., 2008].

2.1.3 Main Phases of Automotive Software Engineering

In the work of [Heumesser & Houdek, 2004], they have concluded the major steps in developing software products in the automotive industry. This is however focusing on the aspect of Requirements Engineering and Management, which can be summarized as the following:

1. Internal product scoping
   In this phase, the OEM defines scopes for a certain subsystem to be outsourced, for example, key requirements for communication, optical design and hardware.

2. Creation of a call-for-tender specification
   Based on output from the previous phase, functional requirements of the subsystem is specified up to a certain level of abstraction. Particularly, requirements that would have an impact on product price.

3. Biding and contracting
   The functional specification is distributed to potential suppliers. They evaluate the requirements and hand in their offer. This phase ends with supplier selection and contract agreement.

4. Product development
   The supplier implements the requirements and the OEM heavily collaborates with the suppliers. It is at this phase that the subsystem requirements are evolving including a detailed specification of each part. During which, the OEM must handle changes and modifications made to the requirements.

2.2 Supplier Involvement in Product Development

Supplier involvement (SI) has been commonly referred to as the degree to which a manufacturer shares responsibility with a supplier in order to develop subsystems or components for a new product [Takeishi, 2001]. This could be in forms of capability integration [Hartley et al., 1997], accountability in decision making or the sharing of necessary information with the supplier [Handfield et al., 1999].

In [van Echtelt et al., 2008], the authors refer to the concept of supplier involvement as the resources (capabilities, investments, information, knowledge, ideas) that suppliers provide, the tasks they carry out and the responsibilities they assume regarding the development of a part, process or service for the benefit of a buyer's current or future product development projects.

Supplier involvement is then viewed as a way to cut concept-to-market development time. Previous research has shown that involving the suppliers into product development is a key to reduce time to market, decrease development cost and improve product qualities [Wasti & Liker, 1997; Primo & Amundson, 2002; Ragatz et al., 2002]. Manufacturers have been utilizing their suppliers in the development of a new product from a simply consultation on product designs to acquiring an entire subsystem from a supplier.

Although integrating the suppliers are proven to be a success in many cases, it has been revealed that supplier involvement poses inevitable complexity in order to effectively manage these suppliers [McIvor & Humphreys, 2004; Wynstra et al., 2001; Andersen & Drejer, 2009]. It is even worse when previous studies have demonstrated that supplier involvement does not lead to reduced development cost, shortened lead-time or higher quality [Hartley et al., 1997]. This is however not to construe that supplier involvement in product development is an inappropriate strategy, rather the buyer should understand the situation thoroughly and adopt apposite processes and practices to overcome challenges brought with the concept.

2.2.1 Managing Supplier in Product Development

In the research of [Ragatz et al., 1997], they have conducted a survey with 210 members of Global Procurement and Supply Chain Electronic Benchmarking Network(GEBN) and determined factors necessary for a successful supplier integration, from which they have drawn a conceptual model regarding how companies can minimize barriers posed by supplier involvement in product development. The research has investigated the dimensions of practices and project environment, and focused on the comparison of factors that are reported as '*most successful*' and '*least successful*'. Of all twenty-two managerial practices identified as necessary requirements for an effective supplier management, only twelve are determined to be statistically significant to differentiate most successful from least successful cases. In terms of project environment, four factors out of sixteen are considered as statistically significant to be a differentiator. The success factors are listed as the following:

1. Managerial Practices for Supplier Integration:
    - Supplier membership/participation on buying company's project team
    - Direct cross-functional, inter-company communication
    - Shared education and training
    - Common and linked information systems (EDI, CAD/CAM, e-mail)
    - Co-location of buyer/seller personnel
    - Technology sharing
    - Formal trust development processes/practices
    - Customer requirements information sharing
    - Technology information sharing
    - Shared physical assets (plant and equipment)
    - Formalized risk/reward sharing agreement
    - Joint agreement on performance measurements

2. Project Environment Factors for Supplier Integration:
   - Familiarity with supplier's capabilities prior to integration in this project
   - Strength of supplying firm top management commitment to their involvement
   - Strength of consensus that right supplier is selected
   - Strength of buying firm top management commitment to supplier integration

Open and direct communication is extensive used and is critical to early identification and rapid resolutions of problems [Ragatz et al., 1997]. Moreover, communication frequency and intensity has a significant relationship with the performance of supplier involvement in product development projects [Hoegl & Wagner, 2005]. This implies that companies shall not limit their decision and commitment at a strategic organizational level, instead they should propagate and find an appropriate level of communication frequency and intensity at the operational/project level to ensure a strong collaboration. Supplier participating in buyer's project teams is often presented in a form of periodic face-to-face meetings, selective co-location or a linked information system [Ragatz et al., 1997], which also facilitates operational communication and information exchange [Hoegl & Wagner, 2005].

The sharing of uncensored customer requirements to key suppliers is perceived as a part of extended enterprise. This helps the two parties to strengthen trust and is a great way to stimulate supplier innovation [Ragatz et al., 1997]. Moreover, the more the suppliers know about the buyer's customer, the greater the suppliers feel committed and thus share their information and have more tendency to involve in decision making process [Petersen et al., 2003].

Technology information sharing leads to creative solutions [Petersen et al., 2003]. An insight into emerging new technologies leads to new product ideas, and a common form widely used is a technology roadmap [Ragatz et al., 1997]. Therefore buyer/supplier share their technology roadmaps on a regular basis [Petersen et al., 2003]. By sharing this information, buyer and supplier can align their technology direction and early discuss technology options that can meet market requirements.

Based on these success factors, [Ragatz et al., 1997] have created a conceptual model regarding relationship structuring and asset allocation factors, as illustrated in Figure 2.1. The relationship structuring factors are necessary requirements to help expand the boundary of buyer-supplier relationship, open communication and share common goals and build trust. The relationship structuring practices are viewed as a facilitator for the asset sharing factors, for example, top management at both companies share commitment and help to change the organizational cultures by approving that it is '*okay*' to share information and that resources will be made available to support the integration effort.

[van Echtelt et al., 2008] argues that it seems not practical to discuss only project-related short-term process and success factors. Instead, the result of supplier involvement in product development could be best described by the degree to which a manufacturer manages associated suppliers in short-term, operational decision making and

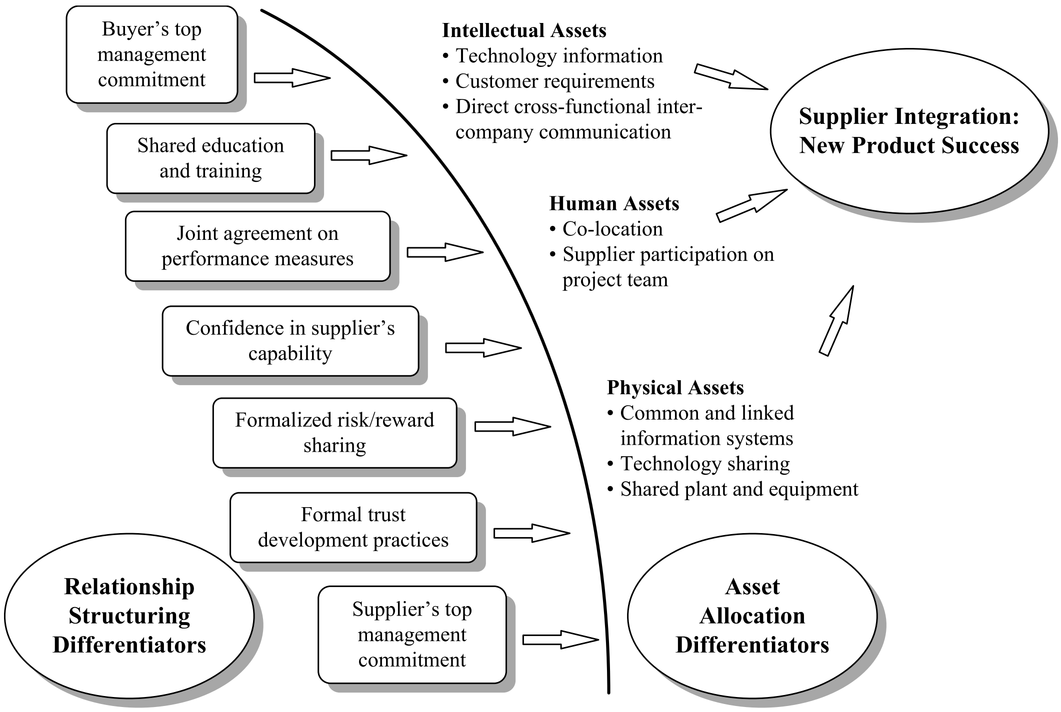

Figure 2.1: Explanatory model: Successful supplier integration into new product development [Ragatz et al., 1997].

also long-term, strategic management activities. They have conducted a longitude multiple case studies and propose a framework for managerial activities in both short-term and long-term management processes which is illustrated in Figure 2.2.

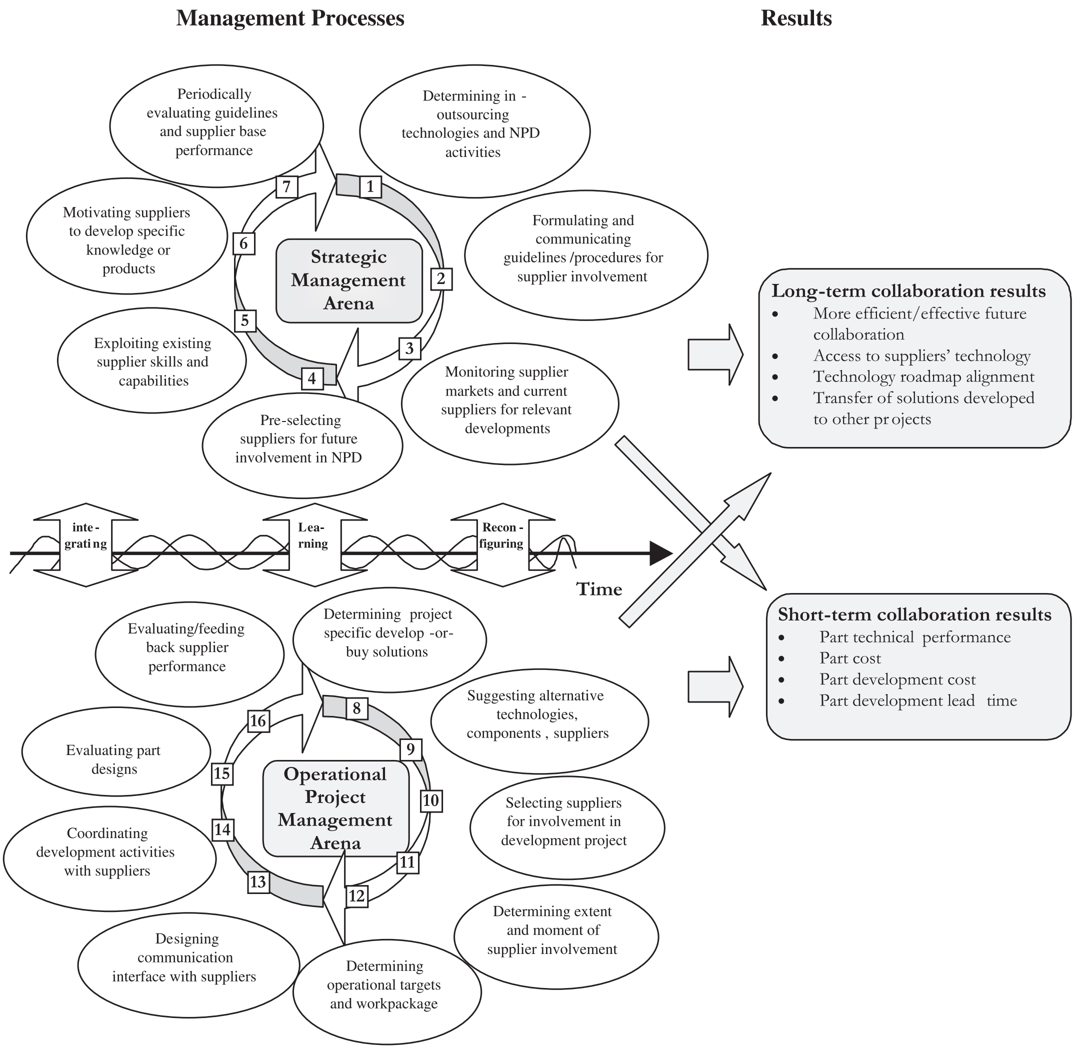

Figure 2.2: The framework for supplier management in new product development [van Echtelt et al., 2008].

Supplier involvement in new product development is a concept proven to be successful in reducing development time, sharing development cost and resources with the supplier, enabling product innovation and increasing product quality [Wasti & Liker, 1997; Primo & Amundson, 2002; Ragatz et al., 2002]. However, buyer firms or manufacturers have to employ effective managerial processes in order to leverage supplier's resources to the maximum [Ragatz et al., 1997]. This includes strategic long-term visions and short-term operation strategies for day-to-day project work [van Echtelt et al., 2008]. There are many variables leading to a success of supplier integration, for example, tier structure, degree of responsibility in design, specific responsibility in requirements setting process, when to involve supplier, inter-company communication, intellectual property agreement, supplier memberships on the project team and alignment of organizational objectives with regards to outcomes. The buyer should not only consider about technical expertise and price but also in terms of collaboration fit and precision through past experience with some certain suppliers. Both management and engineers should create an atmosphere that enable open sharing of information, mutual support and accommodate high commitment [Petersen et al., 2003]. Therefore, to achieve the goal of supplier involvement in new product development, the two organizations need to recognize not only technical skills but also soft skills such as social and project management [Hoegl & Wagner, 2005].

2.3 Company Introduction

The thesis is conducted at an European automotive OEM, which will be referred to as OEM A during the rest of the thesis. The company provides unique brand products and product development solutions to several automotive brands. This study is conducted within the Electrical & Electronics department whose responsibility concerns primarily the development of software applications and embedded systems in a vehicle.

Development project management is controlled by a global development framework, which basically is a set of milestones and activities to be performed between the milestones. This project management framework controls the development life cycle from pre-study to aftermarket. The framework is established to be commonly used among departments and other business units. The system engineering process adopted at the studied department follows the V model which complements the global framework. As shown in Figure 2.3, a standard V model is mapped to decision gates (DG) of the company's global framework. The development starts on the upper left and goes to the upper right.

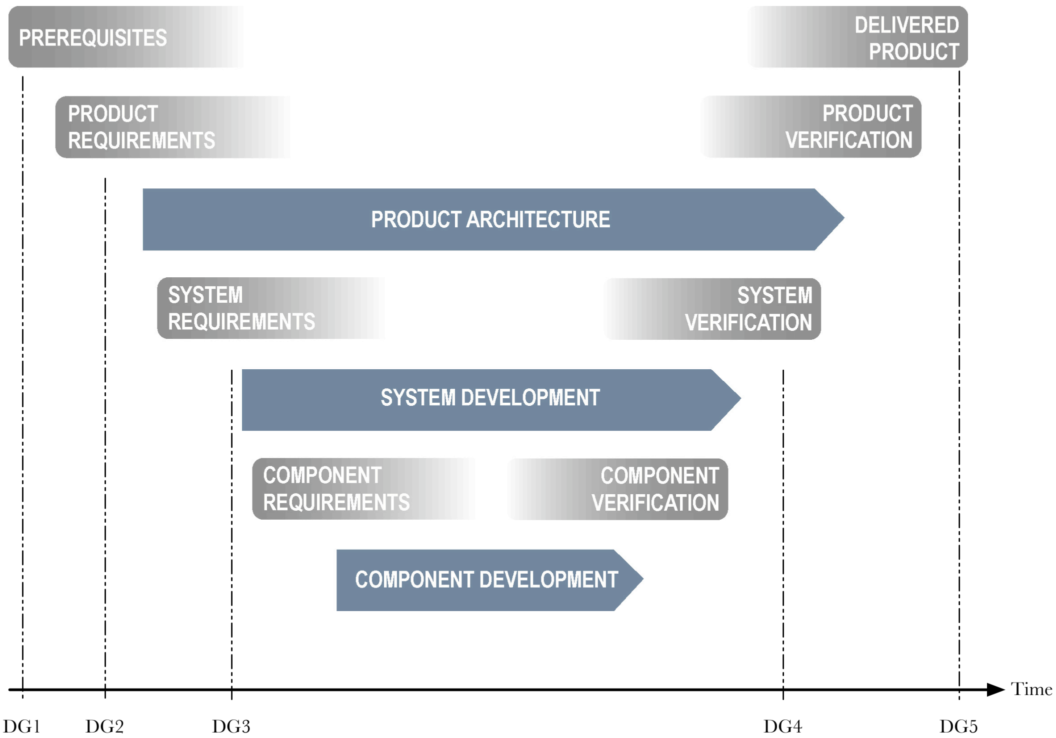

Figure 2.3: The V-model development process.

3. Research Methodology

This section discusses in details how the thesis is conducted. It describes research questions being addressed during the thesis, how the thesis is designed, its approach, techniques employed to collect and analyze procedure and types of validity the thesis pursues. It also provides a detailed discussion of how each technique is utilized to address the research questions as well as how the study instrument is developed.

3.1 Research Questions

The purpose of this study is to conduct the detailed investigation of how the practitioners work together with their suppliers providing software-intensive systems in the automotive industry. Also, it aims to find suggestions to improve the OEM-supplier cooperation for the studied organization. However, the suggestions for improvement serve only as hints that require further analysis which is not included in the scope of this thesis.

To accomplish the purpose of the thesis, the following objectives must be fulfilled during the study.

- Obtain an in-depth knowledge of how an automotive OEM and associated software suppliers work together during product development.
- Identify challenges or problems encountered by the practitioners.
- Suggest strategies or best practices discussed in the literature that are related to the challenges or difficulties.

Based on the objectives, the following research questions are formulated and thus addressed during the study.

RQ 1. How do the practitioners at an automotive OEM cooperate with their suppliers to develop software-intensive systems?

- *1.1* How do the practitioners work with the supplier in Functions Development?
- *1.2* How do the practitioners work with the supplier in Change Management?
- *1.3* How do the practitioners work with the supplier in Measurement *&* Monitoring?

1.4 How do the practitioners work with the supplier in Test *&* Verification?

RQ 2. Which areas are identified as challenges or improvement issues for the practitioners in order to develop software-intensive systems?

RQ 3. How can the practitioners improve the OEM-supplier cooperation?

3.2 Case Study Research

Case study is a procedure to observe one or a few special cases, whose phenomena under the study unit are not readily distinguishable from its context, to probe deeply and to analyze intensively the multifarious phenomena that constitute the life cycle of the study unit with a view to generalizations about the wider population to which that unit belongs [Yin, 2008; Mikkelsen, 2005; Sharp et al., 2002]. A case study can give a unique example of real people in real situations, which provides readers the understanding of a particular situation clearly more than presenting with an abstract theory [Cohen et al., 2007].

Case studies aim to portray the description of what it is like to be in a particular situation. Therefore, it is crucial that case studies must be able to speak for themselves rather than to be influenced by the judgement or evaluation of researchers [Cohen et al., 2007]. Case studies provide insights into reality and recognition of complexity. The embedding into social truths enable a case study to capture unique features that a large-scale study such as surveys can not catch [Blaxter et al., 2006; Cohen et al., 2007]. These features maybe important elements facilitating the understanding of the situation [Cohen et al., 2007]. Moreover, it enables the possibility to capture discrepancies or conflicts between participants' viewpoints. A case study also allows readers to judge the implications of the study for themselves. As the information presented by a case study is built on actual practices and experience [Blaxter et al., 2006], this insight can then be directly interpreted and put to action *e.g.* for organizational development [Cohen et al., 2007]. Also, a case study can be conducted by a small-scale researcher or even a single researcher [Blaxter et al., 2006; Cohen et al., 2007]. However, the case study approach has also some drawbacks. The outcome of a case study may not be generalizable, unless other readers or researchers can recognize the application [Cohen et al., 2007].

This thesis employs the case study approach in order to provide insights into the cooperation between an automotive OEM and its suppliers during the development of software-intensive products. The study follows the guideline of Software Process Improvement (SPI) called iFLAP (Improvement Framework Utilizing Light Weight Assessment and Improvement Planning) developed by [Pettersson et al., 2008]. As iFLAP is a tool for SPI, it is then related to generic research methodology and literature, which is discussed in details in Section 3.3.

3.3 iFLAP

iFLAP is a framework for SPI initiatives which includes both assessment and improvement planning. Unlike CMMI, iFLAP is an inductive assessment framework which, based on a comprehensive understanding of the current situation, improvement issues are drawn from the findings that are tailored to organization's specific needs [Pettersson et al., 2008]. iFLAP does not rely on a predetermined model, therefore improvement plans derived from the findings are assured to address what is needed to be improved regarding the organization's situation. This has also a benefit in terms of employee commitment because iFLAP bases SPI activity on the areas that are in the need of improvement, while the prescriptive frameworks such as CMMI and SPICE forces an organization to adopt a set of best practices which the employees might consider as irrelevant or unnecessary to the organization [Pettersson et al., 2008].

The execution of iFLAP contains basically three main steps: Selection, Assessment and Improvement Planning, illustrated in Figure 3.1. These steps are described in the following section.

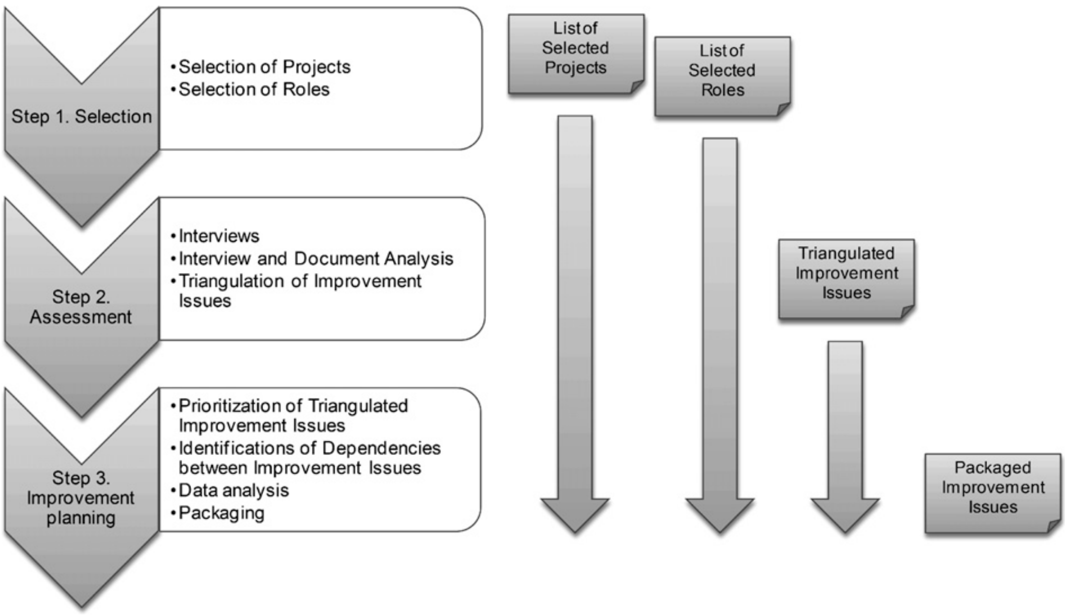

Figure 3.1: Overview of iFLAP method [Pettersson et al., 2008].

3.3.1 Selection

The selection step is to choose the right participants for the study to reflect the situation of the organization as much as possible. It is then important to select the people with care since including everybody working in the organization is not practicable in most cases [Pettersson et al., 2008]. It is a good idea for an assessor to have basic knowledge about the organization such as business model, products produced and customers. A workshop with company representatives could be organized in order to facilitate the understanding of the organization and the process under study [Pettersson et al., 2008]. This also includes main activities performed as well as roles and projects. Sample selection in iFLAP is achieved in three steps which are 1. to select projects to study 2. to select roles of participants from project and line organization and 3. to appoint persons representing each role.

3.3.1.1 Projects selection

Projects to be included in the study should represent other current projects and, if possible, potential future projects to ensure that the results from process assessment reach high validity [Pettersson et al., 2008]. In iFLAP, it is recommended to choose a project that is either recently completed or close to completion for the study. For an ongoing project that is far from completion, the people involved do not know the final outcome of project yet, therefore evaluating the success of current practices is difficult [Pettersson et al., 2008].

Moreover, it is advisable to rely on the judgement of the management organization (expert judgement) in the selection of the projects to be studied as the management has better understanding of the organization, project and staff availability, and it is eventually up to the management to grant access to participants and documents [Pettersson et al., 2008].

3.3.1.2 Roles selection

The roles of the participants should represent roles influenced or involved in the process being studied. This can be the roles that take part in the process or the roles that are affected by the product resulted from an activity in the process. It may however be less obvious to select roles that are influenced by the process when selecting line organization roles. Therefore, it is recommended to select roles from line organization that govern the process being assessed [Pettersson et al., 2008]. Also, the expert judgement of the organization representative is preferable when selecting the participant roles.

3.3.1.2.1 Participants selection

The number of subjects for each selected role can be determined by either the relative influence that the process being assessed and its products have on the role in question or by using quota sampling to reflect the distribution in the entire population [Pettersson et al., 2008]. If the projects being studied have the same organizational structure, it is then sensible to have the same distribution of the role representatives across all projects. This is because the disproportional number of role representatives between projects might affect the applicability of the assessment results [Pettersson et al., 2008]. The actual appointment of personnel should be done by expert judgement by representatives of the studied organization [Pettersson et al., 2008].

3.3.1.3 Relation to state-of-the-art in research methodology

It is crucial to include the right set of respondents to represent the whole population in a research [Patton, 2001]. In qualitative study, the sample should be able to illuminate in-depth understanding and insights into the research topic [Maykut & Morehouse, 1994; Patton, 2001]. Moreover, the respondents in qualitative research should express various viewpoints and different experience [Maykut & Morehouse, 1994]. The participants for qualitative research should then be selected based on predetermined criteria with an aim to give researchers information rich and in-depth explanations of the phenomena being studied [Cohen et al., 2007]. This is also referred to as purposive sampling, purposeful sampling or judgement sampling [Patton, 2001]. That is diversity and characteristics of the respondents are predetermined rather than random [Cohen et al., 2007; Patton, 2001].

Sample size in qualitative research is often smaller in scale compared to quantitative research [Creswell, 2002]. In purposive sampling, the number of study subjects is not necessarily specified, however recruiting a new subject usually stops when the new subject does not bring additional perspective or insightful information to existing data [Maykut & Morehouse, 1994]. On the other hand, quota sampling - one type of purposive sampling - determines from the beginning how many participants to be included. That is, it predefines the distribution of participants to reflect the entire population [Cohen et al., 2007].

The selection strategy presented in iFLAP seems to employ the purposive sampling method. The projects are selected with the criteria that they should be recently completed or almost completed, and they should be good representatives of entire population of current and future projects [Pettersson et al., 2008]. To select participant roles, iFLAP bases the selection on the result of a workshop which is organized in order to understand the overview of activities being studied and roles that are affected by the activities [Pettersson et al., 2008]. For the sample size, iFLAP leaves an open choice for an assessor to determine the number of participants representing each selected role by either using quota sampling to reflect the distribution of the entire organization or judging by the relative influence that the process studied has on each role [Pettersson et al., 2008].

3.3.2 Assessment

An assessment effort in iFLAP consists of two streams of study - project study and line study. Project study involves the study of one or more projects by utilizing two data sources which are interviews and documentation. As similar to project study, the study of line organization which is not part of any particular project is done through interviews with respondents from line organization and through line documentation. Therefore, there are four data sources in iFLAP as shown in Figure 3.2. Interviews with project representatives serves as data source A, while an analysis of project documentation is denoted by source B. Source C and D are line interviews and an analysis of line documentation respectively. Improvement issues are drawn by the triangulation of four data sources to increase the validity of the findings [Pettersson et al., 2008].

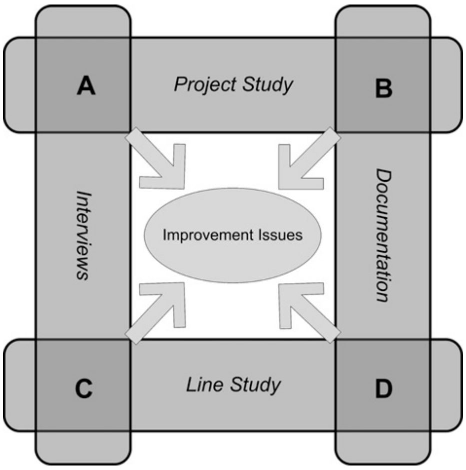

Figure 3.2: Triangulation of data sources [Pettersson et al., 2008].

It is however important to note that, in iFLAP, the primary source of data is the data gathered from the interviews with the practitioners and documentation is a supplementary data source used to either complement or contradict findings from an analysis of interview data. Using interviews as a leading data source is to assure that the findings will reflect the situation of the organization. Otherwise, if documentation is a primary source, the assessment will then be similar to using prescriptive frameworks that is basing on state-of-the-art practices which contradicts to the purpose of utilizing iFLAP [Pettersson et al., 2008]. The activities needed to be performed during the assessment step are mainly interviews, interviews and documentation analysis and triangulation of improvement issues. The following sub sections describe these activities in more details.

3.3.2.1 Interviews

An interview should be conducted to a certain degree of structure in order to keep the discussion topic relevant to the research topic [Pettersson et al., 2008]. An interviewer might have a set of questions to be covered during the interview to set out the interview context, but these questions are unnecessarily asked in the order or form prepared. It is also recommended to have warm-up questions to gather basic information about a respondent, and end the interview with wrap up questions that helps capture topics that are not discussed earlier [Pettersson et al., 2008]. For warm-up questions, the interviewer could ask about the respondent's former and current position. Whilst for rounding-off questions, the respondent could be asked for three things he thinks the organization is best at and three things that have the greatest improvement potential [Pettersson et al., 2008].

The content of the interview could be guided by state-of-the-art practices such as those from prescriptive frameworks *e.g.* CMMI or SWEBOK [Abran & Moore, 2004]. However, the purpose of an inductive approach must be kept in mind. That is, if relying the questions on model-based frameworks, they should be used only to elicit the respondent's attitude and opinions and not to benchmark the current process against the activities dictated by the model [Pettersson et al., 2008].

The length of an interview should be at least thirty minutes because an interview shorter than this is unlikely to produce valuable results [Pettersson et al., 2008]. It should be however noted that an interview longer than one hour would require too much demand on a busy respondent [Pettersson et al., 2008].

Regarding the mechanism to collect interview data, the interviewer can choose to take notes or to record the interviews. If more than one interviewers are available, it is then considered as less intrusive to take notes during the interviews than to record them [Pettersson et al., 2008]. If only one interviewer is present, it is recommended to record to keep up the flow of the interview and to minimize the risk of missing something important.

3.3.2.2 Interviews and documentation analysis

The answers from the interviews can be analyzed by classifying whether it expresses the respondent's opinion or not. This is to choose only data that is potential source of improvement issues [Pettersson et al., 2008]. The data is coded and is gone through iteratively to categorize the opinions into groups by dividing and merging the categories to reflect the respondents' opinions [Pettersson et al., 2008]. It should be kept in mind that these categories should express concepts of improvement issues instead of problems so that they are applicable to different contexts such as several projects [Pettersson et al., 2008].

In each category, additional comments describing problems that the respondents have faced could be included in order to make the improvement issue information rich [Pettersson et al., 2008]. The number of respondents that support each improvement issue should be recorded. Also, project and line documentation related to the improvement issues should be identified during the analysis of interviews to be collected later on.

The document analysis is guided by the results of the interviews. For each improvement issue, the gather documents are analyzed to check whether or not it supports the issue. For example, the line documentation is considered as it supports an issue if it does not contain how to address it [Pettersson et al., 2008]. On the other hand, if the line documentation describes practices that address an improvement issue, it is then considered as contradict (not supporting) to the issue [Pettersson et al., 2008].

3.3.2.3 Triangulation of improvement issues

The triangulation step is performed in order to increase reliability of an improvement issue [Pettersson et al., 2008]. That is, an issue raised by respondents from project organization is not automatically considered as a valid improvement issue. As iFLAP utilizes four data sources: project interviews and documentation, and line interviews and documentation as illustrated in Figure 3.2. The triangulation of improvement issues is then achieved by comparing the number of supporting data sources to a threshold value, for each improvement issue. It is recommended to set a cut-off threshold of two or three for an issue to be confirmed as valid [Pettersson et al., 2008]. However, the unconfirmed issues are sorted out at this stage but should be considered in later iterations of SPI [Pettersson et al., 2008].

3.3.2.4 Relation to state-of-the-art in research methodology

The assessment step in iFLAP can be related to methods to collect and analyze data in qualitative study, which are discussed in the following sections.

3.3.2.4.1 Data collection

Methods employed to collect data in iFLAP are individual interviews and documentation. Interview with practitioners is used as a primary source of data. One can distinguish the families of interview into structured- and unstructured interview. A structured interview is conducted with predefined objectives and specific questions. In contrast to a structured interview, an interviewer only suggests the theme of the interview and has a few specific questions in an unstructured interview. In iFLAP, the two approaches are combined - semi-structured interview. The objectives and questions are predefined and constructed. However, the respondents are asked with open-ended questions to get in-depth information, opinions as well as the feelings of the respondents [Hove & Anda, 2005]. As the quality of collected data is directly influenced by how the interviews is conducted, careful planning of the interview is a vital step and should be perform with care [Hove & Anda, 2005].

As a supplementary data source, public documents such as process instructions, meeting minutes, training materials are also collected. These documents can include information about practices, decisions or actions relevant to the process under the assessment.

3.3.2.4.2 Data Analysis

It is a method of content analysis that iFLAP utilizes to extract improvement issues from the interview data. The content analysis is an approach to analyze written communicative materials which can be anything from articles, newspapers to interview transcripts [Cohen et al., 2007]. Texts are coded to allow a replication as well as a valid inference from written data [Krippendorff, 2004]. It is preferably if the codes used are derived from data responsively rather than created beforehand, as it is considered to be more faithful to the data [Cohen et al., 2007]. A code can be either a word or an abbreviation sufficiently close to that it is describing to allow a researcher to see at a glance what it means [Cohen et al., 2007]. Following the coding step is to cluster the data into category, which is similar to the process of categorization in [Lincoln & Guba, 1985]. This is to group the main features of the text to form the richness of the data and to provide descriptive and inferential information [Cohen et al., 2007; Lincoln & Guba, 1985]. Code is a label for a piece of text, whilst a category is a node that different codes are collected [Cohen et al., 2007]. To relate to iFLAP, coding represents problems found and improvement issues are based on categories.

3.3.3 Improvement Planning

As mentioned, iFLAP is an inductive approach therefore it is important for an organization to determine an appropriate improvement plan that reflects the needs of the organization [Pettersson et al., 2008]. Solving all issues at once would be too expensive, also it poses too high risk [Pettersson et al., 2008]. Subsequently, this affects the time to return on investment. Therefore, it seems rational to determine the boundary of the issues to be addressed at one time. In iFLAP, this is achieved by performing two activities: prioritization and dependencies identification.

3.3.3.1 Prioritization of triangulated improvement issues

The order of which improvement issues to be addressed first can be obtained by involving the company representatives to prioritize the improvement issues identified. In iFLAP, the same participant roles as those who have attended the interviews are targeted, however those that do not involve directly to the studied process might be removed later when identifying dependencies in the next step [Pettersson et al., 2008].

The prioritization of the improvement issues is performed in order to single out few issues that are critical to solve as soon as possible, while it also gives an opportunity to exclude those issues that have been incorrectly included [Pettersson et al., 2008]. The choice of prioritization technique to be used depends on the number of issues to be prioritized. Prioritization techniques commonly used for requirements prioritization can be used to order the improvement issues, as they are basically requirements on the development process [Pettersson et al., 2008]. These techniques are for example analytical hierarchy process (AHP) [Saaty & Vargas, 2001], cumulative voting, the top-ten approach and ranking [Berander & Andrews, 2005]. Scale, granularity and scalability are three properties that differentiate one method from the others, as summarized in Table 3.1.

It is however important that participants have common understanding on what to based the prioritization on. The aspects considered could be in terms of product quality, cost of development or time-to-market [Pettersson et al., 2008]. The aspect should be agreed upon and communicated to the participants before starting prioritization.

3.3.3.2 Identification of dependencies between improvement issues

This step is performed in addition to the prioritization step, as the priority of improvement issues may not be an ideal order to address the issues [Pettersson et al., 2008].

Technique	Scale	Granularity	Scalability
AHP	Ratio	Fine	Low
Cumulative Voting	Ratio	Fine	Medium
Ranking	Ordinal	Medium	High
Top-ten	-	Extremely coarse	High

Table 3.1: The prioritization techniques [Pettersson et al., 2008].

An issue with the highest priority may have a number of other issues as prerequisites. Therefore, dependencies between the improvement issues should be recognized in order to effectively include any issue in the implementation of improvement [Pettersson et al., 2008].

In iFLAP, the practitioners can identify dependencies by associating any two issues together using a line with an arrow. The direction of the line starts from a dependent issue (issue A) towards an issue that it depends on (issue B). So, in this case, a line is drawn between issue A and B with an arrow pointing to issue B. The participants are also asked to give motivation to an individual dependency in order to ease the compilation of results.

To scrutinize the results, the dependencies that are vague or irrelevant are removed, and the rest are compiled in a list of dependencies that includes relationship and its associated weight. The weight of each relationship is determined by the number of participants that have specified the dependency [Pettersson et al., 2008]. Low weighted dependencies should be also removed in order to avoid consideration too many weak dependencies in later step [Pettersson et al., 2008]. Similar to confirming a valid issue, a threshold of what is to be considered as valid dependencies should be specified.

3.3.3.3 Data analysis

Another aspect to consider before commencing the implementation of improvement is to measure the level of agreement among the participants from the result of prioritization [Pettersson et al., 2008]. Generally, agreement among participants is positively associated with level of commitment to the improvement effort. That is, if a strong agreement can be identified, the improvement proposals can then be based on the results of the prioritization and dependencies identification [Pettersson et al., 2008]. On the other hand, if a great level of disagreement is found, additional measures may be needed to assure the commitment to the improvement implementation.

The methods to analyze the agreement and disagreement among the participants are different depending on the techniques used in prioritization. The disagreement chart [Regnell et al., 2001] can be used to measure the disagreement level among participants on an individual issue [Pettersson et al., 2008]. A satisfaction level of an individual participant on the overall ranking of improvement issues can be evaluated by calculating Spearman's rank correlation coefficient, which then can be visualized using the satisfaction chart [Regnell et al., 2001]. Consistency ratio [Saaty & Vargas, 2001] indicates the reliability of the results by indicating the amount of contradictory comparisons, if prioritization is achieved by using AHP [Pettersson et al., 2008]. Principal component analysis can be used to indicate if different groups of participants have an influence on the differences in opinions, in the case of a disagreement is found from a disagreement or satisfactory chart [Pettersson et al., 2008]. A summary of prioritization techniques and their applicable analysis methods is shown in Table 3.2.

Technique	Scale	Disagreement Chart	Satisfaction Chart	Consistency Ratio	PCA
AHP	Ratio	X	X	X	X
Cumulative Voting	Ratio	X	X		X
Ranking	Ordinal		X		
Top-ten	-				

Table 3.2: Applicability of prioritization analysis methods [Pettersson et al., 2008].

3.3.3.4 Packaging

The last step is to package the improvement issues based on the outcomes of the prioritization and dependencies identification. This is to guide the planning and implementation of changes. Together with the priority and dependency, the aspects of the effects of candidate solutions and the cost of implementation should be taken into consideration [Pettersson et al., 2008]. Diagrams combining priorities and weighted dependencies can be used as a decision support when establishing packages [Pettersson et al., 2008]. One way to find candidate solutions to the improvement issues is to relate them to best practices and state-of-the-art methodologies [Pettersson et al., 2008]. In addition, the agreement level achieved by data analysis and the priorities can be used as indicators of people commitment to improvement efforts [Pettersson et al., 2008].

3.4 Operation

This section describes in details how each step of iFLAP is prepared and executed during this thesis.

3.4.1 Selection

Pre study about the company is conducted in order to have a comprehensive view of the organization. Although it is advisable to arrange a workshop with company representatives to have an understanding of the process area under study [Pettersson et al., 2008], it is not feasible in this case because the thesis is not initiated by the company studied itself, rather it is an initiation from another company providing supports and consultations to the company studied. Therefore this phase is mainly conducted by studying documentation describing different processes, project organization and the description of roles and responsibilities.

3.4.1.1 Projects Selection

Appropriate projects to be studied should be projects that are already completed or close to completion [Pettersson et al., 2008]. Under the studied department, there is only one project ongoing. However, according to expert judgement, this project is approaching the ending of product development which is the area of focus of this thesis. That is, the project has entered the last phase of requirements development, which is the phase that requires the most collaboration with associated suppliers. Moreover, although it is the only project, this project is suitable to be a representative for future projects within the Electrical *&* Electronics department due to the fact that the project is developing the new architecture for future products. This means that the future vehicle projects will make use of components developed by this project, therefore processes currently adopted within this project will be maintained for future use.

3.4.1.2 Roles Selection

The roles of participants are selected based on the purpose of the study, which is to understand the cooperation between an automotive OEM and its supplier during the development of new software-intensive products. As suggested in iFLAP, participant roles should be those that take part or are affected by the resulting products of the process being studied. Therefore, to identify such roles, published documents such as process description, process flowchart, and role *&* responsibility description are studied in order to have an overview of what activities are performed and by who. A list of potential roles to be interviewed is then established. Next, a meeting with Project Manager of the studied project is held in order to consult if the identified roles have covered all roles that take part or are affected by the cooperation with the suppliers.

For the roles from line organization, those who monitor resources and competences of people in their group or section are identified through the use of organizational chart of the department.

3.4.1.2.1 Participants Selection

The number of practitioner in each selected role is determined by the relative influence that the OEM-supplier cooperation activities have on each role. The appointment of actual personnel from the studied project is achieved during the meeting with Project Manager. He grants access to the practitioners in the project, and provides contact information of the participants.

3.4.2 Assessment

The goal of this step is to understand thoroughly the current state of the software supplier cooperation. This is achieved by collecting data through interviews and documents, then performing data analysis.

3.4.2.1 Interviews

An individual interview is conducted with each of the respondents. The length of the interview is varied from 50 to 90 minutes depending on the respondent availability. The subject to be covered in the interviews is determined by the purpose of the thesis, and as a result, questions to be covered during the interviews are created. The following section describes in details how an interview instrument is developed.

3.4.2.1.1 Development of interview instrument

The interview questions are developed based on the research questions previously shown in Section 3.1. All sub questions under *RQ 1* can be answered using the data gathered through interviews with practitioners.

To investigate the processes specified in *RQ 1*, the interview questions are created based on four different viewpoints which are working method, roles *&* responsibilities, tools and documentation.

- Working method
  This viewpoint concerns investigating the process in question in terms of practices and activities occurring during the whole process. The purpose is to understand the series of actions carried out by the practitioners including when and how to perform those practices.

- Roles *&* responsibilities
  Besides the activities performed, it is also important to know who is in charge of carrying out the activities of the process in question.

- Tools
  This is to investigate what tools the practitioners are utilizing to support their work process.

- Documentation
  This viewpoint concerns any artifacts as the product of the process in question, templates of the artifacts as well as instruction of the process.

Table 3.3 shows the outline of the interview questions produced, based on the four viewpoints, to investigate the current practices of the supplier cooperation. The answers to these questions provide the understanding of how the practitioners work and interact with the supplier.

In order to explore the opinion of the practitioners towards their cooperation with the supplier, the practitioners are asked to evaluate their processes as a follow up question. For example, the following questions are added to the basic questions in Table 3.3.

- What would you rate for the effectiveness of your System Engineering process, on a scale from 0 to 5 where 0 is very bad and 5 is very good?
- What would you rate for the quality of the specification which you provide to the supplier, on a scale from 0 to 5 where 0 is very bad and 5 is very good?
- What would you rate for the usefulness of the process instruction, on a scale from 0 to 5 where 0 is very bad and 5 is very good?

These quantitative questions allow the author to grasp the respondent's opinion towards the process in question immediately during the interview. Therefore, the author can use this benefit to further explore the respondent's opinion by asking follow up questions such as why doesn't the process deserve a 5, and how would you like the process to be improved to be rated as a 5? Moreover, the additional benefit of the quantitative questions and their followup questions is that they help discover the underlying challenges and difficulties the practitioners encounter in the supplier cooperation, which is related to *RQ 2*. However, the direct question concerning *RQ 2* is also created to be able to capture other aspects of difficulties other than the main processes investigated in *RQ 1*.

In addition to the basic questions presented in Table 3.3, a number of warming-up questions and rounding off questions are included in the interview guideline used during the interview. The warming-up questions are asked to gather the basic information of the respondent. The rounding-off questions are asked to avoid overlooking any important aspects during the interview.

The completed interview instrument including all questions and their corresponding research questions is presented in Appendix A. The interview instrument is tested and the questions are tweaked to fit the time of the interview as well as to make it easy to understand and, thus, a relevant answer is given. It is important to mention that the instrument is used as a guideline for the "*semi-structure*" interview; therefore, some of the questions might be skipped and some might be added depending on the situation in which the interview is conducted. Also, the instrument is continuously revised throughout the interview period to be more relevant to the scope of the study and to adapt to the practitioners' vocabulary.

3.4.2.2 Interview and documentation analysis

All interviews are digitally recorded and subsequently transcribed. Interview transcripts of all participants are coded and analyzed as described in Section 3.4.2.2.1. This list is further used as a basis for collecting supplementary documentation for analysis.

3.4.2.2.1 Interview coding

There are in total twenty transcripts; one transcript for each respondent. Data records in the transcripts are coded according to coding criteria that are developed and continuously refined. The codes used comprise of four levels: Level 1, 2, 3 and 4. The

Research Question	Viewpoint			
	Work Method	Roles & Responsibilities	Documentation	Tool
RQ 1.1 How do the practitioners work with the supplier in Functions Development?	What is the process of breaking down from the customer requirements to the specification that is sent to the supplier?	Who (What roles) are involving during the process?	Are there organizational policies or instructions guiding how this process should be conducted?	What tools are utilized during the process?
RQ 1.2 How do the practitioners work with the supplier in Change Management?	How do you inform the supplier if there are changes in the functional requirements?	Who (What roles) are involving during the process?	Are there organizational policies or instructions guiding how this process should be conducted?	What tools are utilized during the process?
	How does the supplier inform you if there are modifications to their implementation?			
	How do you handle deviations to requirement baselines?			
RQ 1.3 How do the practitioners work with the supplier in Measurement & Monitoring?	How do you keep track of the development status at the supplier?	Who (What roles) are involving during the process?	Are there organizational policies or instructions guiding how this process should be conducted?	What tools are utilized during the process?
RQ 1.4 How do the practitioners work with the supplier in Test & Verification?	How do you test & verify the supplier product? Who (What roles) are involving during the process?	Are there organizational policies or instructions guiding how this process should be conducted?	What tools are utilized during the process?	

Table 3.3: Basic Interview Questions

Level 1 codes are primarily based on *RQ 1* and *RQ 2*. The codes are at a high level of abstraction and are utilized to coarsely divide data records into two groups of whether a particular record explains current activities or expresses opinions about problems occurred. Illustrated in Table 3.4 is an initial list of high level codes used in this thesis.

Abbr.	Category	Description	RQ.
C	Current Practice	Description, clarification, explanation of practices, processes or *etc.* of how the practitioners cooperate with suppliers. This includes both direct and indirect practices that influence the cooperation. Also, this includes practices or processes that the practitioners think they are already good.	RQ 1
D	Difficulty/Challenge	Problems, issues, bad practices or *etc.* that are related to OEM-supplier cooperation. Use this category even if the supplier cooperation is indirectly affected by the referred practice.	RQ 2

Table 3.4: Initial high level codes.

The next level codes are constructed by, first, reading through the records that are coded with "*C*" and label them with the codes that are derived from the viewpoints used when developing interview questions, which are working method, roles *&* responsibilities, tool and documentation. These are categories used in the Level 3 codes. Then, these data records are iteratively scrutinized to categorize them in terms of which process area they are referring to, and this is corresponding to codes used in Level 2. Level 4 are left for comment or an interpretation of a certain text.

Next, the data records that are grouped as "*D*" are processed by classifying into process areas corresponding to Level 2. Each of these process areas are then continuously scrutinized to put together similar responses into categories and to sort out responses that do not belong in a particular category. These categories represent the Level 3 codes for data records in group "*D*". These steps are conducted in an iterative manner and the Level 3 codes are continuously refined by merging or dividing them in order to reflect the data as much as possible. Again, Level 4 is an interpretation of a particular data record or a comment. A list of improvement issues is derived from the Level 2 codes, as they are representing process areas that interact or influence the supplier cooperation. Appendix C shows the codes used within this thesis.

3.4.2.2.2 Document analysis

A list of documents needed for further analysis is established during the coding and analysis of the interview transcripts. This includes the documentation from project and line organization. The documents collected from the project studied are, for example, project plan, project prerequisites, meeting minutes, training materials, process change documentation and some "HOW-TO" documents.

The line organization provides instructions for many different processes and practices such as system engineering process, test & verification process, function synchronization practices, global sourcing process and *etc.* All relevant documents are collected and analyzed.

3.4.2.3 Triangulation of improvement issues

To validate findings from the interview respondents, each improvement issue is triangulated among different data sources [Pettersson et al., 2008]. As in iFLAP, data from the interview respondents is the primary source while documentation acts as a supplementary source. In addition to "*Project*" and "*Line*" studies, respondents from "*Supplier*"'s organization is also included in the interviews in this thesis. Therefore a threshold of three is desired in order for an improvement issue to be considered as a valid issue (triangulated).

3.4.3 Improvement Planning

A workshop is conducted in order to validate intermediate findings with the practitioners. These findings are a synthesized list of improvement issues found as a result of interview analysis. The workshop is planned for 2 hours uninterrupted. All respondents of individual interviews are invited to participate in the workshop. The workshop gives possibility to discuss the improvement issues and ensure the common understanding on each issue.

In this workshop, the participants are asked to prioritize the improvement issues triangulated from the previous step. Cumulative voting is the method employed for prioritization. Together with priority identification, the practitioners are also requested to associate the improvement issues based on their dependencies. This is to find, as much as possible, the practical way to perform the implementation of improvement [Pettersson et al., 2008]. As improvement issue A might have a mitigation of improvement issue B as a prerequisite, this dependency should be recognized and used as support for improvement decision. s

3.4.3.1 Prioritization of triangulated issues

The method of prioritization is cumulative voting. That is, each participant is given an imaginary cash with the amount of 100 SEK, and asked how much money he would like to spend to solve each of the issues. The only rule to this is that each issue must be received at least 1 SEK.

3.4.3.2 Identification of dependencies between improvement issues

The participants are asked to recognize dependencies between improvement issues by associating them using an arrow line. Each line starts from an issue that is a dependent and ends at the other issue that it depends on with an arrow pointing towards the latter. Each dependency must be accompanied by motivation as to why the issue depends on the other. A cut-off weight for a dependency to be considered as valid is seventy five percent of the number of attended participants in the workshop.

3.4.3.3 Data Analysis

3.4.3.3.1 Disagreement Level

A disagreement level among participants for each improvement issues is measured by calculating the coefficient of variation (C_V) from the priorities. The coefficient of variation is calculated from Formula 3.1,

$$\mathrm{C}_V = \frac{\mathrm{S}D_x}{\bar{x}} \tag{3.1}$$

where $\mathrm{S}D_x$ is the standard deviation of sample x and $\bar{x}$ is the mean value of sample x. The coefficient is the ratio of standard deviation to the mean of a sample. For each improvement issue, the priority values that the participants have assigned to a particular issue are calculated for the standard deviation, the mean and finally the coefficient of variation.

The coefficient of variation enables the comparison of data sets that have different means [Devore, 2008]. In this case, one data set is the priority values of each issue. The application of the coefficient of variation in this thesis is to measure a disagreement level among participants towards a particular issue, and to be able to compare it to other issues.

To compare the disagreement level among the improvement issues, it is based on an assumption that the disagreement placed on the higher prioritized issues should not be significantly more than the disagreement found in the lower prioritized issues. This is because a high degree of disagreement on the higher prioritized issue could influence the commitment to the implementation of improvement initiatives. Generally speaking, people do not agree with the prioritization results. In order to compare if the disagreement level is significant, the t-test procedure [Devore, 2008] is applied on the coefficient of variation calculated for an individual issue.

The C_V values are first sorted by the prioritization result, and then divided into two groups of higher and lower priorities. The null hypothesis (H_0) is that these two groups of variables have the same mean. That is, the disagreement level is not statistically significant. The alternative hypothesis (H_a) is that the disagreement level of the higher prioritized issues are significantly higher than those of the lower prioritized issues. The test statistic (t) is then calculated and the $p - value$ is then obtained. The significant level chosen in this thesis is 95%. Following is the step to conduct the t-test procedure on two samples.

- Given X as the values of C_V of the high priority issues.
- Given Y as the values of C_V of the low priority issues.
- $H_0 : \bar{X} = \bar{Y}$ (This is equivalent to $H_0 : \bar{X} - \bar{Y} = 0$)

- $H_a : \bar{X} > \bar{Y}$ (This is equivalent to $H_a : \bar{X} - \bar{Y} > 0$)
- Find degree of freedom from

$$df = \frac{\left(\frac{S_1^2}{m} + \frac{S_2^2}{n}\right)^2}{\frac{\left(\frac{S_1^2}{m}\right)^2}{m-1} + \frac{\left(\frac{S_2^2}{n}\right)^2}{n-1}}$$

- Calculate test statistic (t) from

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{s_1^2}{m} + \frac{s_2^2}{n}}}$$

- Find the $p - value$ from a t-distribution tail area table using the t and df calculated, for upper tail test.
- Compare the $p - value$ to a significant level of 0.05 and decide whether H_0 is rejected. H_0 is rejected ($= H_a$ is accepted) if $p - value < 0.05$.

3.4.3.3.2 Satisfaction Level

The prioritization of each participant is compared to the overall ranking of improvement issues by calculating Spearman's rank correlation coefficient (or Spearman's rho). It measures how well the two data sets relate to each other by describing with a monotonic function. The two data sets are perfectly monotone to each other when the value calculated is either 1 or -1 [Devore, 2008]. The sign of the Spearman's correlation coefficient indicates the direction of the association between the two data set. If a positive coefficient is yielded, data set A tends to increase when data set B also increases. On the other hand, a negative values suggests that data set A increases when data set B decreases [Devore, 2008]. In this case, one data set is a ranking of one participant towards the improvement issues and the other set is the overall ranking of the improvement issues. That is, the ranking of an individual is compared to the overall priority to see how well they are correlated to each other. If the value approaches 1, the prioritization of an individual is significantly associated with the overall prioritization. This suggests that he is satisfied with the overall ranking of the improvement issues. On the other hand, if the value approaches -1, his prioritization seems to go the opposite direction of the overall ranking. Therefore, his satisfaction level is low. The Spearman's rank correlation coefficient (ρ) is calculated by Formula 3.2,

$$\rho = 1 - \frac{6 \sum d^2}{n\,(n^2 - 1)} \tag{3.2}$$

where n is sample size and d is a distance between the rank of the two variables. The following steps are performed in order to calculate the value of d:

1. Given X as a set of priority values person A has assigned to the improvement issues, sort by X, then create a new column and assign a rank of 1, 2, 3, ..., n.
2. Given Y as a set of overall priority values of the improvement issues, sort by Y, then create a new column and assign a rank of 1, 2, 3, ..., n.
3. Create a new column and calculate the differences of ranks (d_i) by subtracting y_i from x_i.
4. Create a last column to hold the values of d_i^2, and then calculate $\sum d^2$.
5. In the case of tie, a rank to be assigned is an average rank of the tied priority value.

Table 3.5 shows an example of the calculation of $\sum d^2$, and yield the value of 10

X	rank x_i	Y	rank y_i	$x_i - y_i$	d_i^2
20	2	80	1	1	1
25	1	60	3	-2	4
10	4	75	2	2	4
15	3	55	4	-1	1

Table 3.5: Example of calculating $\sum d^2$.

3.4.3.4 Packaging

The packaging of candidate improvement issues is guided by the prioritization result as a primary lead and dependencies are taken into consideration.

3.5 Literature Review

The intent of the literature review is to gather existing evidence in a particular area. In this thesis, research on literature is conducted in favor of relating the findings to state-of-the-art and also proposing suggestions for improvements. It was first intended to conduct the literature review in a systematic manner - systematic literature review [Kitchenham & Charters, 2007]. However, due to the time and resource constraint, traditional literature review is favorable. In order to limit a threat to validity, the steps in conducting the literature review is recorded and presented in the following sections.

3.5.1 Search Strategy

The review is constructed targeting the improvement issues derived from the interview analysis, therefore search terms are identified focusing on the improvement issues that are selected at the packaging step (Section 3.4.3.4). Inspec is chosen as the main database providing relevant and current research conducted in software engineering.

An execution of literature search is done through a web search engine, Engineering Village, which supports searches in terms of complex queries using 'AND' or 'OR' Boolean operators. It also has a feature to limit search fields to only relevant fields such as title, abstraction and keywords. Appendix B summarizes the search strings used during the review. Title, abstraction and keywords are the attributes that the search strings are applied on.

3.5.2 Study Selection

3.5.2.1 Inclusion Criteria

To determine whether a study is a potential candidate to become a primary study, the title, abstract and keywords are analyzed if the study deals with the subject of interests. The following study will be classified as a potential study:

- Study that discusses subjects related to the improvement issues.
- Study that aims to present success or failure stories regarding the improvement issues.
- Study that mentions challenges and strategies regarding the improvement issues.
- Study that orients towards the improvement suggestions of improvement issues.
- Study that does not deal with the improvement issues from educational point of view *e.g.*to present teaching methodologies or to develop a course regarding a particular issue.
- Study that is available in full text.

3.5.2.2 Exclusion Criteria

- Study that does not discuss any real life experience regarding the improvement issues.
- Study that is workshop summary, technical report, position paper and tutorial.
- Study that does not clearly explain the findings.

3.5.2.3 Selection Procedure

For each search term, the search results are sorted by relevance and only the first 40 papers are first hand picked. The inclusion criteria are then applied on these 40 studies. If a study satisfies the inclusion criteria, it is classified as a potential candidate or relevant. The exclusion criteria are then applied on the study. If the study satisfies the exclusion criteria, it is excluded. In other words, the potential study that does not satisfy the exclusion criteria is selected and saved as one of the primary studies for full-paper reading. During the full-text reading, studies that are not related to the theme of this thesis or the selected improvement issues are also excluded from the review.

3.6 Research Validity

A piece of research must pursue some certain kinds of validity, otherwise it would be absurd to declare it invalid [Cohen et al., 2007]. These are, for example, generalizability, replicability, controllability, *etc.* This particular piece of research strives to convey its findings providing a rich picture of what transpires through words, thus in this respect, it is considered as a qualitative research in nature [Cornford & Smithson, 2005].

Many writers debate that "*validity*" is not a best suitable word to evaluate a qualitative study [Maxwell, 1992]. Instead, they prefer to judge a narrative piece of work in terms of understandability, plausibility and creditability [Maxwell, 1992; Lincoln & Guba, 1985]. Whether a study is qualitative or quantitative, it must be however able to demonstrate the extent to which its information is accurate.

There are many different types of validity. It is not the intention of this study to discuss in details for each of them. Thus only important validity aspects are selected [Cohen et al., 2007].

1. Internal Validity
   Internal validity concerns the degree to which the explanation of the situation can be sustained by its data. The findings must accurately convey the description of the events, issues, situation, *etc.* In qualitative study, this refers to creditability and plausibility [Hammersley, 1991], which can be attenuated by, for example, the means of:

   - Employing a mechanical mean to record, store and retrieve data.
   - Prolonging engagement to the study.
   - Respondent validation.

2. External Validity
   External validity is the evaluation of the extent to which the result can be generalized to wider population, cases or situations. Generalization, in qualitative respect, can be construed as compatibility and transferability [Cohen et al., 2007]. It is subject to the reader or the user of the study to decide whether the result is transferable. However, it is very much depending on the ability of the researcher to be able to provide substantial and sufficient in-depth description so that the others can determine whether the information conveyed is generalizable or not.

3. Concurrent Validity
   This form of validity seeks the high correlation of data gathered from different instruments. In brief, the data gathered from interviews must agree with data gathered through observations in order to draw an accurate conclusion. Triangulation of methods, sources and investigators are techniques employed when researchers endeavor concurrent validity.

3.6.1 Validity Evaluation

To ensure validity of this thesis, many techniques have been utilized in order to attenuate threats to validity. Within iFLAP, validity factors such as population *&* sampling and result reliability are addressed. The following is the discussion of the relation to the validity types mentioned above.

1. Internal Validity
   The selection of respondents is based on the instructive description of respondent's roles and responsibilities. The criteria of, whether or not, a certain role is selected is predefined, as suggested in [Cornford & Smithson, 2005] that how the individuals are selected should be identified.

   Interview instrument is systematically developed and is subject to review and pilot. This is to ensure that questions are understandable and to be able to rectify the instrument. Ambiguous questions mislead the respondent resulting in irrelevant data collected [Cornford & Smithson, 2005].

   All interviews are digitally recorded, transcribed and coded. The criteria used for coding the interview transcriptions are predefined and subject to review to reduce bias and inconsistencies.

   The results from analysis are subject to respondent validation, as described in improvement planning [Pettersson et al., 2008].

   The documents included in this study is listed and information extracted are noted down in a template.

2. External Validity
   A single-case study, as this thesis, does not have an advantage of having a great degree of generalizable [Cornford & Smithson, 2005]. This issue could however be addressed by study multiple cases or typical situations which the findings from the studies will be more sustained [Cornford & Smithson, 2005; LeCompte et al., 1993; Lincoln & Guba, 1985]. However, this study, at its best, provides clear, detailed and in-depth description so that the reader and the user have sufficient richness of information to determine if this study piece is transferable to other environments.

3. Concurrent Validity
   Triangulation is a powerful technique to demonstrate concurrent validity [Cohen et al., 2007]. iFLAP is explicitly designed to gather data from multiple methods - interviews and documentation [Pettersson et al., 2008]. In addition, it allows the triangulation of different data sources - project and line study. In this study, the author has a privilege to collect data from suppliers, therefore the supplier is treated as one standpoint of triangulation.

4. Results and Findings

This section presents the data and findings of the case study. First, it presents the results obtained through the interviews, from which a list of improvement issues is drawn. Then, it discusses the results from a workshop which is arranged in order to validate the found improvement issues, prioritize them and find their dependencies.

4.1 Selection

The following sections presents the results from performing the selection step in iFLAP.

4.1.1 Projects Selection

There is only one ongoing project during the time of study. The project goal is to develop the electronic *&* electrical components for vehicles.

4.1.2 Roles Selection

The roles of the respondents in the project are selected based on the degree of involvement with the supplier. Therefore the practitioners who have intensive interactions with the supplier are the first target, whom in this case study is a person taking a role as Component Owner. The next criterion is to select a practitioner who produces specifications that are later sent to the supplier - Function Engineer. Base on the assumption that requirements are dynamically changing, a role that has input or influence on the specifications is also determined, which is the role of Feature Owner. System Tester is also selected as he is responsible for integrating and verifying the supplier's subsystem. The participants who hold an accountability for administrative tasks such as planning, monitoring and securing resources are also included in this study, who are Project Manager and Acquired-system Team Leader.

Participants from line organization are typically Group Manager, Section Manager and Process Manager. The group manager has the area of responsibilities within component development, thus personnel within his group take active role in the project as Component Owner. Section managers are selected based on that their areas of responsibilities cover from creating specifications that are sent to the supplier to receiving and verifying the supplier product. Process manager is responsible for process development within the department. He defines and leads process improvement plan as well as follow up.

In addition to the respondents from the studied OEM, a few of associated suppliers are also participated in this study. The roles of these participants are Project Manager, Engineer and Internal Supplier. The internal upplier is the OEM's own development team for implementing specific software-intensive systems that are kept in-house. Table 4.1 summarizes all of the selected roles, responsibilities and their associated organization.

4.1.2.1 Participants Selection

Similar to the role selection, the number of practitioners for each selected role is also determined by the degree of involvement with the supplier and the relative influence that the role has on the OEM-supplier cooperation. The roles that closely collaborate with the supplierss such as Component Owner and Acquired System Team Leader are then the majority of participants. Seven people are the representatives from such roles. The role of Function Owner is represented by three personnel. One respondent stands for Feature Owner and one for System Tester. The distribution of participants from project organization is demonstrated in Figure 4.1. In addition, three respondents are suppliers for this project.

As for line organization, two section managers participate and one group manager. The department has only one Process manager. The distribution of participants from line organization is demonstrated in Figure 4.2.

4.2 Assessment

This section provides the findings of the assessment step, discussed in Section 3.4.2. There are 2,638 transcribed records in total of which 561 records are coded. The analysis of the interviews and documentation data is discussed in the following sections.

4.2.1 Interview and documentation analysis

The following is the summary of all the codes resulting from executing the interview coding step discussed earlier in Section 3.4.2.2.1. There are 4 levels of codes in total. Level 1 is a high abstraction code which classifies a particular record into either current practice ("*C*") or challenge faced ("*D*"). Level 2 is an area of interest that a particular record is referring to. Then, Level 3 depends on what a particular record is coded in Level 1. For the "*C*" group, the Level 3 codes are corresponding to the viewpoints from which the interview questions has derived. For the "*D*" group, Level 3 represents an attribute of improvement areas coded in Level 2. Lastly, Level 4 is an interpretation of a particular response. The final version of interview codes are summarized in Appendix C; however, Level 4 is not included as they are varied and just a narrative text.

Presented in this section is the result of analyzing the interview responses. The data is first organized according to the Level 1 codes - current practice or difficulty

Organization	Role	Responsibility
Project	Feature Owner	Define customer needs and translate them into measurable requirements. Also, the feature owner verifies and validates the product with customers. Artifacts from the feature owner have influence on the specifications that are sent to the supplier
	Project Manager	Plan project time and resources, monitor the actual results compared to the estimated plan. The project manager is also responsible for communication between stakeholders and the project team. Also, he monitors the overall supplier performance and status.
	Function Engineer	The function engineer analyzes customer requirements and formalizes what functional requirements in a vehicle that are to be realized in software-intensive systems. He documents functional specifications that are later sent to the supplier.
	Component Owner	Responsible for documented component requirements and follow up the development at the supplier. He forwards issues/tasks between the supplier and internal stakeholders and secures that the supplier has sufficient support and information to continue progress.
	Acquired-system Team Leader	Manage and secure that the activities performed by the supplier fulfill and meet the quality, cost and time targets. His role towards the supplier is a project manager monitoring time plan, resources and cost.
	System Tester	The system tester uses functional specifications to verify the systems procured from the supplier.
Line	Process Manager	Lead and coordinate process improvement activities as well as track the result of the initiatives. The process manager also conducts process reviews and audits to assure the quality of a process.
	Group Manager	Responsible for resources and competence of employees within his group. He allocates and distribute his resources to a project
	Section Manager	Responsible for several groups within a section. He monitor activities and manages resources.
Supplier	Project Manager	Plan, manage and monitor the development of software-intensive system. He is a counterpart of the Acquired-system Team Leader above.
	Engineer	Develop software-system according to specification.
	Internal Supplier (Component Owner)	Responsible for managing and distributing functional requirements within his team. He breaks down functional requirements into software component specification.

Table 4.1: The selected roles and associated responsibilities.

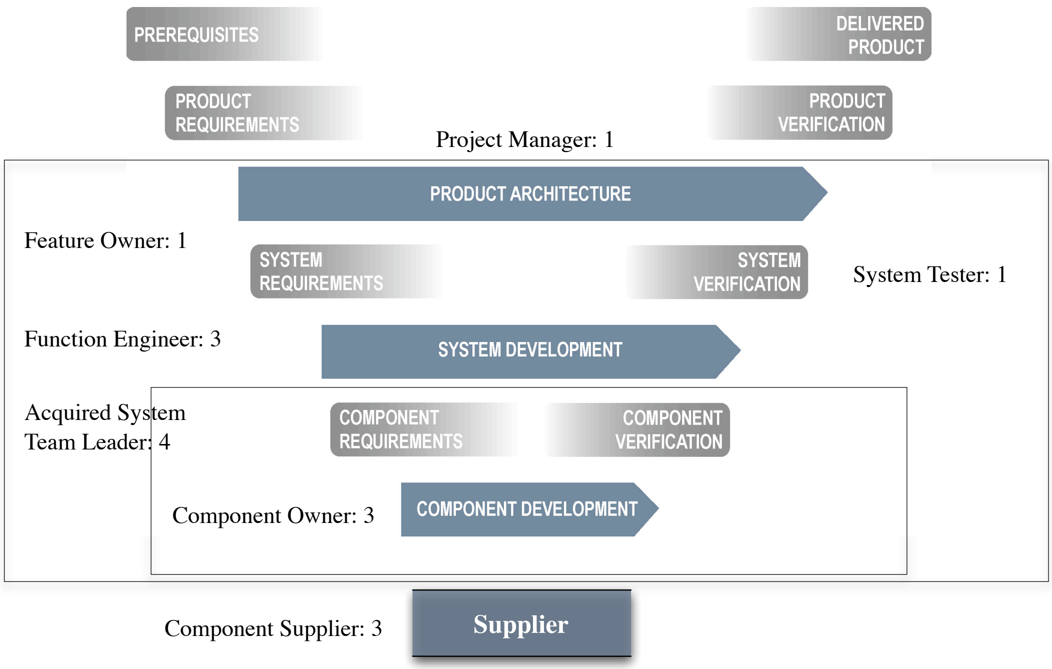

Figure 4.1: Number of participants and associated project roles.

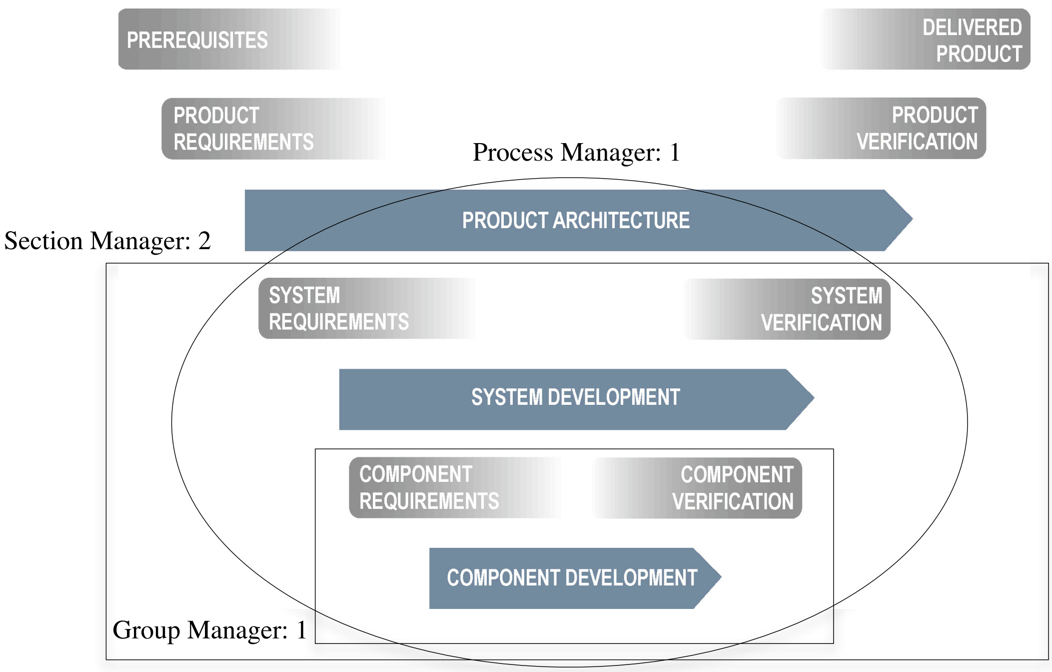

Figure 4.2: Number of participants and associated line position.

encountered. For each of these categories, the data is then structured corresponding to the Level 2 codes which are areas of process referred to. An individual process area is also assigned a unique ID. The ID starts with a P (Practice) for the "*C*" group, and with II (Improvement Issue) for the "*D*" group.

4.2.1.1 Current Process (Level 1 = "*C*")

All data that is coded with a "*C*" in Level 1 is extracted and presented here by structuring according to the Level 2 codes. A unique ID for each of the process areas is parenthesized after the area name.

4.2.1.1.1 Supplier Selection and Contract Agreement (P1)

Which systems to be outsourced to external suppliers are decided at an early stage of the project. A number of suppliers are then contacted to initiate a dialog if they are interested in a joint development effort with OEM A. The suppliers who are interested in the development then propose their concepts to OEM A. These concepts are evaluated internally at OEM A by relevant stakeholders, and one supplier is then selected for each of the defined systems.

> "*... If I start from the beginning, first obviously there is internal work done, what type of part do we need. Then you make a specification of describing these parts ...*" PROCESS

> "*... We informed a lot of our suppliers. We had concept presentation from our suppliers. We had 5-8 different suppliers for each and every acquired system. We reviewed their concepts ...*" PROCESS

> "*... There are different proposals on how to implement requirements. At some point, until it is crystal clear, the number of suppliers should be reduced and we eventually sign contract with one in the final round ...*" PROCESS

This phase of the project is referred to as RFQ (Request for Quotation) phase. The main deliverable during the RFQ phase is a quotation specification. This specification is used as a tool to negotiate with suppliers before they are selected. Based on this specification, the suppliers can ask questions, give feedback or comments, and subsequently provide OEM A with their counter proposal of implementation and cost. The Purchasing department is mainly responsible for negotiating the cost aspect and the quality of software development process at the suppliers, while the studied department holds responsibilities in reviewing technical solutions proposed by the supplier.

> "*... During RFQ activities, we create what we call a quotation specification which is a very brief functional description and also preliminary locations of the functions. Then from this document we formulate RFQ packages and send to different suppliers ...*" ARTIFACT

> "... *couple of reviews where the supplier has a possibility to ask questions and also interpretation of RFQ document. They have a chance to talk to different persons here to see what they are thinking is the same as what we have in mind here, to get first hand knowledge. Then they summarize all these into a quotation and say that this is their counter proposal to what we deliver, are we in the business? ...*" PROCESS

> "... *there are of course commercial aspect as well but that is handled by the Purchasing department. For the Engineering department, we are analyzing if they are offering what we have in mind at the first place. This is a big job, there are a lot of materials to go through. Then we compare between all the suppliers that are involving in this phase to see which one is the best ...*" ROLE

> "... *We have lots and lots of criteria especially from the purchasing side. We have global sourcing committee who works with selecting suppliers mainly on the commercial side. We have also supplier quality assurance who looks into quality and how the supplier works and so on ...*" ROLE

4.2.1.1.2 Functions Development (P2)

The development of vehicle features and functionality follows the traditional waterfall process from market needs down to component specification. This is corresponding to the left side of the V-model shown in Figure 2.3. The stakeholders needs are broken down to functional requirements and then subsequent component requirements.

> "... *Customer requirements can be very different kinds but what we are dealing with are mostly functional requirements. These requirements are project prerequisites and target features. These prerequisites are broken down to vehicle functions which are basically the interaction between a driver with a vehicle from pushing a button until something happens, triggers for software and signals ...*" PROCESS

A complete functional requirement is realized by the collaboration of a chain of logical components. These logical components are then allocated onto different ECUs. Therefore, an ECU realizes a part of different functional requirements. The tool used is a customized database used for developing vehicle functions. The tool handles the allocation of logical components onto different physical locations. Therefore the function engineers specify their functions without having to be aware of the actual allocation. However, it is the physical location or an ECU that is outsourced to the supplier.

> "... *Well, it's a network and there're several ECU in the network. And what we do is that we write requirements for 1 function and 1 function could be, for instance, it could be the horn, like the horn of the vehicle. And parts of that function go in different ECUs, so, some requirements go into this ECU and some other requirements go into the other ECU ...*" PROCESS

"*... These vehicle functions are then allocated on logical design components, which in turns, are allocated on allocation target or ECU. One ECU contains logical parts for several vehicle functions ...*" PROCESS

"*... It's big a database which has user interface that holds meta-model for how we model stuff to see how requirements are related to each other, how we create components, how we create signals and the relation between components. It's the same concept as UML but we create our own language for this meta-model and the language is evolved with the development of the project ...*" TOOL

"*... Then we generate, from the tool, a specification for a specific ECU. This specification goes to a supplier, that this is a specification of one ECU ...*" ARTIFACT

The specification of the functions altogether is evolved in an incremental way. That is, for the first version, the specification only contains enough functionality to make a vehicle run. Then the functionality is continuously increased. Each increment comprises of its own V-cycle. At each version, the specification is sent to the supplier for implementation.

"*... When I talked about the next specification, that is based on an incremental growth of the project. For example, for one specific component we deliver the first half of functionality in the first specification and the remaining in the second half of the next specification. But they need to start, they cannot wait until the functionality is complete ...*" PROCESS

"*... We have different versions, i.e. 1, 2, 3, 4. Version 1 has only basic functions for the vehicle. And then we will add some new functions to each version. Each version has its own V-cycle: specification, implementation and verification ...*" PROCESS

The functionality of vehicle functions is specified by function engineers. The function engineers are organized according to vehicle functions which are independent of ECUs. Therefore, there are several function engineers contributing to one ECU specification.

"*... the teams are organized into functions. That means that it's not only my team that's try to write specification that will end up in each ECU ...*" ROLE

"*... that's done by the function owners. There are several functions in this box which I am responsible for. So, there are several people who contribute to this document. It is built up from all kind of components ...*" ROLE

Review activities are performed within the function engineer team to review the network of logical components. This activity is performed before an ECU specification is generated. The ECU specification is owned by a component owner who performs the last review activity before the specification is delivered to the supplier.

> "*... we do sort of a review on the system level within the logical design, we have an item called collaboration, which we take all the components that are located on different ECUs and we make this whole chain on these components in a vehicle. For instance, the exterior light, from the stroke steering wheels and the components on different ECUs out to the actual lamp. So, we make a review of that chain ...*" PROCESS

> "*... we have a task on a component owner that they shall review. They shall look at the ECU specification and see that the correct components are allocated. So, they see if it looks correct at that level. But they don't know the functionality so they can't review the functionality. And we don't go in afterwards looking at the document to review the functionality. That we do in the tool or when we do the specification ...*" ROLE

The tool can generate several kinds of specifications. The first one is at a very high level which is a functional specification of the system. The second is a functional design of logical components realizing one system functional requirement. It also generates an ECU specification which is a physical location of several logical components.

> "*... It's varied a little bit depending on the team but the system specification. Then, a set of components realizing one system function are included in functional design document. Then, an ECU specification. These are the main artifacts and generated from the tool ...*" ARTIFACT

4.2.1.1.3 Delivery of ECU specifications to the supplier (P3)

Once the ECU specification is released, a component owner has a period to review, compile this specification together with other requirements such as non-functional specification and system specification and then put up these specifications on a file sharing system that his corresponding supplier has access to.

> "*... Before we deliver the specification to the supplier, he reviews it and gives direct feedbacks to the function engineer ...*" PROCESS

> "*... It's not only just functional specification, but we have system specification, and also maybe the component owner might add his own non functional requirements that he wants his software to structure in a specific way, so there are many aspect of the implementation that you add it as non-functional requirement for example we want this memory to be freed. He compiles all specification and put them on the sharing system ...*" ROLE

This specification not only serves as customer requirements to the supplier but also to serve as a dialogue between the OEM and the supplier to ensure that the supplier has understood the requirements. The supplier has a time-limited period to go through the specification, and provide the OEM with feedback, comments or questions about the component requirements. These questions are sent to component owners, who in turn, direct them to the corresponding function engineers. A commercial tool is used as an official method to communicate and to follow up that the questions are answered.

> "*... The process as we have understood it is that the supplier are given 2 weeks to review it, and during this they should come back to us with questions. And we should try to answer that as quick as possible. Well, more or less after that time, they should have asked all the questions so that they could go back and implement ...*" PROCESS

> "*... This period is used for taking in questions, comments or feedbacks from the suppliers. Then these questions are directed to the function engineer who is responsible for the vehicle functions ...*" PROCESS

> "*... The supplier read it and write questions in the tool. The deadline for all the questions is 2 weeks. The component owner starts as soon as he receives the questions and directs them to the right function engineers. The component owner makes sure that the questions are answered. ...*" ROLE

> "*... Then the component owner will take on the task and try to answer as many as possible. It's me and component owner who are the first interaction to the suppliers. Often that we cannot answer the questions myself so we turn to the function engineer ...*" ROLE

> "*... The way we handle it so far is that we are using the tool for discussing with suppliers. The suppliers review the specification and if they find problems they raise issues in the tool. And then we use the tool internally also to communicate with the function engineer organization to solve the found issues ...*" TOOL

The main artifacts delivered to the supplier are an ECU specification, a hardware specification, system specifications and a set of HMI view flows. The ECU specification is, to the supplier, the functional specification of an ECU. The HMI view flow is used in order to have a better understanding and an overview of the functionality of a particular ECU. The hardware specification defines legal demands, implementation and test methods for the hardware part of a particular ECU.

> "*... This is the functional part we send to the suppliers. ECU specification for functional parts where the suppliers develop software. And there are also hardware specification, for example, how they should test, how they should implement it and legal demands ...*" ARTIFACT

> "... *The way that I understand it is that the suppliers use our drawings to understand the technical requirements to get the overview of the interaction with the driver. We actually send them together with the computer simulation, so they can actually navigate them in the menu. So, they use these two kinds of requirements to understand the other technical things ...*"
> ARTIFACT

4.2.1.1.4 Monitor the progress of implementation (P4)

Monitoring the development status occurs in two phases: during the development activities and at the delivery of component. During development, the acquired system team has weekly communication with their supplier. This weekly meeting can be classified into project management meeting and technical meeting. The project meeting involves an acquired system team leader and a project manager at the supplier as the main participants. They discuss primarily project time plan, resources and if everything is on track. For the technical meeting, the component owner and the counter person at the supplier discuss implementation issues and status in general. There is also the use of an open-item list between a component owner and associated supplier to record an open issue and to track it for closure.

> "... *But during weekly technical meeting with suppliers, we also have day-to-day status with them. So, we are not expecting only for the official delivery to know the status but also we check their status each week ...*"
> PROCESS

> "... *we have different weekly technical meetings with suppliers: software, hardware and project management. I as an acquired system team leader have a meeting with Project Manager from the suppliers. We discuss time plan, manage and secure samples and milestones. For technical meeting by component owners, we discuss software related issues and how to solve them and follow the status ...*" ROLE

> "... *I have my weekly meeting with the supplier where we usually have what we call an open item list. We follow up on all the previous ones and they put up new ones if needed. So, this is the formal way I follow up. Of course if something happens, I need to call them or send an email ...*"
> ARTIFACTS

The detailed follow up of the status is performed at the delivery of component. The supplier fills in a requirements trace matrix which are sent to the supplier together with the specification. Prior to the delivery, the supplier sends back this matrix that indicates which requirements have been implemented, if the requirements have been tested and what the test results are. Then, the component owner reviews this matrix and other documents to judge the status of the delivery.

> "... *We have requirements trace matrix which suppliers are supposed to send us 2 weeks before the delivery to say which requirements that have been implemented and also which ones have been verified ...*" ARTIFACT

> "... *We send out the requirement trace file which is an excel format showing all the logical components that should be implemented. Then 2 weeks prior to the delivery the supplier should send this requirement trace file to us and in that file should state which components have been implemented and which ones have not ...*" PROCESS

4.2.1.1.5 Change Management (P5)

Changes to the specification happen throughout implementation period. Generally, there are two types of modification: hardware modification and software modification. These two families of modification are handled differently in the project.

Hardware modification is managed by a formal change request process. A modification can be initiated by either the OEM or by the supplier. A summary of the change control process is that the project sends a product change request (PCR) to the supplier, in case the modification is initiated by the OEM, and then the supplier will respond to the request by providing the OEM time and cost needed to implement the change. The time and cost impact will be evaluated by different decision boards at the OEM. Once the decision is made, the OEM will update the hardware specification and send out an implementation order to the supplier. The supplier can also initiate the modification, and this is done in a similar approach. However, the supplier must provide the OEM with necessary information such as the reason of modification, cost impact both subtraction and addition, and if the modification affects software functions.

> "... *This is done through Purchasing and and they ask suppliers if they can implement this change and how much this will cost and then we have internal change request board to review the change ...*" ROLE

> "... *We use change request template. After we have decided internally here based on cost estimation to decide which solution is the best for our project, we send the change request to the supplier. They will send back the quotation related to this hardware modification. When we approve the quotation, we modify the hardware specification and send to the suppliers. Then, we get an official acceptation ...*" PROCESS

> "... *It's always the change request. They can also send a change request on their own initiative. Then, if I see it's software impacted, I'll ask them for more information. Then they will send the information package to the software team, if this is okay or we need to discuss it further. When I get an OK from the software team, I say okay to my supplier ...*" PROCESS

On the contrary to hardware modification, software functions can be modified directly to the specification without any formal change request. The function engineer can include, remove or edit the functionality of software without having to inform the supplier in advance. The official modifications will be visible to the supplier in the next generation of the specification.

> "*... In the software specification, we just write it in the specification for each increment. If we change something in the functions we just add it directly to the specification. We don't have to create any change request ...*" PROCESS

> "*... The modification is already included in the specification. We are talking about the new generation of the specification compared to the previous one. This is not the same way as modification to hardware. For software modification, the function engineer changes the specification, and we analyze this modification with the supplier during review ...*" PROCESS

> "*... We have the tool where we send change request and bug report directly to our supplier and we also keep track of the status of these changes ...*" PROCESS

Changes in software functions are driven by feedback from the supplier during the review period described in Section 4.2.1.1.3. During this review period, the questions and answers might cause relevant changes to the software functions. However, there is no generation of a new software specification according to the changes between versions. Therefore, the questions and answers are logged in a tool which is a change management system that serves as main communication channel between the project and the associated suppliers regarding software modification before it is included in the software specification. This means any changes regarding the current software specification will be logged in the change management system. In the next version of software specification, the function engineer will compile all these logs and include in the software specification.

> "*... but they will also see much earlier in the tool. That is also an input to the specification. So, the change is already in the requirement database and also communicated through the tool. So, the specification may come after but the supplier gets the answer immediately after we have taken decision ...*" ARTIFACT

> "*... we send out the specification and then the supplier is supposed to come back with their feedbacks. Then we answers their questions in the tool that now the specification has been changed to this. Maybe they cannot see it in the current specification. So, they have to know that they should use the tool when they start their work ...*" PROCESS

"... *we have the frozen one that we have delivered and then we have a list that are questions from the suppliers that should be included in this delivery. So, this delivery is the frozen specification plus this list ...*" ARTIFACTS

4.2.1.1.6 Delivery of ECU components and Test *&* Verification (P6)

The supplier is responsible to perform testing activities on their own component before delivering it to the project. An official delivery of a component includes source codes, software release notes, requirements trace matrix and a test report. The supplier delivers all artifacts through a file sharing system. The component owner ensures that the supplier has uploaded everything. The component owner then performs a bench test or a smoke test by integrating a software component with a hardware unit. This is just a basic testing activity to see if the software part is compatible with the hardware part. The purpose is to ensure that there will not be a failure that comes from the software-hardware communication problems when functional verification activities start.

"... *For sourced software, the supplier is responsible from parts of software components until an ECU. Then we take on with the level where we take an ECU together with its sensors and actuators and we verify that ...*" ROLE

"... *So, from the supplier delivery, we have software which is the code that we'll put in our electronic unit. We have trace matrix which explains what exactly have been implemented and what outcomes of the test are and we also have release note which is supplier's official statement of what is included, what performance is and also outcome of the test and so on. In each delivery, all documents from the suppliers are uploaded in the file sharing system by the suppliers ...*" ARTIFACTS

"... *What component owners do is that to make sure that everything is delivered but he does not review everything because he is just the receiver of the hardware or software. And there they are just doing the integration work for the first time, take all the components and connect to the ECU and see, OK the lamp is working and so on ...*" ROLE

"... *First within the acquired system team, testing is done to make sure that software from supplier A works together with hardware from supplier B ...*" PROCESS

"... *It's just a test to see if the ECU is burning. As a first step, we just test to see that it's alive and it talks without disturbing the other ECU in the network. It doesn't exceed the limit of power consumption, things like that. It downloads the software with our tool and so on ...*" PROCESS

"... we do first acceptance test when we see that this delivery is OK to go on to the big test. This is important because we cannot waste time in our system testing. We cannot put the ECU that we know it doesn't work in the system testing environment ..." PROCESS

The next level is functional verification where system testers connect more than one ECUs and grow them to a complete system. The main purpose of the verification activities at this level is to assure that vehicle functions are fulfilled. Also, this is an important step to be able to evaluate the overall project status. If there is a mismatch between the test outcome and the supplier test result, the system tester will create a defect report and route it to the component owner who carries out the communication with the supplier. Again, the commercial tool is used as an official communication tool. At this level, the verification activities are performed in a simulation environment. Last verification activities are performed in a real vehicle, which is beyond the responsibility of the studied project.

"... When we get the delivery from suppliers, we have a testing on different levels but it's a test of more than one components. Then we grow the integration of components to a complete vehicle and then we put in a real vehicle ..." PROCESS

"... Start by the suppliers perform at the ECU level. Then ECU system level which is performed internally here where we put ECU with other components. Then we grow from subsystems to system verification level where we put all the components together ..." ROLE

"... We use specification to say that the behavior is not exact as specified in the specification and then we create defect report in the tool. We open a defect report and say there is deviation from the specification. Then the project, not system tester, will follow that the defect report we have opened have been understood and there are people trying to solve this issue, which is actually directed to the component owner ..." TOOL

"... we of course have the complete vehicle test taking place after that. But that is more like the delivery from our department to the complete vehicle which takes over the testing at some point. And they test with the more potential customer in that phase ..." PROCESS

4.2.1.1.7 Project Planning and Estimation (P7)

There is no data record that is coded as "*C*" in this category, but it is listed here to be an improvement issue counterpart discussed later.

4.2.1.1.8 Supplier Involvement and Management (P8)

The supplier is involved at different stages of development. For a high experienced supplier, they might be involved since a concepts generation phase to help the project defines customer requirements. This supplier could be involved from this concept study phase until providing components. Or, they could leave when the concepts generation end and another supplier takes over the development of components. This depends on a strategic decision within the organization.

> "*... it depends on which suppliers you are talking about. Some of the suppliers you might want to involve them already in the concept phase to help you define the concept because they might be the one who has domain knowledge in certain area that we don't have. Then you have to involve them at the beginning. We might even have supplier who specifies the concept up to a certain point then they leave and then we have another supplier who provides the component. Or, it maybe that we have this supplier from the concept and we have them all the way to provide components. That is from case to case. That's why we have different way to manage the suppliers because it depends on what kind of suppliers they are ...*"

However, it is the involvement of supplier during component development that is the prime focus of this thesis. The goal of involving the supplier during product development is to be able to utilize supplier's expertise to contribute to product solutions. This is achieved by incorporating the feedback from the supplier into the functions development process. That is, the feedback serves as one source of input to the development of vehicle functions. The supplier involves by giving comments, questions and criticism on the software specification.

> "*... The basics for sourcing activities are to combine different expert knowledge from different areas. I don't want to mix that expert area. I want to keep the responsibilities at the suppliers ...*"

> "*... They give feedback to us like, you need this signal in order to realize this function. They review and send the comments back to us ...*"

> "*... sometimes, we have heavy feedback from the supplier with longer experience, for example, they say, I'm not sure you've made the right thinking here. Maybe they see some architectural problem with what we propose. And in that case we can set up a workshop to work together and to find optimal solution with the supplier ...*"

The supplier that is relatively close to the OEM's development sites are more likely to be approached for the joint development effort. This also includes past experience and delivery precision aspects. If the supplier is a domain expert, the cooperation during the development seems to be a success as the project can leverage supplier's skill for product innovation.

> *". . . we should have interaction, communication with suppliers early in the nomination stage. This is based on prices, geographically availability and previous experience when it comes to delivery precision and quality. Then the supplier is nominated and the actual implementation begins . . . "*

> *". . . If the suppliers are geographically close then it is easy to involve them early and actually have weekly meetings with them. It is not possible to do this kind of communication when the suppliers are far away. . . . "*

> *". . . what we have done and that has been really good is we have involved the suppliers early in the requirement process and to get feedback from them, that we actually develop the requirements with the supplier. This has been working pretty good but it depends on who the suppliers are. We have suppliers that are expert so they know requirements better than we do. So, supplier competence is the key . . . "*

To monitor the supplier, the Purchasing department has a Supplier Quality Assurance (SQA) organization who assesses the supplier's software development process and project. Then, the development project is responsible for the delivery and integration of software components provided by the supplier.

> *". . . And we have the SQA, supplier quality assurance which is assigned to each component in a project. They are supposed to look into the supplier's process and follow up on the supplier quality of the delivery. It's a joint venture between product development and the SQA. The SQA is on a general quality level saying like, you have an OK process from our point of view to deliver software to us. Then product development should follow the quality of a specific delivery as such . . . "*

4.2.1.1.9 Locations Distribution

Working globally with the supplier is perceived as a positive thing because this brings different viewpoints and a variety of knowledge to the table. To overcome communication issue, the OEM has organized a special team that handles all communication from internal stakeholders to the supplier. Moreover, the supplier has discussed that they have also set up their counterparts to the OEM team. Some suppliers also provide the OEM with a field engineer on-site at the development project at the OEM. Some suppliers have their contact persons and project leads locally in the same country, while their development workforces are located at the other continents.

> *". . . I think it is very very good actually. If we only would have worked with local companies, it's very easy to be a square. But when you are working with suppliers from different countries, they are more open minded and perhaps they are thinking in different ways . . . "*

4.2.1.2 Improvement issues (Level 1 = "*D*")

This section presents the data records that are coded with "*D*" in Level 1. Similar to the current process presented in Section 4.2.1.1, the data here is structured according to the Level 2 codes. Whilst the previous section describes different process areas, this section provides insight into challenges the practitioners encounter in each of the processes.

4.2.1.2.1 Supplier Selection and Contract Agreement (II1)

During the supplier selection activities, there are factors that affect the cooperation with the suppliers later on. These factors are contract conditions, the time when the contract is signed and the basis of the contract awarded.

- Contract condition (CONTER)
  The nature of contract does not support the way the project works with incremental functions development. This mainly concerns changes that occur during the functions development work. Responsibility matrix is not clear - what is covered by the agreement, what is not and who should pay for the changes.

  > "*... it's like if you have 10 functions in the beginning then you add more function and to make it optimal you might want to go back and change those functions that you have delivered, but there is no such loop. And I think that is a problem ...*"

  > "*... each change costs money, and it's a lot of administrative tasks. We have to go through change request every time we need to change something small. I think that is because how the contract has been set up with the suppliers. I think the way we set up the contract was wrong ...*"

- Readiness when a contract is established (CONTIM)
  The contract should be established when the OEM has a good picture of their own product requirements. It has been shown that the contract is established with the supplier before the project knows the real requirements and knows the scope of the project. The supplier only involves in a short time when the contract is awarded. The respondents have discussed that it is because of the immaturity of the requirements at the beginning of the project that leads to a lot of commercial discussions with suppliers.

  > "*... I think it's due to that very early in the project we said this is the product price and this is the set of requirements which is very high level and at that early stage we don't know our requirements ...*"

> "... *I think this is the area that should be improved. It should be formalized. You need to have a very strict requirement review with the supplier. First of all when you establish the contract, you should work very hard to understand the requirements during review. I think it's too informal and very variety ways of doing depending on who the suppliers are and also who the people from us are ...*"

> "... *If this was clear from the beginning, then we wouldn't have this kind of cost related discussion. So, not good enough preparation. Working together with the supplier longer before you sign the contract. You need the supplier in the process for questions for implementation related, but it doesn't necessary mean that you need to sign the contract...*"

- Base of supplier selection (SELBAS)
  The basis of the contract awarded refers to how a particular supplier is selected. The suppliers should be selected based on their domain knowledge and experience rather than focusing on price. This is for the OEM to be able to leverage supplier's skills for solution innovation.

> "... *we are not sure if they are competent. That is what was communicated to us before we selected the supplier. But it feels like it has been more about the commercial aspect when we did the actual selection. ...*"

> "... *Our expectation and also what was communicated to us at the beginning was that we will select the suppliers that are experienced, they have done this before, they can contribute to our solution so that we can take advantage of their experiences. That has not worked in most cases, I would say ...*"

4.2.1.2.2 Functions Development (II2)

During the development of vehicle functions, there are many activities that could influence the quality of the specifications that are later sent to the supplier. It is however not just the quality of the specification that is affected, but also the cooperation with the supplier as a consequence. This is because flaws happened during the functions development process usually lead to difficult commercial discussions.

- Requirements handover from business level (BUSREQ)
  The stakeholders needs transfered to the project are at a very high level of abstraction and difficult to pinpoint what exactly the stakeholders want. The requirements are from many sources, but they are not from end customers or drivers. The format of an input also contributes to the difficulties in developing vehicle functions. That is, the majority of the personnel are used to the traditional way

of developing a component that handles several functions. Therefore the input that the function engineers receive is not in the preferable format as the function engineers think in forms of functions and not physical component.

> "*... one part that could be improved is the communication with stakeholders. And also the focus of the project that we are more in line with the stakeholders before we start writing the specification. We should improve the handing over of requirements from stakeholders ...*"

> "*... we would really need to know more on the end customer expectation. We don't have that down to us as a function owner. We don't experience driver. That would be good. We don't really have good input from the product planning organization, what the expectations are from the end customer ...*"

> "*... the majority of the company, they are still thinking components. But we, as a function engineer, write system functions. So, the input we do get comes in a difficult format since they don't have the same mindset ...*"

> "*... when we get input from product planning, they say this and this and this component should be in a vehicle. They think sensors. They don't really think on why we need this sensor. We think on the customer use. The customer wants to have good climate in the vehicle, therefore we need this sensor. We don't have the sensor just to have it. We have a reason to have it. It would be good if we get an input in a more of that way ...*"

- Coordination with other teams (TEASYN)
  A number of teams involve in developing a vehicle function, for example, a HMI design team or a team at another department such as the Cab and Chassis development department. Insufficient communication between the HMI team and the function development team leads to an inconsistency in the specifications. Uncoordinated time plans between the studied department and the others cause late changes that eventually affect the supplier.

> "*... I have one function in the GUI but I don't find the specification of that function in software specification. I see that I could perform this function in the GUI. I know how it should look. But there is no logic for that function in the software specification. So, I have no idea how to implement the software ...*"

> "*... we work towards the Power train and the Chassis department. they have in many cases not the same time plan. They work on their projects with the time plan that is not coordinated with the EE time*

plan. That makes some difficulty because we are in different stages of thinking on the same function. We are trying to do our work in order to be finished according to our deadline. But they haven't started thinking about it, so they don't have resource to do the input for us. And when they come to that level, they will come with the new input to us. So, we are not in synch between different departments within the company. That is a problem that affects the supplier because that is one reason why we do have updates on things that we've said we are done with it ..."

- Requirements engineering activities (REQPRO)
  The requirements engineering process is not performed at a complete level. Several steps such as review activities are skipped due to time and resource limitations. Also, not all relevant roles are participating in the requirements engineering process especially system tester. Moreover, there is no predefined instruction of specifying a function that is common to all function engineers.

  > "*... The system engineering process is really immature. It should have a lot more reviews, and they should call persons who have the knowledge of requirements to review if there are any missing requirements, perhaps people from After Market or Production. So, working proactively should be prioritized number 1 and a lot of reviews in an early stage. Not just sending out ...*"

  > "*... Many persons are involved in creating the document. 25 persons create components that go into 1 ECU. So, this means there're 25 persons writing requirements in this document that goes to one supplier. The way of 25 people writing are not the same. The way that I write is maybe not the same as the 24 other people. That means there are differences in the style of writing requirements for one ECU. It could be a HMI for starting the vehicle. We have 1 ECU that handles all HMI functions. Everybody's creating HMI for how to do something and then you have all function engineers from different functions create all the HMIs in the vehicle. Perhaps everybody is adding a function like how to handle a signal from a button. It should be one person adds one way of how to handle a button in one ECU but instead it is 25 people writing how to handle the signals of one button in the same ECU. The high focus on working with system functions makes 25 people adding 25 different disciplines in the requirements setting for doing one function, not 25 different functions. As a function engineer, we're responsible for the whole chain. And like we've said before that no review activities have been carried out. Project planning is very poor from the start, no one is aware of what problems they could have. This results in pretty poor ECU specification ...*"

> *"... if you have a water fall you will have so much test activities at the end, and that was so wrong. Test and verification should be already up here. Test and validation should be part of the specification ..."*

> *"... what we are missing today is: 1. Review within system engineering if the specification is consistent. 2. Review with the verification team if the specification is good enough to be tested, if it has enough information to verify ..."*

- Quality of specification (SPEQUA)
  Software specifications produced are found to be irregular in terms of quality, especially the content and abstraction level of the requirements. The specifications are found to have missing information and inconsistencies of requirements. The requirements are ambiguous, which can lead to commercial discussions with the supplier. Moreover, focus is not placed at the right place, that is the function engineers has put a lot of efforts on specifying logics inside a component but not so much on interfaces between components.

  > *"... it is hard to find the best detailed level to be in the specification. I am not 100% confident with the detailed level that we have. The basics for sourcing activities are to bind different expert knowledge from different areas. I'm a little bit afraid that the specification that we have now drives the suppliers too far in a certain design direction ..."*

  > *"... there are errors in the specification itself. There are some missing data, empty table and some undefined signals. Also, the layout of the specification is hard to get a good overview. We have also a lot of discussions with the supplier about the content of the specification that it is not 100% clear ..."*

  > *"... the suppliers find it hard to interpret and it is not in the detailed level that it should be. Some of the areas have been left out of the scope ..."*

  > *"... The reason is that we focus it at the wrong place. We should focus on the interface between components. Now we don't focus that much on specifying the interfaces for example response time. We focus on the inside how the component should look like. But we have components from different suppliers, so the integration won't work if we don't have good synchronization between components. Now we leave the interface part very unclear and it's up to the suppliers to decide ..."*

- Incremental way of specifying functions (INCFUN)
  The adding of new functionality is not fully incremental. That is, new concepts

cause modifications to existing software parts. This can lead to delay in the project as well as commercial discussions as the supplier has to do much more job than anticipated.

> "... *normally, between the two versions of the specification, only the new functions should be implemented. But instead of only implementing the new functionality according to the incremental function plan, the supplier has to correct the modification which results in they don't have time to implement the new functionality. And this creates delay in the project* ..."

> "... *we have to re-implement, redo the software which we have already developed. And that increases effort. It would be improved and less effort if the specification has been set up in a way that it is incremental* ..."

4.2.1.2.3 Communication and Information Sharing (II3)

When it comes to communication, there are a few problems that the practitioners have mentioned. This could be communicating of requirements from the project to the associated supplier, or it could be communicating between development sites. The practitioners find it challenging to ensure that the supplier has understood and interpreted their requirements correctly. This includes explaining the overview and structure of specification documents as there are many documents altogether that refer to one another. Another aspect of this issue is the information flow between teams and between development sites of the company. The contact persons for the supplier should have all relevant and needed information in order to effectively communicate with the supplier. Also, the awareness of practitioners between two development sites should be maintained at the same level of information.

- Clarification of requirements (REQHAN)
  This is an engineer-level communication to secure that the supplier has understood and interpreted the requirements correctly, and their interpretation is aligned with what the project wants to have. This includes describing the structure of the different documents specifying requirements on one component. As there are many references from one specification to another, it is difficult to get a good picture of the overall requirements.

> "... *this is one of the main difficulties. We have to make sure that our specification and supplier's internal specification are consistent and ensure that the suppliers have understood our requirements correctly* ..."

> "... *in this document there are a lot of links to other documents and so on. They are heavily linked. It is difficult to get the overview of the overall requirements and specification for a certain component* ..."

- Internal information flow (INFFLO)
  The practitioners have experienced different information levels between development sites. It is sometimes difficult for the practitioners at the remote site to be at the same level of awareness as those who reside in the main site, due to a lack of informal meetings. This affects the supplier who talks to the both sites.

  > "*... internally within the organization is a little difficult for me to be on the same information level as other acquired system team leaders who are located in main development site. It takes a little bit more time for me to be on the same level as the others. But it is not a problem. We just get all the information we need during our weekly meetings internally. But this is the official meetings. But I don't benefit from the corridor meetings as I'm not there ...*"

  > "*... sometimes we feel that the information level is not fully synchronized between Site A and Site B. We even feel that the supplier is the message sender, and that we shouldn't be ...*"

  Another aspect concerns the flow of information from other teams to the acquired system team who is the linking hub between the project and the supplier. The component owner does not have necessary information in hands to inform the supplier, especially when it comes to development-related information such as amount of changes and function-related information to answer the questions from the supplier.

  > "*... It is difficult and tricky especially for my software component owner. He is the one who receives the specification and send to the suppliers and also the one who gets questions back. And for him, it is difficult to know what has been changed and why they are changed. He doesn't have a full picture of the function ...*"

  > "*... I think it is a weakness of the organization that the function engineers are making changes but we are not aware of these changes and we cannot inform our suppliers to wait or to change it ...*"

  > "*... the modification is not discussed before the modification is done to the software specification. We don't have the review with the function engineers before the modifications and we have to manage the changes in the specification without official information from the function engineers before the changes are made...*"

4.2.1.2.4 Development Progress (II4)

During the development, it is important for the project to follow the status at the supplier. Although the process has been set up well, there are still rooms for improvement.

First of all, the project has all necessary information as well as documentation in order to evaluate the progress of the supplier. However, it is a lack of time that hinders an accuracy of status judging.

> "... *The process is very good and clear. The real issue is that we don't have time to read all the documents and make sure that everything is fully understood. It's not about modifying the process itself but it's about we need more time* ..."

It is also important to define what the OEM needs to know from the supplier and how the OEM wants the supplier to describe it to know the status of development. The issue that the practitioners have now is that there is a lack of a formal and standard way of describing what the supplier has done. Moreover, there is no tool to support this activity of following up the progress.

> "... *it is the communication that we should have a common way of communicating to our suppliers for all ECU suppliers. We should be clear how to deliver and what exactly to deliver because it is right now a little bit up to me. Apart from requirement traceability matrix and some document they deliver, it's up to me how they should describe how they have implemented the requirements* ..."

> "... *we don't have any tool for monitoring supplier progress or performance. We have been relying on interactions that we talk to each other about problems. The weekly reports, they are good but it is up to us to state exactly what we want to know. I think we could improve here by having a template or tool support for follow up on the implementation progress at suppliers* ..."

> "... *We don't have any tool or template to help us do this. We have just weekly report from suppliers saying what they are doing and what issues they have. And we have weekly meeting to follow up issues and so on* ..."

4.2.1.2.5 Change Management (II5)

Modifications to software requirements are unavoidable but they should be well managed. There are several problems regarding the change management process that incorporate or impact the supplier.

- Change control process (CHAPRO)
  This concerns the change control process for deviations made to the component requirements. The evaluation of change impact and decision process takes too long time until the final decision has reached.

> "... *cost related change is not so effective. Today is done by a change request and sent to Purchasing and then to the change request board. This is many steps and takes a lot of weeks before we get the decision of how we should do. That's not so effective* ..."

> "... *I think there can be more efficient way to do this. There are a lot boards that need to go through before we can come to decision. And a lot of these boards, they are pretty much the same people* ..."

- Specification != Actual implementation (SPEUPD)
  There is a mismatch between the specification and the supplier product. That is the specification is not kept up-to-date corresponding to the actual implementation because the specification cannot be released between software deliveries. This causes difficulty for the test *&* verification team in order to find the right specification of the component. And this difficulty will eventually affect the supplier because it causes a delay in the testing activities.

> "... *we have a lot of problems. Today, when receiving the components, there is no way for test & verification team to know what specification the components belongs to. There are some deviations from the functional specification. And this is a huge issue. We don't have the specification for this function in this delivery, so we have to guess. And it's even more annoying when we don't know exactly how the components are connected to each other. We guess based on official specification and the deviation* ..."

> "... *the problem could be even worse if we got the question really late. If we have version 3.1, 3.2 and 4.0. And we have released 3.1, then the question comes very late and it's not possible to include in version 3.2. Then this answer will be visible in version 4.0. So they will already implement it in the version 3.1 software delivery, which will not be visible in the specification until version 4.0* ..."

> "... *it's not good, because the specification should reflect the software we have in our vehicles. Because if we find a problem, we then can easily go back and see how this is implemented or what is the idea behind this software so that it actually works, so that we can map these two together if we have a delta. The specification must be updated to what we want to have in the software. If we don't have this, the verification team will have difficulty to find the root cause of the problem* ..."

4.2.1.2.6 Product Acceptance (II6)

This issue concerns the acceptance test process at the OEM when the supplier delivers their product. The problem is that there is no formal acceptance test process, thus no formal feedback of each delivery is provided to the supplier. Moreover, qualification criteria are not always fulfilled.

> "*... we regulate how many test cases must be passed or how many test cases they have to perform before they deliver to us. And this is something that is an issue today. Because the suppliers are very late and don't have time to perform the test so they don't fulfill our qualification criteria that we have. ...*"

> "*... we don't get an active response from X that our delivery is accepted. Sometimes we ask directly because our process requires customer approval ...*"

> "*... we should give feedbacks to our suppliers on what we are doing when it comes to testing and also the time plan on this saying that when they can expect the feedback on each delivery. We should be more transparent with this ...*"

4.2.1.2.7 Project Planning and Estimation (II7)

This improvement issue concerns the planning of the project as well as the estimation of time, resource and cost in general. There is a lack of a method for estimation of work. Therefore there is an issue when presenting the estimates to a steering committee. This results in a very tight time schedule and pressure is then put on the supplier.

> "*... the main reason why we are in a pretty bad shape right now is that the time is so compress. The supplier has short time for implementation. And we don't have enough time to verify what we've received from the supplier ...*"

> "*... nobody in upper management or steering committee wants to hear realistic plans. We always get challenged and have to shorten the plan, but later it will blow up ...*"

> "*... we also should get better in estimation in order to defend ourself towards steering committee ...*"

4.2.1.2.8 Supplier Involvement and Management (II8)

The concept of supplier involvement in software development put challenges on managerial tasks and interpersonal skills. Following is the difficulties the practitioners have expressed.

- Contribution of supplier expertise (EXPCON)
  The supplier is expected to contribute their knowledge to analyze requirements, give feedback and, if possible, find better solutions for implementation. There is

an issue when the supplier doesn't contribute their expertise, instead they take on a role as an implementor and do only what specified in the specification. This could result in problems are caught too late in the development phase.

> "... *the feedback we have from suppliers are detailed questions like how do you want this to be implemented. But that is not what I would like to have. I want them to say that ok, this is your function requirement, so this is our proposal of how this should be implemented. I would like them to contribute with their expertise. But I have really seen the opposite* ..."

> "... *the supplier should really use the experienced development team. I know for the fact that it's the other way around that the supplier uses inexperienced team. They use implementors who seem to have more or less no knowledge with the vehicle applications. Sometimes we question if they know that they are developing the system for a vehicle, or they don't have any clue where it will end up* ..."

- Transparency between organizations (TRAORG)
  Both organizations should be open to each other. However, it is not always achieved in practice. The OEM finds that some suppliers are not open enough and that they are hiding problems to the last minute. Therefore there is a need of a method to assure the communication of relevant risks and problems that occur during the development phase from one organization to the other.

> "... *we need information in advance when something is not on track. We are informed too late by the suppliers so there is not enough time for us to anticipate the issues and to find the best possible action plan for the project* ..."

> "... *the suppliers don't say or report anything without us asking them to. They are not that open that we would like them to be. We need our suppliers to be more proactive in a way that they see problems much earlier than us because they are working with it. And we want them to communicate this to us so we can do something before it's too late* ..."

- Partnership mindset (PARMIN)
  This concerns the establishing of a partnership concept between the two organizations. This could be to share the same goals, to have responsibility and ownership of the product. There is a need of practices to motivate the building of long-term relationship and commitment.

> "... *we are very cost oriented within the company, so we force our suppliers very hard in every step along the way. But I would like to*

have a little bit more long term relationship with the suppliers. We are a short type when working with the suppliers. We should decide that we're gonna have a long-term good relationship and then we can lose on this one but we will win on the next one. That attitude we don't have towards our suppliers. We want to win all the time. So, we are not building a long term relationship in that way ..."

"*... I don't think it's a success. I think now we have too little partnership. We have too much detailed discussion and arguments on responsibility matrix. We spend too much time chasing who should do what. It should be clear to the suppliers that they work together with us to build the best vehicle in the world ...*"

4.2.1.2.9 Locations Distribution (II9)

This issue concerns the globally distributed locations of parties involved. The main problem is the insufficiency of face-to-face meeting with the practitioners' colleagues and counterparts. This also includes insufficient estimation of time needed to communicate in the global setting environment.

"*... it's really good to have a face to face meeting to know who you are working with. It's easier to work with someone who you know his face. ...*"

"*... we are impacted by the global distribution. This doesn't mean that we are inefficient. It means to me that we should not underestimate the time to communicate but it is underestimated now so this makes us lack of efficiency ...*"

"*... we have to have the right level of communication. Today I would say it's not-well managed in terms of communication. We need to plan to have more time for communication between sites ...*"

4.2.1.2.10 Tool (II10)

The issue concerns the tools used throughout requirements development phase. The tools are not set up properly so that they could support the OEM work process better.

"*... the tool itself is just a database. What should be improved is the way we work with the tool. We don't really have a good idea of how to use the tool. We actually have problems with the meta-model. The tool can do anything but how we manage the tool is not good ...*"

The improvement issues are summarized in Table 4.2. Also, the supporting vote for each improvement issue is presented in Table 4.3. The overview of improvement issues related to the V model is displayed in Figure 4.3.

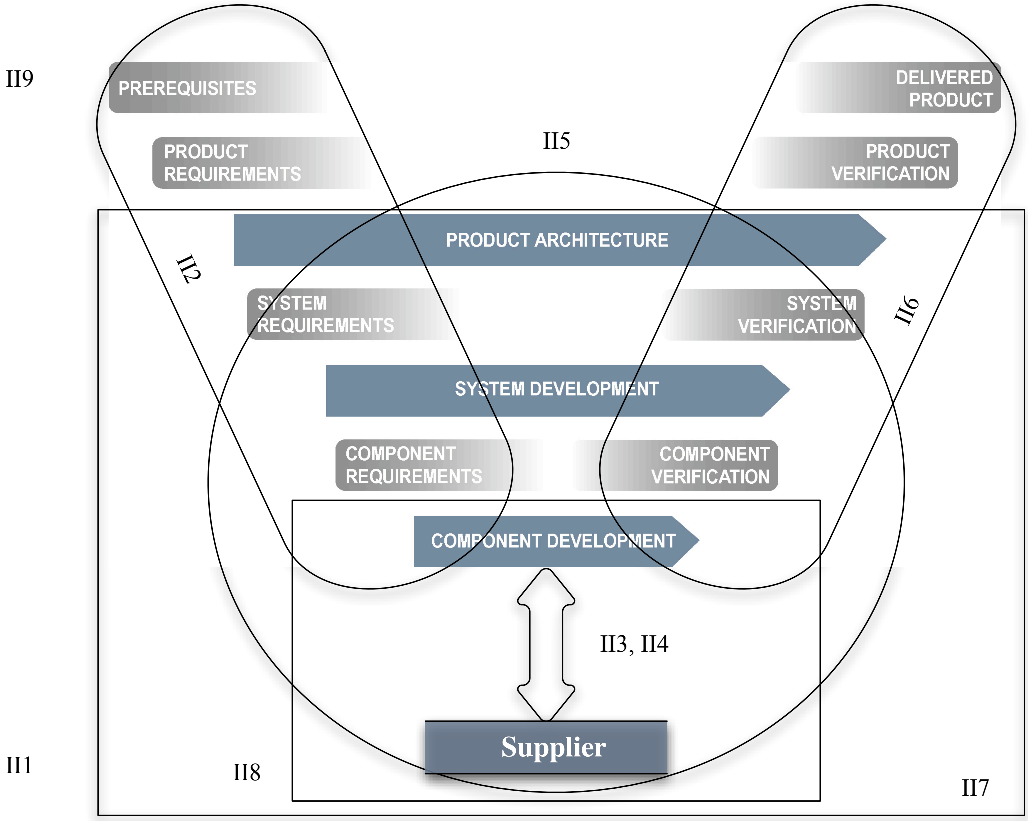

Figure 4.3: Illustration of improvement issues on the V model.

ID	Name	Description
II1.	Supplier Selection and Contract Agreement	This issue concerns the supplier selection activities performed at an early stage at the beginning of the project. This includes reviewing of implementation proposal, selection criteria as well as contract agreement. The problem is that there is a lack of a formal and defined process that the practitioners at the OEM should follow in order to perform the supplier selection and contracting activities.
II2.	Functions Development	This issue concerns the creation of deliverables that are later sent to the supplier. It includes finding out business needs, translate them to system requirements and write functional specification.
II3.	Communication and Information Sharing	The issue concerns ensuring that the OEM and the supplier have a common understanding, and making sure that the information is communicated at the right time to the right people. This can be divided into inter-organization communication and intra-organization communication.
II4.	Development Progress	The issue concerns the method and process to monitor the development status at the suppliers. There is a lack of a defined method to follow up on requirements development.
II5.	Change Management	This improvement issue is about the management of modifications made to requirements throughout the development cycle. This also includes a process for controlling changes.
II6.	Product Acceptance	This issue concerns the acceptance test process at the OEM when the supplier delivers their product. The problem is that there is no formal acceptance test process, thus no formal feedback of each delivery is provided to the supplier. Moreover, qualification criteria are not always fulfilled.
II7.	Project Planning and Estimation	This improvement issue concerns the planning of the project as well as the estimation of time, resource and cost in general. There is a lack of a method for estimation and the project is in a very tight time schedule.
II8.	Supplier Involvement and Management	The issue concerns a method or a process to interact and monitor the supplier in general. This issue is oriented towards the concept of supplier involvement in new product development.
II9.	Locations Distribution	This issue concerns the globally distributed locations of parties involved. The main problem is the insufficiency of face-to-face meeting with the practitioners' colleagues and counterparts. This also includes insufficient estimation of time needed to communicate in the global setting environment.
II10.	Tool	The issue concerns the tools used throughout requirements development phase. The tools are not set up properly so that they could support the OEM work process better.

Table 4.2: Synthesized improvement issues.

ID	Improvement Issue	Supporting Participant				
		Project	Line	Supplier	Total	Percentage
II1.	Supplier Selection and Contract Agreement	6	2	0	8	40.00%
II2.	Functions Development	12	4	3	19	95.00%
II3.	Communication and Information Sharing	7	1	3	14	55.00%
II4.	Development Progress	6	1	1	8	40.00%
II5.	Change Management	11	4	3	18	90.00%
II6.	Product Acceptance	5	2	2	9	45.00%
II7.	Project Planning and Estimation	4	1	2	7	35.00%
II8.	Supplier Involvement and Management	7	1	1	9	45.00%
II9.	Locations Distribution	4	0	1	5	25.00%
II10.	Tool	1	0	0	1	5.00%

Table 4.3: Improvement issues and supporting votes.

4.2.2 Triangulation of improvement issues

As described in Section 3.4.2.3, each improvement issue is triangulated with different data sources in order to draw a conclusion that the issue in question is confirmed as a valid issue. In this thesis, a threshold of three is chosen due to the fact that there are five independent data sources. Table 4.4 presents the result of the triangulation of each improvement issue. Consequently, from II1 to II9 are confirmed as the valid issues because there are three or more sources supporting them. On the other hand, II10 is considered as an invalid issue because there is only one source confirming the issue. Thus, only nine issues are proceeded to the succeeding step which is to prioritize and relate them with dependencies.

ID	Improvement Issue	Interview			Documentation		Triangulated
		Project	Line	Supplier	Project	Line	
II1.	Supplier Selection and Contract Agreement	X	X		X		X
II2.	Functions Development	X	X	X	X		X
II3.	Communication and Information Sharing	X	X	X			X
II4.	Development Progress	X	X	X		X	X
II5.	Change Management	X	X	X	X		X
II6.	Product Acceptance	X	X	X		X	X
II7.	Project Planning and Estimation	X	X	X			X
II8.	Supplier Involvement and Management	X	X	X	X		X
II9.	Locations Distribution	X		X	X	X	X
II10.	Tool	X					

Table 4.4: Triangulation matrix.

4.3 Improvement Planning

Invitation to the workshop are sent out to all respondents of the individual interviews that are co-located at the main development site. The workshop was scheduled for 2 hours. However, due to the project has been undergoing a very high time pressure, only three respondents were able to participate the workshop. In addition to the main workshop, one extra workshop was arranged with one participant. Therefore the prioritization and dependency data is collected from four practitioners, of which two participants are from line organization and the other two are from project organization.

The workshop started with the presentation of the improvement issues discussed in Section 4.2.1.2. As mentioned, only nine out of ten improvement issues are identified as confirmed issues from the triangulation step. The presentation was followed by a discussion among the participants. All of the nine improvement issues were validated, and none of them has been wrongly included. Next, the participants were requested to prioritize the improvement issues, and then to identify their dependencies.

4.3.1 Prioritization of triangulated issues

Table 4.5 shows the raw data (amount of money) that each of the participants has given to an individual improvement issues. The participants from the project are labeled as "*Project 1*" and "*Project 2*" respectively. The participants from the line organization are denoted as "*Line 1*" and "*Line 2*". The summation of money each issue has received is displayed in the last column of Table 4.5.

II8, Supplier Involvement and Management, has been assigned with the highest amount of money which is 112 SEK. This number is almost as much as the twofold of the money II2 (Communication and Information Sharing) is given - 61 SEK which is the second highest amount. Coming next are Product Acceptance (II5), Change Management (II3), Functions Development (II1) and Supplier Selection (II6), which are assigned with the amount of 48 SEK, 45 SEK, 44 SEK and 41 SEK respectively. Project Planning (II7) has received 33 SEK. For the last two improvement issues, Development Progress (II4) is given 12 SEK and Locations Distribution (II9) is given 4 SEK. Figure 4.4 illustrates the amount of money that each issue receives by showing the total amount (line + project), and project and line separately.

4.3.2 Identification of dependencies between improvement issues

After the prioritization, the participants were asked to identify a dependency between the improvement issues. Table 4.6 displays the raw data collected from this step. Column "*From*" is filled in with the issues that are dependents, and "*To*" are the issues on which "*From*" depend. "*Weight*" is the count number as how many participants has recognized a particular dependency. A quick look shows that every single improvement issue has one or more issues as its prerequisite. However, as discussed in Section 3.4.3, a dependency from IIX to IIY must be identified by at least three participants to be considered as a valid dependency. Figure 4.5 then illustrates only those dependencies that

ID	Improvement Issue	Project		Line		Total
		Project 1	Project 2	Line 1	Line 2	
II1.	Supplier Selection and Contract Agreement	10	20	10	1	41
II2.	Functions Development	13	20	6	5	44
II3.	Communication and Information Sharing	11	20	4	26	61
II4.	Development Progress	5	5	1	1	12
II5.	Change Management	8	10	5	22	45
II6.	Product Acceptance	5	10	25	8	48
II7.	Project Planning and Estimation	15	4	2	12	33
II8.	Supplier Involvement and Management	32	10	46	24	112
II9.	Locations Distribution	1	1	1	1	4

Table 4.5: Prioritization raw data.

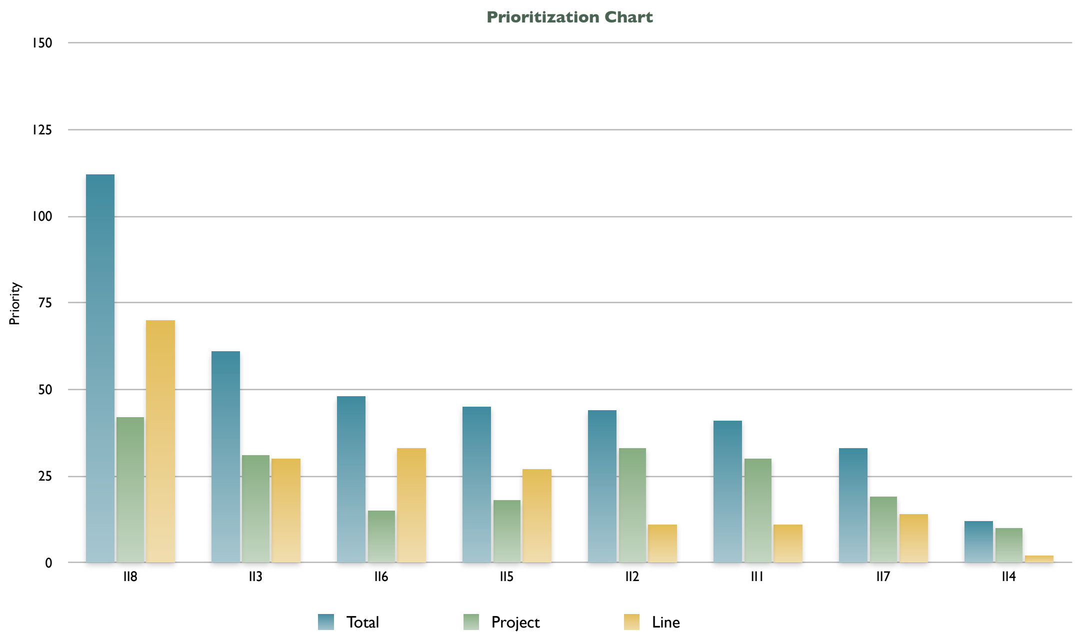

Figure 4.4: The priority of improvement issues.

has the weight of at least three. Communication and Information Sharing (II3) does not have a dependency, while it is the most depended improvement issues; five other issues consider the II3 as their prerequisite. Supplier Involvement and Management (II8), Project Planning (II7) and Supplier Selection (II1) do not have their prerequisite either. In order to tackle II4 (Development Progress), three other issues have to be addressed first which are Communication and Information Sharing (II3), Supplier Involvement and Management (II8) and Project Planning (II7).

From	To	Weight	From	To	Weight
II1	II7	1	II5	II3	**3**
	II8	1		II4	1
	II9	2	II6	II2	1
II2	II3	**3**		II3	**3**
	II5	1		II4	1
	II6	1		II7	**3**
	II7	**3**		II8	2
II3	II4	1	II7	II3	1
	II7	1		II4	1
	II9	2		II8	1
II4	II3	**3**	II8	II1	2
	II5	2		II3	2
	II6	1		II5	1
	II7	**3**		II6	1
	II8	**3**	II9	II3	**3**
II5	II2	1			

Table 4.6: Raw data of dependencies.

4.3.3 Data Analysis

An analysis of prioritization data is conducted in order to see if the result of the prioritization gives a high confidence. This is achieved by using a disagreement chart and a satisfactory chart for visualization. As described in Section 3.4.3, the calculation of variation coefficient and Spearman's rho are the statistical methods used to analyze the prioritization data.

4.3.3.1 Disagreement Chart

The coefficient of variation (C_V) is calculated for an individual improvement issue. Table 4.7 displays the prioritization data together with the C_V of each issue. The values of C_V suggests the dispersion of money different participants have given to a particular issue. The disagreement also varies from one issue to another. Illustrated in Figure 4.6 is the disagreement chart that shows the priority of the issues along with disagreement levels of an individual issue.

To analyze whether this variation is statistically significant, the t-test method is applied. The purpose of this testing is to help analyze whether the prioritization result

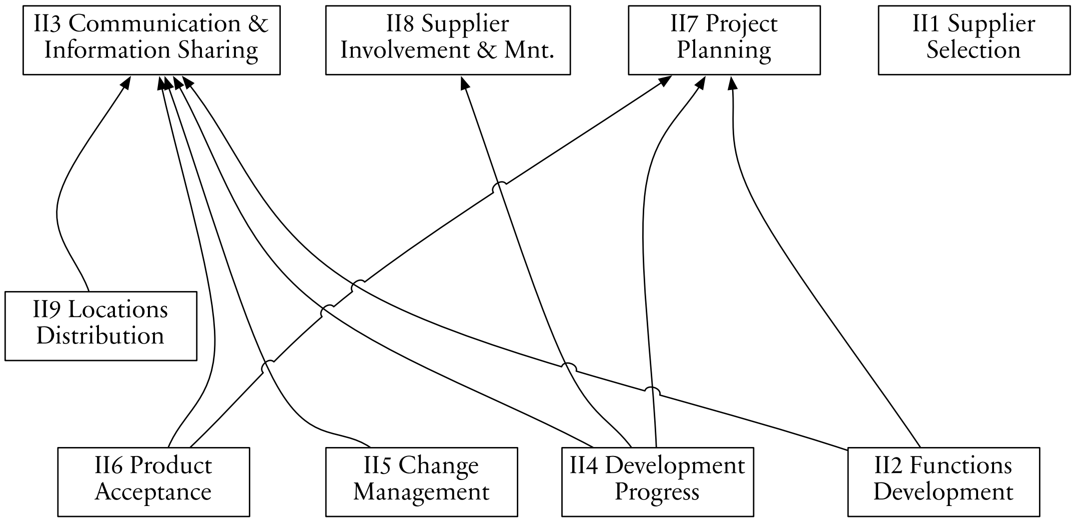

Figure 4.5: The dependencies between improvement issues.

ID	Improvement Issue	Project		Line		
		Project 1	Project 2	Line 1	Line 2	C_V
II1.	Supplier Selection and Contract Agreement	10	20	10	1	65.58%
II2.	Functions Development	13	20	6	5	54.92%
II3.	Communication and Information Sharing	11	20	4	26	55.13%
II4.	Development Progress	5	5	1	1	66.67%
II5.	Change Management	8	10	5	22	57.39%
II6.	Product Acceptance	5	10	25	8	64.28%
II7.	Project Planning and Estimation	15	4	2	12	65.49%
II8.	Supplier Involvement and Management	32	10	46	24	46.57%
II9.	Locations Distribution	1	1	1	1	0.00%

Table 4.7: Overall coefficient of variation.

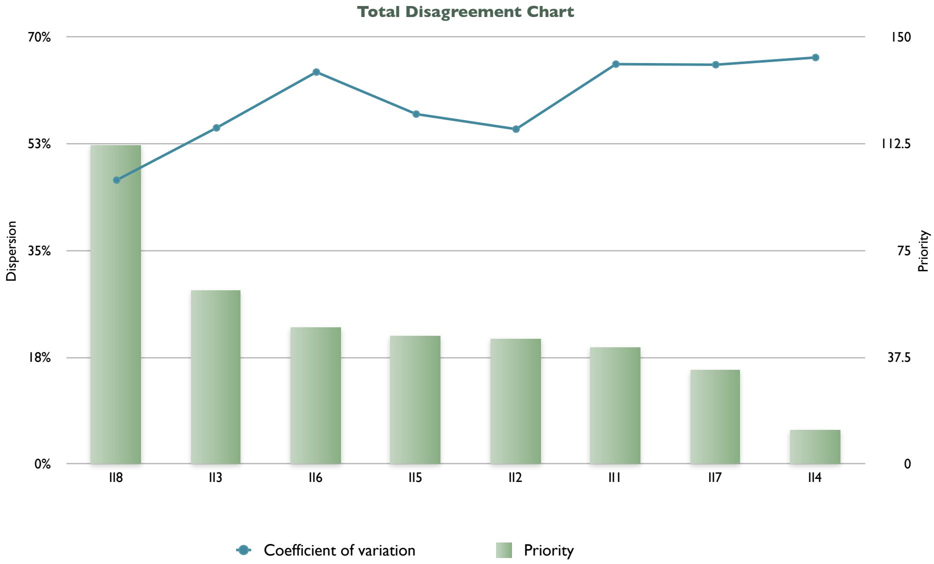

Figure 4.6: The priority and the dispersion calculated from all participants.

is reliable.

To conduct the hypothesis t-test method, the improvement issues are sorted by the priority (the total amount of money received). Then the improvement issues are divided into two groups of most important and least important. Therefore, the first group contains the coefficient of variation of issues II8, II3, II6 and II5. The second group holds the rest of the issues. The null hypothesis (H_0) is that the disagreement level on the high prioritized issues is equally much as the disagreement level placed on the issues with lower priorities. The alternative hypothesis (H_a) is that the disagreement level on the high prioritized issues is significantly higher than those with lower priorities. If the null hypothesis is rejected in favor of the alternative one, this means that a confidence cannot be placed on the prioritization result since the rejection is an evidence that the disagreement among practitioners is significant. Therefore there is a need of further investigation. If, otherwise, the null hypothesis is not rejected, the result of prioritization can be trusted.

1. Given X as the values of C_V of the high priority issues.

2. Given Y as the values of C_V of the low priority issues.

3. $X = 46.57, 55.13, 64.28, 57.39$

4. $Y = 54.92, 65.58, 65.49, 66.67, 0$

5. $H_0 : \bar{X} = \bar{Y}$

6. $H_a : \bar{X} > \bar{Y}$

7. $df = 7$
8. $t = 0.3569$
9. $p - value = 0.3658$
10. Using a significant level of 0.05, H_0 cannot be rejected since $p - value > 0.05$.

The result of the hypothesis test shows that the disagreement among participants towards the high prioritized issues is not significant. This can be implied that the disagreement among participants does not have an influence on the result of the prioritization.

Further, the disagreement is analyzed separately between the practitioners from line and project to get a sense of consensus of people from the same organization. Table 4.8 shows the prioritization data of project practitioners, and the data are visualized in Figure 4.7. Similar statistical test is also applied on the disagreement level of project practitioners. The result shows that there is no significant disagreement among the project practitioners.

1. Given X as the values of C_V of the high priority issues.
2. Given Y as the values of C_V of the low priority issues.
3. $X = 52.38, 29.03, 33.33, 11.11$
4. $Y = 21.21, 33.33, 57.89, 0, 0$
5. $H_0 : \bar{X} = \bar{Y}$
6. $H_a : \bar{X} > \bar{Y}$
7. $df = 7$
8. $t = 0.6215$
9. $p - value = 0.2770$
10. Using a significant level of 0.05, H_0 cannot be rejected since $p - value > 0.05$.

The data of line practitioners are also analyzed in the same way as the data from the project practitioners. Table 4.9 shows the prioritization data of line practitioners, and Figure 4.8 illustrates the disagreement chart of line people. Again, similar statistical test is applied on the disagreement level of line practitioners, and there is no significant disagreement the among line practitioners.

1. Given X as the values of C_V of the high priority issues.
2. Given Y as the values of C_V of the low priority issues.
3. $X = 31.43, 73.33, 51.52, 62.96$

ID	Improvement Issue	Project		C_V
		Project 1	Project 2	
II1.	Supplier Selection and Contract Agreement	10	20	33.33%
II2.	Functions Development	13	20	21.21%
II3.	Communication and Information Sharing	11	20	29.03%
II4.	Development Progress	5	5	0.00%
II5.	Change Management	8	10	11.11%
II6.	Product Acceptance	5	10	33.33%
II7.	Project Planning and Estimation	15	4	57.89%
II8.	Supplier Involvement and Management	32	10	52.38%
II9.	Locations Distribution	1	1	0.00%

Table 4.8: Project coefficient of variation.

Figure 4.7: The priority and the dispersion calculated from project participants.

4. $Y = 9.09, 81.82, 71.43, 0, 0$

5. $H_0 : \bar{X} = \bar{Y}$

6. $H_a : \bar{X} > \bar{Y}$

7. $df = 7$

8. $t = 1.0124$

9. $p - value = 0.1725$

10. Using a significant level of 0.05, H_0 cannot be rejected since $p - value > 0.05$.

ID	Improvement Issue	Line		C_V
		Line 1	Line 2	
II1.	Supplier Selection and Contract Agreement	10	1	81.82%
II2.	Functions Development	6	5	9.09%
II3.	Communication and Information Sharing	4	26	73.33%
II4.	Development Progress	1	1	0.00%
II5.	Change Management	5	22	62.96%
II6.	Product Acceptance	25	8	51.52%
II7.	Project Planning and Estimation	2	12	71.43%
II8.	Supplier Involvement and Management	46	24	31.43%
II9.	Locations Distribution	1	1	0.00%

Table 4.9: Line coefficient of variation.

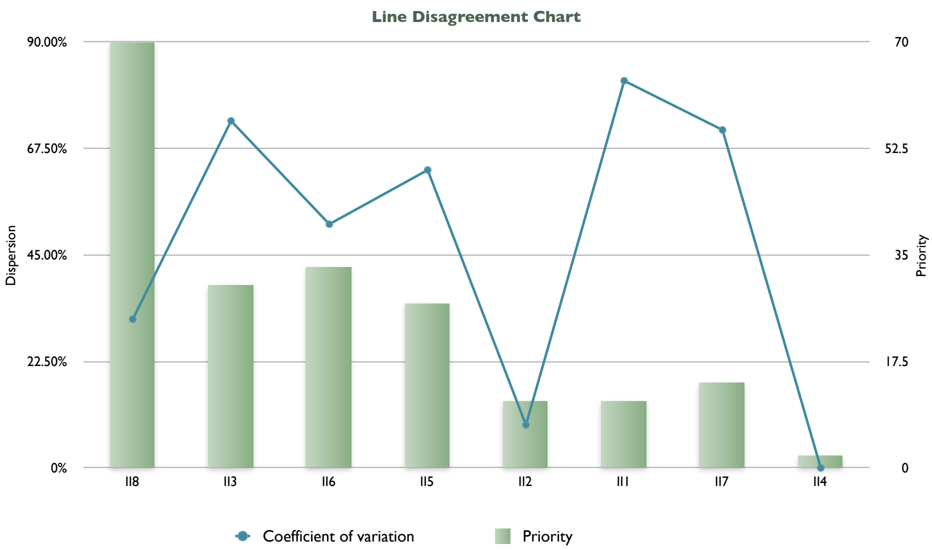

Figure 4.8: The priority and the dispersion calculated from line participants.

It also makes sense to measure the disagreement level between project practitioners and line practitioners as these two groups of people might have a contradict viewpoint on what is the most important. The coefficient of variation is calculated for individual issues and shown in Table 4.10. Figure 4.9 visualizes the disagreement between the project against line participants. The t-test procedure is applied as well, and the disagreement between the project practitioners and the line practitioners is not statistically important.

1. Given X as the values of C_V of the high priority issues.
2. Given Y as the values of C_V of the low priority issues.
3. $X = 25.00, 1.64, 37.50, 20.00$
4. $Y = 50.00, 46.34, 15.15, 66.67, 0$
5. $H_0 : \bar{X} = \bar{Y}$
6. $H_a : \bar{X} > \bar{Y}$
7. $df = 7$
8. $t = -0.9545$
9. $p - value = 0.8141$
10. Using a significant level of 0.05, H_0 cannot be rejected since $p - value > 0.05$.

		Sum of		
ID	Improvement Issue	Project	Line	C_V
II1.	Supplier Selection and Contract Agreement	30	11	46.34%
II2.	Functions Development	33	11	50.00%
II3.	Communication and Information Sharing	31	30	1.64%
II4.	Development Progress	10	2	66.67%
II5.	Change Management	18	27	20.00%
II6.	Product Acceptance	15	33	37.50%
II7.	Project Planning and Estimation	19	14	15.15%
II8.	Supplier Involvement and Management	42	70	25.00%
II9.	Locations Distribution	2	2	0.00%

Table 4.10: Coefficient of variation of project VS. line.

As a short summary, an analysis has been placed on the disagreement among all participants, the disagreement among project practitioners, the disagreement among line practitioners and the disagreement between project against line practitioners. The results of the disagreement analysis have shown that there is no forms of disagreement that is statistically significant so that it could affect the result of prioritization. Therefore, the result of prioritization can be used as a decision support for improvement planning.

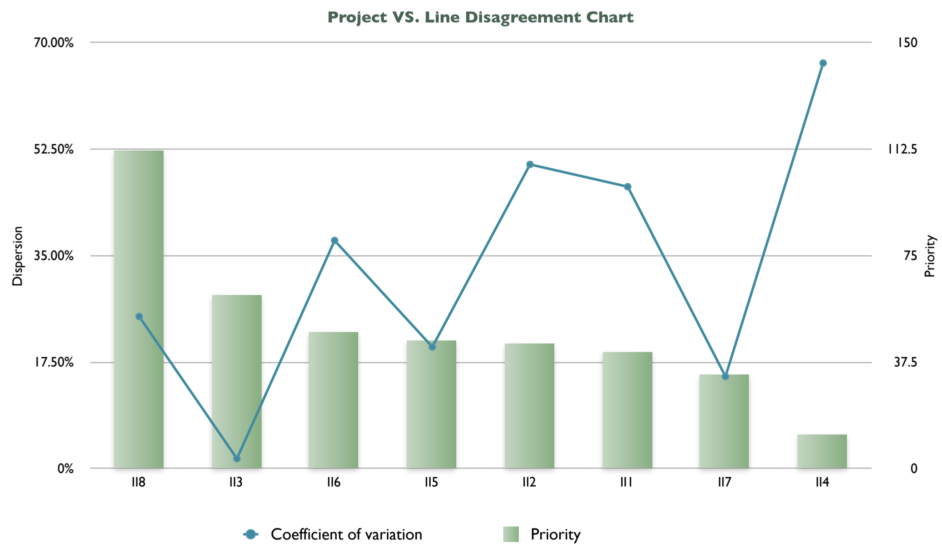

Figure 4.9: The priority and the dispersion calculated from project VS. line participants.

4.3.3.2 Satisfaction Chart

To confirm the claim in the previous section, Spearman's rank correlation coefficient is calculated. This is to assess how well an individual participant's prioritization correlates to the overall prioritization. Table 4.11 to 4.14 shows raw data and intermediate values as the calculation is performed, according to steps described in Section 3.4.3.3. Figure 4.10 demonstrates the final result of Spearman's rank correlation coefficient. All values are positive which suggests that an individual ranking is positively correlated with the overall order of the improvement issues. Also, none of the magnitude has suggested a bad fit. Therefore, it can be concluded that all participants are satisfied with the order of improvement issues. This also supports that the result of prioritization can be used.

ID	Improvement Issue	X	rank x_i	Y	rank y_i	$x_i - y_i$	d_i^2
II1.	Supplier Selection and Contract Agreement	10	5	41	6	-1	1
II2.	Functions Development	13	3	44	5	-2	4
II3.	Communication and Information Sharing	11	4	61	2	2	4
II4.	Development Progress	5	7.5	12	8	-0.5	0.25
II5.	Change Management	8	6	45	4	2	4
II6.	Product Acceptance	5	7.5	48	3	4.5	20.25
II7.	Project Planning and Estimation	15	2	33	7	-5	25
II8.	Supplier Involvement and Management	32	1	112	1	0	0
II9.	Locations Distribution	1	9	4	9	0	0
						$\sum d^2 =$	58.5

Table 4.11: $\sum d^2$ of participant Project 1.

ID	Improvement Issue	X	rank x_i	Y	rank y_i	$x_i - y_i$	d_i^2
II1.	Supplier Selection and Contract Agreement	20	2	41	6	-4	16
II2.	Functions Development	20	2	44	5	-3	9
II3.	Communication and Information Sharing	20	2	61	2	0	0
II4.	Development Progress	5	7	12	8	-1	1
II5.	Change Management	10	5	45	4	1	1
II6.	Product Acceptance	10	5	48	3	2	4
II7.	Project Planning and Estimation	4	8	33	7	1	1
II8.	Supplier Involvement and Management	10	5	112	1	4	16
II9.	Locations Distribution	1	9	4	9	0	0
						$\sum d^2 =$	48

Table 4.12: $\sum d^2$ of participant Project 2.

ID	Improvement Issue	X	rank x_i	Y	rank y_i	$x_i - y_i$	d_i^2
II1.	Supplier Selection and Contract Agreement	10	3	41	6	-3	9
II2.	Functions Development	6	4	44	5	-1	1
II3.	Communication and Information Sharing	4	6	61	2	4	16
II4.	Development Progress	1	8.5	12	8	0.5	0.25
II5.	Change Management	5	5	45	4	1	1
II6.	Product Acceptance	25	2	48	3	-1	1
II7.	Project Planning and Estimation	2	7	33	7	0	0
II8.	Supplier Involvement and Management	46	1	112	1	0	0
II9.	Locations Distribution	1	8.5	4	9	-0.5	0.25
						$\sum d^2 =$	28.5

Table 4.13: $\sum d^2$ of participant Line 1.

4.3.4 Packaging

The result from the prioritization is used as a leading data for improvement planning, and dependencies is used as an indicator if an issue in question can be included as a candidate issue to be solved. II8 (Supplier Involvement and Management) has the highest priority and has no prerequisite, therefore it makes sense to include this as a candidate. II3 (Communication and Information Flow) is identified as the second most critical issue, and is a prerequisite to many other issues therefore this issue should be also included. There are also two more issues that do not depend on other issues. These issues are II7 (Project Planning and Estimation) and II1 (Supplier Selection). However, the prioritization result has suggested that these two issues are not of a high importance.

ID	Improvement Issue	X	rank x_i	Y	rank y_i	$x_i - y_i$	d_i^2
II1.	Supplier Selection and Contract Agreement	1	8	41	6	2	4
II2.	Functions Development	5	6	44	5	1	1
II3.	Communication and Information Sharing	26	1	61	2	-1	1
II4.	Development Progress	1	8	12	8	0	0
II5.	Change Management	22	3	45	4	-1	1
II6.	Product Acceptance	8	5	48	3	2	4
II7.	Project Planning and Estimation	12	4	33	7	-3	9
II8.	Supplier Involvement and Management	24	2	112	1	1	1
II9.	Locations Distribution	1	8	4	9	-1	1
						$\sum d^2 =$	22

Table 4.14: $\sum d^2$ of participant Line 2.

Participant	$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)}$
Project 1	0.51
Project 2	0.60
Line 1	0.76
Line 2	0.82

Table 4.15: Spearman's rho ($n = 4$).

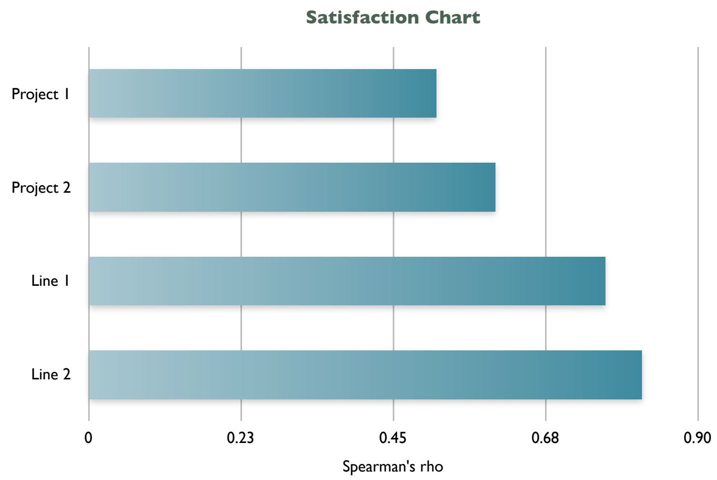

Figure 4.10: The satisfaction chart.

5. Analysis

This section contains the analysis of the thesis findings. It provides the answers to the research questions. Also, it discusses the state-of-the-art of the prioritized improvement issues.

5.1 Answers to Research Questions

5.1.1 RQ 1. How do the practitioners at an automotive OEM cooperate with their suppliers to develop software-intensive systems?

Cooperation with the supplier in software product development comprises the fundamental process steps of preparation, engineering and management. The preparation refers to process P1 (Supplier Selection and Contract Agreement). Engineering process contains process P2 (Functions Development), P4 (Monitor the progress of implementation), P5 (Change Management) and P6 (Product Acceptance). Lastly, management process consists of P3 (Delivery of ECU specifications to the supplier), P7 (Project Planning and Estimation), P8 (Supplier Involvement and Management) and P9 (Locations Distribution).

5.1.1.1 Preparation Process

5.1.1.1.1 Supplier Selection and Contract Agreement

Best practices that the OEM performs during the preparation phase includes

- Define subsystems that are needed to be outsourced.
- Create a requirement specification that is at a negotiable level.
- Negotiate with key suppliers.
- Review implementation proposals by a crossed-functional team.
- Select a supplier and established a contract.

There are however loose ends during the preparation phase that should be kept in mind. The contract should unambiguously specify expectations and responsibility matrix of both OEM and the suppliers. The contract should also be consistent with the nature of incremental development. The time when the contract is established is also important. The OEM should spend more time and effort to get a clear picture of customer requirements to prevent a chain of commercial discussions that would come after as a consequence of unclear requirements from the start. Activities performed and deliverables used during the RFQ phase should achieve a certain degree of formality. This is to ease the evaluation and comparison between proposals from different suppliers. It is crucial to select the right supplier for new product development. Therefore, from the engineering point of view, the aspect of supplier's competence should be placed higher than price. Selecting experienced and competent supplier also increases the trust that the supplier can contribute and deliver good solutions.

5.1.1.2 Engineering Process

5.1.1.2.1 Functions Development

(RQ 1.1 How do the practitioners work with the supplier in Functions Development?)
Several requirements transformation steps are performed starting from a very high level requirement down to requirements that go to a particular software component. First the customer needs are transformed to a set of technical requirements of a vehicle function. These requirements are then allocated onto different logical components. Functional requirements of these logical components are then specified. In the end, the logical components are placed on their targeted physical locations, and the specification is sent to the supplier. Review activities are performed both on the function level and component level. For complex ones, the development of the functions is achieved in incremental steps.

However, inadequate functions development process leads to late changes of implementation which require extra effort than anticipated at the supplier. Several reasons contribute to the late changes are, for example, immature stakeholders needs and uncoordinated time plan with other departments that could have an input on a particular ECU.

The maturity of business requirements (market requirements, end-customer needs, product planning organization and *etc*) should achieve a certain level. That is, the requirements should be clear and well-explained so that the development project can accurately estimate all necessary parameters. Unclear customer needs and insufficient communication with the stakeholders force the development project to assume the requirements, and the solutions are consequently based on an assumption, which sometimes is not what the stakeholders really want. Also, it is important to synchronize the time plan of the department who develops a particular ECU with the time plan of the department who is the owner of the ECU. Not all necessary information is provided to the function development team when the time plans are uncoordinated. This type of situations leads to late changes of implementation that eventually affect the supplier.

Another popular topic of discussion regarding the functions development process concerns the functional specification itself. The specification appears to have missing information and inconsistencies. The specification focus is not at the right place. That is, focus should be put on specifying component interfaces but now the focus is on specifying what inside a component. Also, the requirements are lack of testability and verifiability. These problems are constituted by the fact that there are many people contributing to the specification of a particular ECU, there is a lack of a complete review activity and not all relevant roles are involved in the functions development and review process.

5.1.1.2.2 Monitor the Progress of Implementation

(RQ 1.3 How do the practitioners work with the supplier in Measurement & Monitoring?)
Weekly meetings are defined as the main method of communication when monitoring the development progress at the supplier. The roles that are responsible for arranging and participating in each meeting are defined. In this case study, there is a team that is the main interface towards external suppliers. The weekly meetings cover both technical and management aspect including discussions of problems and risks. There is also the use of an open-item list and status reports during the regular weekly meetings. Also, there is a use of requirements trace matrix for detailed follow up on which requirements have been implemented and tested. This matrix is filled in by the supplier and sent back to the OEM at the official delivery.

The practitioners are, however, struggle in performing this well-defined process and activities in practice. The main reason would be the lack of standard and formality of how the supplier should describe what they have done. Although there is a requirements trace matrix, there is still a need of a template or a standard way of reporting what exactly that have been done, what issues have occurred and what are potential risks. This is because the trace matrix is mainly use for evaluating the status at the official software delivery, and not during development period between deliveries.

Time needed to review all artifacts is also essential to be able to accurately judge the status of the development. It is also difficult for the OEM to make the supplier proactive to problems. This could be linked to the issue of supplier involvement and management (II8) in the following section.

5.1.1.2.3 Change Management

(RQ 1.2 How do the practitioners work with the supplier in Change Management?)
There is an agreement on processes and interfaces of change management process between the OEM and the supplier. They have established a clear change control mechanism through a change request. Resources that are responsible for handling a particular change request are defined. Also, there are decision boards that are responsible for evaluating the impact of changes both in terms of technical impact and benefits associated with a particular change. An approval is required before implementation of the change. The status of a change request is recorded and tracked for closure using a tool.

However, the change control process is claimed to be time consuming and too many stakeholders are involved in the process. The longer the process, the longer the supplier has to wait until the implementation of a particular change can be performed. However, the supplier cannot always wait for the approval since it could lead to delay. Therefore the supplier has to decide and start with the implementation without waiting for the final approval.

It is also important to keep the specification updated to reflect the actual implementation regarding the changes agreed. Due to tool limitations, it is now not feasible for the studied OEM to release a new specification that is corresponding to changes between component deliveries. Although the changes are recorded and tracked in another tool, there are still gaps between these tools and not all changes can be traced. This situation causes a lot of problems for the test team in order to find the right specification to verify a certain software component. Therefore there is a need of a good method to communicate the changes to the testing environment.

5.1.1.2.4 Delivery of ECU Components and Test *&* Verification

(RQ 1.4 How do the practitioners work with the supplier in Test & Verification?)
Artifacts the supplier needs to deliver to the project are predefined, and there are resources at the project who ensures that the supplier has included all necessary deliverables in the delivery package. There is a clear responsibility of testing activities performed by the supplier or the OEM. In this case study, the supplier is in charge of performing software testing and verification activities towards the software specification that is provided by the OEM. The test results and test methods are recorded and described in a test report that is included in the delivery. The OEM then performs system integration test by connecting different system elements to produce an integrated system, and verify this system based on the system requirements. However, before the OEM starts with the system integration testing activity, there is an intermediate activity of a smoke test to secure that an ECU is ready for integrated system verification.

Issues concerning this process area is not directly involved with the engineering process. Instead, it is about time plan, communication and criteria that the supplier is required to fulfill for their software component to be accepted. The OEM does not always perform testing activities as agreed due to time and resource constraints. Therefore the OEM is not able to provide feedback on the software component to the supplier, which the supplier would like to have. Also, as a consequence of a lot of changes and tight time schedule, the supplier themselves are late and they cannot fulfill all qualification criteria set up during the preparation phase. This leads to the inclusion of unqualified software components into system integration test at the OEM.

5.1.1.3 Management Process

5.1.1.3.1 Communication and Information Sharing

To secure that the supplier has interpreted the requirements correctly, there is an establishment of clarification process in which the supplier has possibility to give feedback and ask questions regarding the requirements. The contact person is clearly defined, and there is a tool facilitating this process. The status of a question is recorded and tracked using the tool. Extra meetings or workshops could also be arranged to help speed up the process.

Communication in this case does not, however, focus solely on the communication between two organizations (OEM and supplier), but also on the communication within the OEM organization themselves that influences the communication with the supplier. Having a contact person does not necessary mean that the communication will be effective. It is information that the contact person possesses that is crucial. In this case study, there is a gap of information between a functions development team and an acquired system team. For example, the contact person is not aware of change related information therefore he cannot inform the supplier about changes in advance for a reasonable time period. This unexpected changes can lead to project delay as the supplier cannot ramp up resources to handle modifications in parallel with normal development. Time needed for communication is also an important facet to take into consideration, especially when it is a communication under global environment.

5.1.1.3.2 Project Planning and Estimation

Project planning and estimation method is not investigated in this thesis. However, the practitioners have discussed that a good estimation method is needed in order to have an accurate representation of the estimates to the management. Management goal could also inhibit the estimation, therefore this results in a cut-cost project and consequently a shortened time plan. This eventually affects the supplier as they are forced to deliver under the time pressure.

5.1.1.3.3 Supplier Involvement and Management

There are different phases of incorporating the supplier into a product development life cycle - either at the concepts generation or at the actual development. Leveraging supplier's expertise is achieved through the means of giving feedback and questions on software requirements. An interface between the development project and the supplier is established to ease communication between organizations. Cooperation between different departments is established in order to monitor the supplier in terms of both delivery and quality.

However, there are still difficulties in terms of managerial aspect and inter-organizational communication. There is a reluctance in trying to achieve a fully developed relationship between the OEM and supplier organization. Organizational mindset of building a good long term relationship with the supplier is not fully embraced by practitioners.

The supplier does not always contribute to implementation solutions. The degree of openness in terms of problem-related information is not at the right level. Insufficient communication of expectations from the start results in the lack of supplier's commitment to build a good product together with the OEM. All these make the supplier involvement not as successful as it is expected.

5.1.1.3.4 Locations Distribution

Since the company studied has different sites in different countries, the practitioners are familiar when it comes to working with colleagues from different language and culture. Being a global company makes it easier to cooperate with suppliers from different parts of the world. At least, the practitioners don't see any negative impact of this setting. Instead, they value globalization as they believe domain knowledge is area dependent. Although there is a culture difference, it is seen as a problem of an individual and not at all influence the cooperation with the supplier. The only concern of distributed locations is that the time needed to exchange information should not be underestimated. This issue is however included in II3 (Communication and Information Sharing)

5.1.2 RQ 2. Which areas are identified as challenges or improvement issues for the practitioners in order to develop software-intensive systems?

As a result of interview data analysis, improvement areas are identified and are discussed in details in Section 4.2.1.2. To answer to this research question, a short listed summary of improvement issues previously presented is provided here.

Starting from an early stage, there is a need for an OEM to improve their process of selecting an appropriate supplier to be a partner in product development. II1 (Supplier Selection and Contract Agreement) concerns factors that should be considered when choosing a supplier and when establishing a contract with a particular supplier.

When engineering work starts, first of all an OEM should consider all factors that could influence the development and quality of software specifications that are later sent to the supplier. II2 (Functions Development) covers the process of creating the software specification that is an input to the supplier. It discusses factors that could eventually affect the OEM-supplier cooperation. Secondly, there are improvement needs placed on activities that occur during the development of software components. II4 (Development progress) focuses on how to effectively monitor the status of development at the supplier. II5 (Change Management) discusses issues regarding handling and controlling modifications to software requirements. Finally, when the software component is delivered back to the development project, there is a need of that an OEM should communicate with the supplier concerning verification plan and actively provide feedback to the supplier. This improvement issue is presented in II6 (Product Acceptance). This issue also includes the use of qualification criteria when accepting supplier's software components.

II3 (Communication and Information Sharing) is also identified as one of the challenges in the OEM-supplier cooperation. This concerns the aspect of managing development-related information to be communicated, contact persons and the information levels between two development sites.

Many of issues found have rooted their cause in a tight time schedule. II7 (Project Planning and Estimation) relates to the estimation method used to estimate resources and the planning of what is needed to do in the development project.

To involve a supplier early in product development, one of the goals an OEM aims is to leverage supplier's domain knowledge. However, to effectively manage the supplier is still an issue. II8 (Supplier Involvement and Management) deals with inevitably challenges in the setting of early supplier involvement in product development. This includes partnership building, monitoring and control the supplier and transparencies between two companies.

Lastly, working in a global setting poses some minor problems in language and culture differences which is covered in II9 (Locations Distribution).

5.1.3 RQ 3. How can the practitioners improve the OEM-supplier cooperation?

As it is not feasible to address all improvement issues at once, performing the improvement planning step of iFLAP achieves possible candidates to be included in a plan for improvement.

First the practitioners assign priority to the identified improvement issues. Then, they identify dependencies between the issues. The results of the prioritization and identification of dependencies are analyzed and the detailed analysis is presented in Section 4.3.3. The final outcome yields two improvement issues, which are Supplier Involvement and Management (II8) and Communication and Information Sharing (II3), that should be addressed in order to improve the OEM-supplier cooperation. These two issues are then related to literature and are discussed here.

- Supplier Involvement and Management (II8)
  The barriers to a successful supplier involvement can be minimized by adopting formal trust development practices, sharing risks and rewards, a mutual agreement on performance measurements, exchanging of relevant information, top management commitment and confidence in supplier capability [Ragatz et al., 1997]. Factors influencing the success of supplier involvement are structured into three main groups of 1) supplier selection, 2) supplier relationship development and adaptation and 3) internal customer capabilities [Johnsen, 2009]. The first factor concerns supplier selection processes. The supplier should be selected based on their innovative capability and complementarity [Petersen et al., 2005].

  The second factor covers the need of the development of supplier relationship that involves establishing a long-term integrating effort between customer and supplier [Johnsen, 2009]. This focuses on relationship-specific factors such as mutual trust, mutual commitment [Walter, 2003] and formalized risk and reward sharing [Ragatz et al., 1997]. These factors are identified as critical success factors in literature, while they are often not recognized by managers [Johnsen, 2009].

The last factor - internal customer capabilities - concerns internal factors affecting customer's capabilities. These are, in particular, top management commitment [Ragatz et al., 1997] and internal cross-functional coordination.

Mutual trust and commitment between parties is a key factor for a successful buyer-supplier cooperation [Walter, 2003]. However, trust in the other party is not necessarily obtained through a formal trust development practice, instead, it is built up and evolved through management techniques used in supplier involvement process such as sharing of market information, direct communication and representation of supplier at buyer development project [Ragatz et al., 1997]. The top management commitment is seen as an enabler of implementing those management strategies, for example, the management approves the sharing of some confidential information and make resource available for the involvement effort [Ragatz et al., 1997]. At the studied OEM, management strategies of supplier involvement such as clear contact persons, participation of resident engineers and direct communication are already adopted, and these are a good foundation to an establishment of trust between the OEM and its associated supplier. However, the practitioners should also be committed to the relationship [Walter, 2003]. That is, the practitioners should believe that the relationship is worth working on and maintaining it so it lasts for a long time. Building a partnership mindset should be established at the management level and propagated down crossing all levels of organization to the engineers. The management should function as a relationship promoter to encourage and enable the integration of supplier into new product development [Walter, 2003]. This requires however collaboration of the management at both buyer and supplier organizations. Moreover, trust and commitment are considered to be crucial for the supplier's contribution to product innovation [Walter, 2003]. Therefore, the studied OEM should focus on promoting trust and commitment level to help resolve the difficulty in leveraging supplier's competence.

- Communication and Information Sharing (II3)
  Performing literature review does not find any study that pertains to this improvement issue. The issue of communication and information sharing (II3) concerns the exchanging of development-related and software requirement-related information between the OEM and the associated suppliers. This is for the OEM to ensure that the supplier can continue on their implementation, or to prevent any development issues that could arise. On the other hand, communication and information sharing in state-of-the-art concerns primarily on exchanging strategic information, such as market needs and technology roadmaps, which is not related to the issue found at the studied OEM. Therefore, there is a need for research in the area of information sharing regarding engineering work. Particularly, the exchange of development-related information that facilitates and gives benefits to

the development at the supplier or to jointly solving development problems.

6. Conclusion

The current situation of the automotive OEM-supplier cooperation during software-intensive product development is investigated during the thesis. The study is conducted at an automotive OEM within the Electronics and Electrical department. The approach chosen for the research is case study. The methods employed for collecting data is interviews and documents. The objective of the case study is to investigate how an OEM and associated suppliers collaborate in the development of software-intensive systems for new product. Together with the investigation, it also seeks to identify issues that can be improved in order to pursue a better OEM-supplier cooperation.

The lightweight process improvement framework, iFLAP, is utilized as the research method of this case study. This involves three main steps of selection, assessment and improvement planning, and each step is related to generic research techniques.

The following is the summary of outcomes of an execution of each step:

- Selection
  Selection results in defining roles that are related to or influenced the supplier cooperation process leading to the appointing of practitioners to participate in the study.

- Assessment
  Assessment captures the interplay between the OEM and the supplier organization during software product development. The findings demonstrate that there are three fundamental process areas regarding the early supplier involvement - preparation, engineering and management.

  The preparation process concerns sourcing for an appropriate supplier and subsequently establishing a contract. The engineering process comes when the development phase starts. Four areas under the engineering process have been explored namely functions development, monitoring development progress, change management and product acceptance test. The management aspect covers communication of development-related information, project planning, managing supplier relationship and working with global suppliers.

  Practices, working procedures and responsible roles are presented and discussed for each of the processes. Moreover, issues found under these processes are extracted forming a list of improvement issues.

- Improvement Planning
  Improvement planning groups together a set of improvement issues found from the assessment step that are feasible to be resolved first. This is achieved through prioritization and dependencies identification. As a result, two issues - Supplier Involvement and Management and Communication and Information Sharing - are the candidates for an improvement initiative. Literature review is guided by these short-listed issues to relate them to the state-of-the-art aiming to contribute to resolving the issues. It has been shown that the issue of Supplier Involvement and Management has been extensively studied, whilst there is no literature pertaining to the issue of Communication and Information Sharing found.

Although the thesis initially focused on the engineering aspect of software development between the OEM and the supplier, the findings have shown that the practitioners have faced challenges from processes around the pure engineering tasks. It is these processes that the practitioners have prioritized and need to resolve them first to pursue a better OEM-supplier cooperation in developing a software-intensive product in the automotive industry.

6.1 Lesson Learned

- To conduct an in-depth study investigating the current state-of-the practice, practitioners' cooperation is a vital element to achieve a reliable result. During this study, the practitioners have been actively involved although they are facing a high time pressure. However, the data of the improvement planning step was gathered from only four participants. Therefore, it is advisable for the studied organization to re-arrange a workshop for prioritization and identification of dependencies for a more accurate result more reflecting the organization's need.

- iFLAP is a practical software process improvement tool that can be used as research techniques. Also, it is proven in this thesis that iFLAP can be used to study the process of acquiring software products.

6.2 Suggestions for Future Research

This thesis has investigated a broad area of manufacturer-supplier cooperation covering from sending component requirements until verifying the components. It is shown in this thesis that the issue of communication and sharing of information related to the development work is prioritized by the practitioners. However, there is relatively a few research in this area. Therefore, study focus should be placed on this topic in order to help the practitioners achieve a high degree of cooperation in developing software products. Also, the need for more industrial case studies on involving suppliers during software product development and software supplier management is recognized during the study.

A. Interview Instrument

Table A.1: Completed Interview Instrument.

Interview Item	Question	RQ.
1. Open Question	1. What are your current roles and responsibilities? 2. How long have you been working in this company?	
2. System Engineering	1. What is the process of breaking down from the customer requirements to the specification that is sent to the supplier? 2. Who (What roles) are involving during the process? 3. Are there organizational policies or instructions guiding how this process should be conducted? 4. What tools are utilized during the process? 5. What would you rate for the effectiveness of your System Engineering process, on a scale from 0 to 5 where 0 is very bad and 5 is very good? 6. What would you rate for the efficiency of your System Engineering process, on a scale from 0 to 5 where 0 is very bad and 5 is very good? 7. What would you rate for the quality of the specification which you provide to the supplier, on a scale from 0 to 5 where 0 is very bad and 5 is very good?	*RQ 1.1* How do the practitioners work with the supplier in Functions Development?

Table A.1 – Continued

Interview Item	Question	RQ.
3. Change & Configuration Management	1. How do you inform the supplier if there are changes in the functional requirements? 2. Who (What roles) are involving during the process? 3. Are there organizational policies or instructions guiding how this process should be conducted? 4. What tools are utilized during the process? 5. How does the supplier inform you if there are modifications to their implementation? 6. How do you handle deviations to requirement baselines? 7. What would you rate for the effectiveness of your Change & Configuration Management process, on a scale from 0 to 5 where 0 is very bad and 5 is very good? 8. What would you rate for the efficiency of your Change & Configuration Management process, on a scale from 0 to 5 where 0 is very bad and 5 is very good?	*RQ 1.2* How do the practitioners work with the supplier in Change & Configuration Management?
4. Measurement & Monitoring	1. How do you keep track of the development status at the supplier? 2. Who (What roles) are involving during the process? 3. Are there organizational policies or instructions guiding how this process should be conducted? 4. What tools are utilized during the process? 5. What would you rate for the effectiveness of your Measurement & Monitoring process, on a scale from 0 to 5 where 0 is very bad and 5 is very good?	*RQ 1.3* How do the practitioners work with the supplier in Measurement & Monitoring?

Table A.1 – Continued

Interview Item	Question	RQ.
5. Test & Verification	1. How do you test & verify the supplier product? 2. Who (What roles) are involving during the process? 3. Are there organizational policies or instructions guiding how this process should be conducted? 4. What tools are utilized during the process? 5. What would you rate for the effectiveness of your Test & Verification process, on a scale from 0 to 5 where 0 is very bad and 5 is very good? 6. What would you rate for the efficiency of your Test & Verification process, on a scale from 0 to 5 where 0 is very bad and 5 is very good?	*RQ 1.4* How do the practitioners work with the supplier in Test & Verification?
6. Globally Distributed Location	1. Do you think the cooperation between you and the supplier is impact by the globally distributed locations?	*RQ 2* Which areas are identified as challenges or improvement issues for the practitioners in order to develop software-intensive systems?
7. Attitude towards the Supplier Cooperation	1. Do you think the cooperation between you and the supplier is a success? 2. What would you rate for the successfulness of the supplier cooperation, on a scale from 0 to 5 where 0 is very bad and 5 is very good?	*RQ 2* Which areas are identified as challenges or improvement issues for the practitioners in order to develop software-intensive systems?
8. Finish off Questions	1. What are 3 things regarding supplier management and cooperation that have the highest improvement potential? 2. What are 3 things regarding supplier management and cooperation that your organization is best at? 3. Do you have anything that you think it is relevant for the study, but I have missed?	

B. Search Terms

The following are the search strings used to search for relevant literature in this thesis.

Area	Search String	Search Date
II2 Communication and Information Flow	(technical information) WN KY AND (flow* OR shar* OR communicat*) WN KY AND (product development) WN KY	Apr 10
	(communicat*) WN KY AND (strateg* OR technique*) WN KY AND (supplier) WN KY	Apr 10
	(interorganization* OR inter-organization*) WN KY AND (information OR requirement* OR specification*) WN KY AND (communicat* OR shar*) WN KY	Apr 10
II8 Supplier Involvement and Management	(integrated) WN KY AND (supplier OR vendor) WN KY AND (product development OR software development) WN KY	Mar 10
	(supplier) WN KY AND (involv*) WN KY AND (product development) WN KY	Mar 10

Table B.1: The search strings used within this thesis.

C. Interview Codes

C.1 Level 1 Codes

Abbr.	Category Name	Description	RQ.
C	Current Practice	Description, clarification, explanation of practices, processes or *etc* of how the practitioners cooperate with suppliers. This includes both direct and indirect practices that influence the cooperation. Also, this includes practices or processes that the practitioners think they are already good.	RQ 1
D	Difficulty/Challenge	Problems, issues, bad practices or *etc* that are related to OEM-supplier cooperation. Use this category even if the supplier cooperation is indirectly affected by the referred practice.	RQ 2

Table C.1: Level 1 codes.

C.2 Level 2 Codes

Table C.2 shows the Level 2 codes.

C.3 Level 3 Codes

The level 3 codes are divided into two groups. The first group contains the codes that are used with a record that is coded with "*C*" in Level 1. The other group contains the codes for data that is coded with "*D*" in Level 1. Table C.3 shows the

Abbr.	Category Name	Description
SS	Supplier Selection	Information related to an early stage of the project when selecting appropriate suppliers and setting up contract agreement.
FD	Functions Development	Information related to the functions development process from customer viewpoints to requirements specification sent to suppliers. Anything related to how specification is created, how requirements are broken down, how requirements are elicited, *etc*
CO	Communication	Information related to communication between teams, sites and between supplier and OEM.
DP	Development Progress	Information related to monitoring the development status at the supplier.
CM	Change Management	Information related to how modifications to requirements specification are handled and managed.
TV	Test & Verification	Information related to the test and verification process.
ES	Estimation	Information related to project planning and estimation of resources.
SM	Supplier Management	Information related to supplier involvement in product development and how to manage them.
LD	Locations Distribution	Information related to how the distributed locations affect or influence the cooperation.

Table C.2: Level 2 codes.

Level 3 codes for the "*C*" category, and Table C.4 shows the codes used for the "*D*" category.

Table C.4: Level 3 codes for "*D*" category.

Abbr.	Category Name	Description
BUSREQ	Business Requirements	Information related to when the stakeholders needs is transfered to the function development team. Anything that occurs before a project has started. Comments about the high-level requirements before the system requirements are developed.
SPEQUA	Specification Quality	Information related to contents of component specification i.e. abstraction level at which they are specified. INCLUDES incomplete requirements, inconsistencies of requirements, missing specification of signals and any error in requirements. Where applicable, the referred specification must be given in the Comments column whether it is LDS, system specification, TR or other specification. INCLUDES testability and verifiability of requirements. INCLUDES roles, methods, activities performed that is related to the quality of specifications.

Table C.4 – Continued

Abbr.	Category Name	Description
REQPRO	Requirements Engineering Process	Information related to activities, processes and roles involved in the requirements engineering process. This includes activities performed before a project has started until component specification is created and maintained.
REQHAN	Requirements Handover	Information related to activities performed when the OEM delivers requirements specification to the suppliers. INCLUDES roles, communication channels and methods used to clarify and secure that the requirements are fully and mutually understood.
EXPCON	Contribution of Expertise	Information related to the sharing of competency and expert knowledge between two organizations.
INFFLO	Information Flow	Information related to the flow of information between teams and development sites of the OEM organization.
PARMIN	Partnership Mindset	Information related to partnership concept between two organizations. This could be anything related to the mutual understanding of company goals, development process, project scopes between the two organizations, or it could be the companies sharing the goals and commitment. INCLUDES activities, methods, discussions that make the two companies be more transparent to each other.
INCFUN	Incremental Functions Development	Information related to the incremental way of specifying functions.
TEASYN	Synchronization between teams	Information related to the synchronization and coordination between different teams that have influence on the development of functions.
TRAORG	Transparency of organization	Information related to communication and exchange of information from one organization to another. This concerns mainly openness between any two different organizations or companies.
SPEUPD	Specification Update	Anything (activities, processes, roles, methods, artifacts, tools, etc.) related to updating and releasing requirement specifications when changes are made to the requirements throughout the implementation phase. For example, regenerating or releasing the new version of requirement specification and frozen specification during implementation (but requirements keep being updated which make it difficult for creating test cases). INCLUDES the correction loop of the specification by including addendum issues.
CHAPRO	Change Process	Information related to change control process both internal and external to the studied company.
TOOL	Tool	Information related to tools that cannot be coded with any of the above categories.

Abbr.	Category Name	Description
PROCESS	Process & Activities	Information related to working method, practices, activities or process explanation.
ROLE	Roles & Responsibilities	Information related to who do what regarding a particular process.
ARTIFACT	Artifacts	Information related to documentation as the product of a particular process. This includes templates of the artifacts as well as an instruction of the process.
TOOL	Tool	Information related to tools employed to support a particular process or activity.

Table C.3: Level 3 codes for *"C"* category.

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