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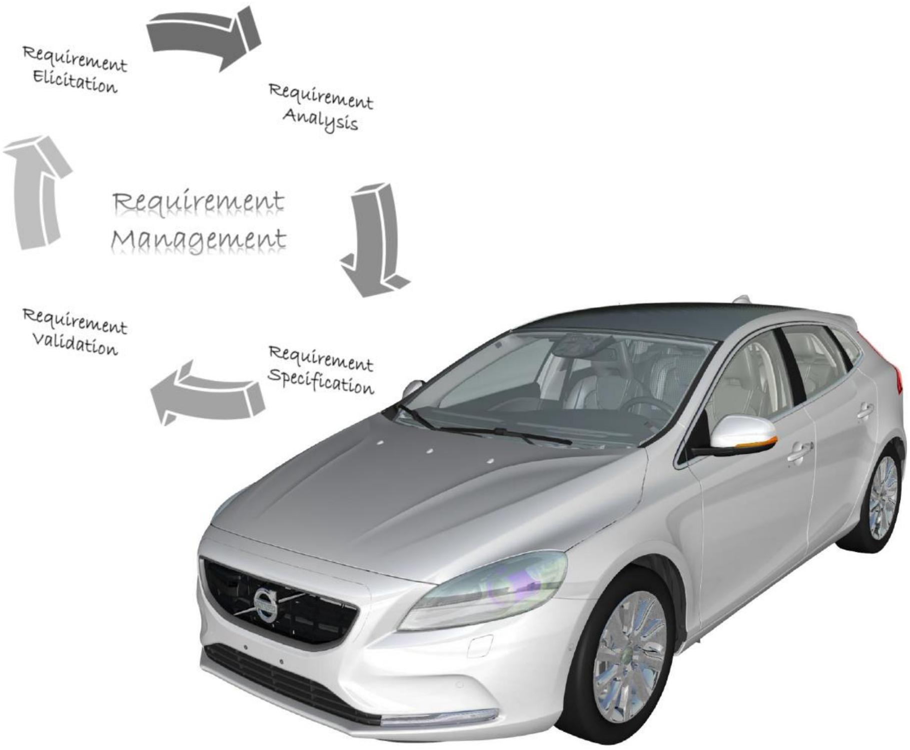

Geometry-Based Requirements

Support requirement owners in connecting and mediating requirements from SystemWeaver to CATIA V5

Final Report

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Preface

The Master Thesis carried out by two students. Jakob Hamilton, being examined at Linköping University by Johan Persson and supervised by Anton Wiberg. Mahmoud Jeresi, being examined at Chalmers University of Technology by Ola Isaksson and supervised by Jonas Landahl. The Master Thesis has been conducted as a case and in collaboration with Volvo Car Group. The thesis work has been done during one term corresponding to 30 study credits. The Master Thesis report exists in two copies, in the name of both universities. The thesis work has been within CAD modelling in CATIA V5, project management, PLM and PDM systems knowledge.

Some of the main contributors at the company has been the supervisors Carl Hansson and Mikael Diedrichs at the CAD & Mechanical Development department. In addition, a main contributor has been the supervisor from ergonomics department, Henrik Thorsén for applying the pilot case on their vehicle luggage compartment requirements and models. From the same department, thanks go to Sara Alpsten, Magnus Jerksjö and Per Stigson for being a part of the interviews and contributors to ideas and solutions. From SystemWeaver department, special thanks go to Urban Dahlberg as supervisor and Andreas Knoblauch, Andy Chan and Hans Löfstrand for help in using and giving perspective in the SystemWeaver software. We would also like to thank Per Bergener, Oscar Rasmussen and Magnus Gustafsson for participating in the interviews as being part of the requirement management process.

Abstract

Requirements of a Volvo car are stored in a requirements management system at Volvo Car Group (VCG). VCG recently implemented a new requirements management system, a system called SystemWeaver. Many different types of requirements are stored in the SystemWeaver software, where the requirements can only be described in text and pictures. However, some requirements are geometry-based, describing some type of shape or measurement in space that the car should fulfil. Geometry-based requirements are stored in Teamcenter and have two components, the requirement text and requirement geometry in the form of CAD-models. The models are used to illustrate the requirement in space. This master thesis examines the possibilities of connecting text-based requirements in SystemWeaver to requirement geometries. The technical aspects are studied as well as the organizational mechanisms of creating and changing a geometry-based requirement. To find a working solution, research relating to the issue gave input to the project. Furthermore, interviews were conducted at different departments at VCG to get insight in the working tasks of requirement management at the company. The project resulted in a concept of a new process, describing the actions of geometry-based requirement management and how requirement geometries should be connected to SystemWeaver. The new concept outlined the logical steps that are required to work with SystemWeaver and geometry-based requirements. The work has laid a foundation on which future studies can be conducted to further streamline management of geometry-based requirements at VCG.

Contents

1. Introduction

This Master Thesis and the research has been conducted at Volvo Car Group (VCG) in Gothenburg, Sweden at the department of CAD & Mechanical Development. Internally at the Volvo Car Group, this project has been done in collaboration with the ergonomics department and the team responsible for the newly introduced requirement system, SystemWeaver [1]. The Master Thesis project has been a part of the Master Thesis course at the Industrial and Materials Science department (course code IMSX30) at Chalmers University of Technology for Mahmoud Jeresi and at the department of Management and Engineering (IEI), Division of Machine Design (course code TQMT33) at Linköping University for Jakob Hamilton. Both courses come as compulsory parts for the fulfilment of both students' civil engineer and master's degrees. In turn the report content for this Master Thesis will be the same at both universities as this was a joint project. As part of the two university courses, research questions relating to the problem definition case has been proposed and addressed in this Master Thesis report.

1.1 Background

Today at VCG, the product development process is performed following a VCG gated methodology. In the early stages of the development process, the most basic properties of the vehicle such as distance between the wheels are set. Further on in the product development process, more specific requirements, sometimes new and sometimes redefined are continuously implemented. The development of a new car at VCG is an agile process, meaning that several design iterations are necessary before the final design of the vehicle is set. Therefore, requirement management systems at VCG must be well adapted to design and requirement updates in the development process. Furthermore, changing one requirement might affect several other requirements, resulting in chains of complex requirement dependencies [2] [3]. A requirement management software is an essential tool to handle such complex structures of requirement data [1].

In the end of 2016, VCG decided to widely implement the requirement management software SystemWeaver in more than only the active safety department at the company [1]. SystemWeaver is a requirements management software developed by Systemite AB, based in Gothenburg [6]. Since Systemite is a small company based within close proximity, it allows for close collaboration and customer adaption to VCG.

There are many different types of requirements being considered in development process at VCG. Firstly, legal requirements are always considered in early stages of development. Furthermore, VCG has a set of Volvo Mandatory Requirements (VMR) which are internal requirements that must be fulfilled. Other types of requirements are being changed and considered during the development process and can be divided in two categories. One is "Attributes" managing how the car customer perceives the vehicle in terms of composition, behaviour and performance. The other category is “Function” regarding the actual functionality of the vehicle. At VCG some attribute requirements of the car have requirement data connected to them in the form of requirement geometries. Requirements described with CAD geometries are typically some predefined physical measurement in the vehicle. The ergonomics department have many such measurements. Some examples include the specific height from the ground to the luggage space opening (see Figure 1) and the space in which the driver is presumed to have his or her head during normal usage.

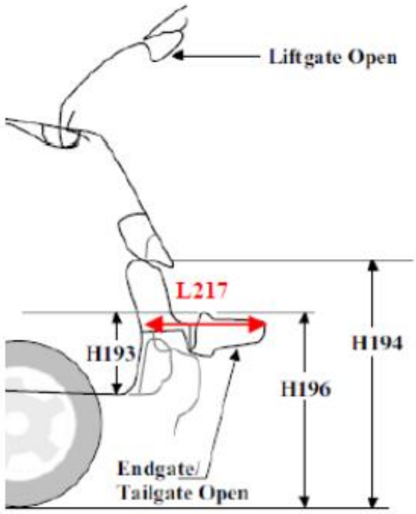

Figure 1. An example of ergonomics requirements in the car luggage area

Presenting the requirements in 3D geometries make requirements easier to interpret and understand when visualized. The requirement geometries are integrated in the PLM database, Teamcenter and easily accessible to designers.

Requirements in SystemWeaver are created in a way that makes them solely text-based. Such requirements, which are only described in text can be problematic as the requirements text can be interpreted differently by different users. A solution to this problem is to describe the requirement further in a geometric model. However, integrating geometric models with SystemWeaver requirements is not possible. Therefore, there is currently no existing solution for integrating requirement geometries in the SystemWeaver software, hence a connection between requirement text and requirement geometry is needed to allow for an agile work flow, see figure below. Since SystemWeaver has been recently implemented no connection exist today. The department of CAD & Mechanical Development is working with this issue aiming at finding a solution. As a pilot case in this Master Thesis, the requirement geometries owned by the ergonomics department will be used to create such a connection.

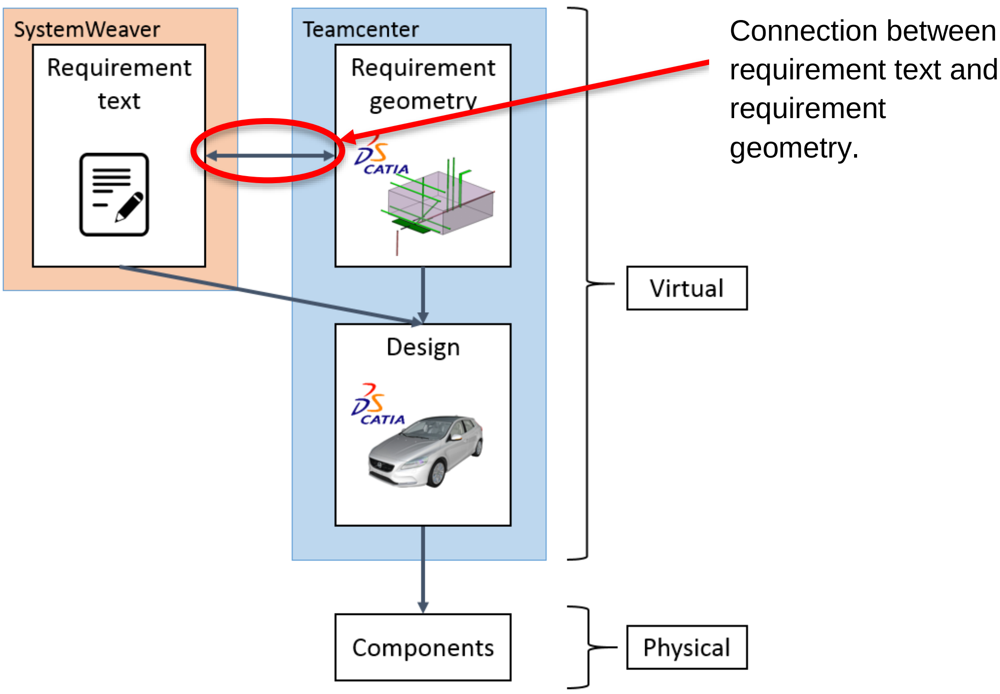

Figure 2. Overviewing relationship illustration. Both text and geometry-based requirements are used in design, and thereafter in physical parts/components.

The working process towards a feasible solution will be done internally at VCG, where employees with insights into the problem will be interviewed. Learnings from this pilot case and this thesis work will then be used for further studies and further geometry-based requirement implementations at VCG.

1.2 Aim

The aim of this Master Thesis has been to support requirement owners in mediating geometric requirement data. The requirement geometry information needed to be connected to SystemWeaver to ensure that requirement information is up to date and to control requirement dependencies.

This was done by the studies conducted during the Master Thesis project, which included a concept planning phase, concept generation and validation phase. The planning part of the project consisted of a data collection part (including literature studies) and knowledge gathering. The second part related to the concept generation, development and evaluation. By theoretically analysing, and in the company evaluating the different concepts, the possibility of implementing these solutions has been explained. Thereafter, all sources of error with respect to evaluation, and opportunities for further development has been described.

To further specify the Master Thesis aim, the following research questions has been posed:

1. What eventual advantages and disadvantages are there with the current requirement management system, SystemWeaver?

2. How can geometry information be connected to SystemWeaver?

3. How can an information flow be created to ensure that the last geometry-based requirement revision is being used with a clear ownership structure?

4. How will a potential solution change the current process at the departments having requirement ownership?

1.3 Limitations and constraints

The Master Thesis project is limited to only consider the practices of the chosen Requirement Management system, SystemWeaver for requirement management at VCG. This also implies the usage of CATIA V5 software as a design tool for creating all geometry-based requirements. Moreover, all the tools and work done should follow the Volvo Car Group's standards, e.g. VCG's CAD standard VCS 5027.

The project is then also delegated to two master students, with a limited time, 30 study credits corresponding to one term full time studies and a budget issued by the stakeholders' departments at the Volvo Car Group.

1.4 Overview of Method

The Master Thesis project can conceptually be understood according to the Ullrich & Eppinger methodology, and thereby be divided into four main parts (see Figure 3), Investigate, Explore, Compare and Validate [7]. These four steps are expected to be completed, and result in the final delivery as explained below. Also the Gantt-chart has been created according to the four parts, see Appendix A. Other sources and information than what is mentioned in the report has contributed to the master thesis project. However, they are not mentioned in the report due to company secrecy and publication reasons.

Figure 3. The main categories in the working process.

1. **Investigate** the chain at Volvo Car Group for how to create, configure and manage geometry-based requirements and how they are implemented in the car development process.

To answer the second and third research questions, a knowledge gathering phase will be carried out. The knowledge gathering phase can be divided in two main parts, internal data collection at VCG and a literature study. The reason for relying on these two parts, is to include the inputs both from an internal point of view but also from a research point of view [8]. The internal data collection will consist of interviews and meetings with the staff at the SystemWeaver department (a department at VCG responsible for SystemWeaver implementation at the company) and with people working with ergonomics and mechanical integration. The purpose of the internal data collection is to get a deeper understanding of the current situation at VCG regarding work procedures and the reasoning behind past and future decisions regarding working methodology. In addition, interviews have been conducted at different departments at VCG. The outcome is to benefit from SystemWeaver functionality. The data from the internal data collection will be qualitatively analysed, to compare their behaviour and usage to what the e.g. users say and think [9].

2. **Explore** and learn how geometry-based requirements are being used and what difficulties exists in working with them together with SystemWeaver.

So, after investigating VCG internally as in the first phase, the second part of the data collection goes into the exploring phase, relying more on literature. The literature studies will be based on research made within requirements management, along with other keywords related to requirement managements systems, PDM systems and PLM. The main key areas in the literature study will also include geometry-based requirements and change management to explore relevant tools for implementing the final concept.

Along with the data collection, a market analysis will be performed, examining the stakeholders and market segments from a requirement management perspective. It also analyses the business strategy and technology mapping to see eventual trends within the field. In addition, the market analysis will consist of a SWOT and PEST analysis classifying the internal and external environment and factors at VCG. All of these tools should then be narrowed down and continued by phase three, compare.

3. **Compare** and use findings from the internal data collection and literature study. Information from the internal data collection and the literature study will be analysed to identify needs and possibilities in managing geometry-based requirements.

Learnings and conclusions from the analysed data will be the main pillar for developing requirements and user preferences for the final concept of managing geometry-based requirements. Furthermore, scenarios of process for changing requirements will be mapped and considered. Since the process of managing geometry-based requirements is complex and requires several steps, the problem definition will be divided and addressed in sub-problems. Concepts for each sub-problem will be generated with brainstorming and morphological matrix and compared in two steps using Elimination matrix followed by Pugh’s decision matrix. Firstly, concepts will be screened from identified basic requirements that are essential to the final concepts. Secondly, the remaining concepts will be compared in respect to user preferences identified in the internal data collection. Finally, the winning concepts from each sub-section are put together as one process which is the final concept. At this stage, the thesis will attempt to answer research questions three and four more by clearly presenting the final solution which should be validated from a user perspective.

4. **Validate** the solutions for the requirement owner to assign a requirement and distribute requirement geometry information to complete requirement validation. The validation should result in acceptance from the stakeholders, mainly the requirement owners, requirement users and the requirement management system department, i.e. System Weaver department at VCG. It is then important that the following aspects get approved:

1. Requirement geometry connection to SystemWeaver including requirement relations and dependencies. In addition, a validation of requirement information management in terms of management of ownership, version and status should be done.

2. Requirement management process including recipient information. In such case the process of receiving, managing and assigning requirements to recipients should be more standardised and clearly defined.

The validation process will be performed with help from user input, thereby the validation process will be subjective as different users may have different opinions [8]. The user input relies on "pilot testing", where the requirement users can test the final concept and validate it. The validation process will therefore be iterative to some extent until the final concept can result in a compromise and balanced solution. However, a final concept will be presented, and developed depending on the time limitation of the project. Especially the working process of requirement management at VCG will be left as a recommendation for future work. The reason is that the requirement management working process is continuously being changed and developed at VCG. Such working process related changes will in turn affect the requirement management process along the way.

1.5 Deliverables

The deliverables of this Master Thesis will include the following for VCG:

- Identified requirements for managing geometry-based requirements stated and used in the evaluation process.
- Proposed solution process for requirements management.
- User guides and methods for implementing the solution concept.
- Recommendations for future work on managing geometry-based requirements at VCG.

The deliverables include a detailed description of the information flow connection between requirement geometry and SystemWeaver. The process should be validated in a smaller scale model and visually presented in a way that is easily interpretable to the stakeholders.

1.6 Overview of report

This section presents an overview and the essence of the entire report. The first section after the introduction is the Theoretical Frame of Reference. The chapter contains relevant theory relating to this Master Thesis case, which is necessary to understand to get a sense of the problem. The chapter puts the problem description and the goal into the right context and begins with an explanation about the requirement process in "Requirement Management". Thereafter the chapter explains the theory and context behind Product Lifecycle Management (PLM) in general, which is then being specified more into Product Data Management (PDM) systems and the correlations to requirement management. Some theory about Geometry-Based Requirement, Change management and Traceability is thereafter presented. The theory is presented at a level where an engineering student or a person of interest should be able to understand and comprehend the theory.

The third chapter contains a Method Theory explaining the theory behind the methodology in more detail. The chapter after is a Pre-Study chapter including a Market Analysis where the thesis project is analysed both externally and internally. Firstly, an external outlook is made in a "Stakeholders and Market Segmentation" and "Business Strategy and Technology" mapping, followed by an internal examination using SWOT and PEST matrices (presented in Appendix). Finally, the chapter goes through functional analysis tools e.g. black box, SIPOC to visualize the main problem and break it down.

Chapter five is the results chapter, which contains all the results that the Master Thesis generated with respect to addressing the research questions and contains the final solution and the validation of it. Chapter six is a discussion reflecting upon the methods and working process. Furthermore, the discussion reflects on the attained results in relation to the theory in the second chapter. An analysis of the results also investigates potential future work and recommendations where findings from this project could be expanded and explored further. Finally, the last chapter consists of the conclusion that is made from this Master Thesis project.

2. Theoretical Frame of Reference

In this section, the theory needed to understand the full report is presented. The theory presented is mainly based on literature study. The section is for the reader to be able to understand and critically analyse the concepts and later on the results and conclusions within this context. The first subsection introduces the general theory in both research and industries for defining requirements and then managing them. That is to later put the research findings about e.g. requirement management into VCG context. In addition, the following two subsections in this chapter presents PLM and some current trends within PLM observed in recent literature. In the next section PDM systems is covered, specifically in correlation to requirement management. This information comes as an introduction for a later presentation about SystemWeaver within the limited context. Furthermore, existing literature on geometry-based requirements are presented, as well as theory regarding traceability in an industry context. Lastly, the foundations of change management in an organization is presented.

2.1 Requirement Management

As defined by Klaus Pohl and Chris Rupp (2015), “Requirements management comprises purposefully assigning attributes to requirements, defining views on requirements, prioritizing requirements, and tracing requirements as well as versioning requirements, managing requirements changes, and measuring requirements” [10]. As previously mentioned, the product development process is conducted according to a methodology. Today, at most firms, the requirements are what determine the specifications of a product. Therefore, before designing a part, a previously set of requirements are decided, which needs to be fulfilled and used as references. The area of requirement engineering, also includes that requirements are identified, communicated and maintained throughout the lifecycle of the product [11]. Requirements are determined according to a cycle similar to the product planning cycle, as illustrated in Figure 4 [12] [2].

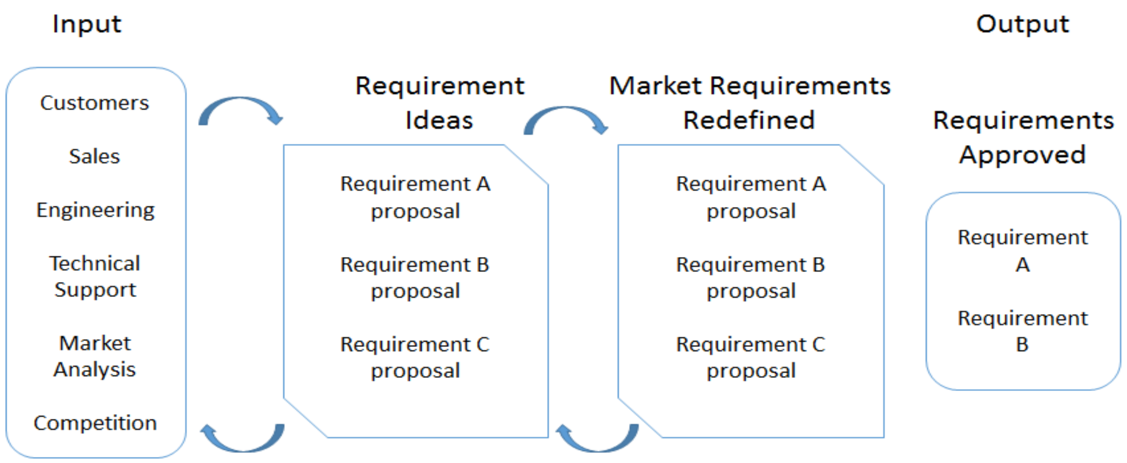

Figure 4. Illustrating a part of the “requirement planning process”.

In Figure 4 it is illustrated how inputs come from what is usually called marketing, along with some technical inputs. In this phase, inputs come in from main stakeholders, e.g. competitors, customers, sales, engineering and market analysis [2]. Thereafter, a set of requirement proposals are presented, which may then be redefined. Both of these steps, but also the last step usually comes in an iterative process at companies, as a result of many discussions in meetings between departments and managers [2]. Some of the requirements then get approved, and most of them changed several times. This requirement setting stage includes some sub-stages such as requirement collection, structuring, classification, assuring consistency and finally documentation as shown below [11].

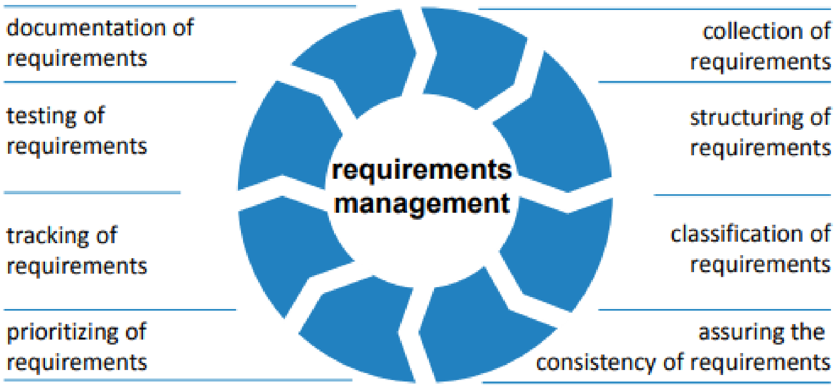

Figure 5. Stages in the requirements management process cycle [11].

After comes e.g. tracking and prioritizing of requirements according to Holder (2017). Nowadays many different requirement management software exists e.g. Teamcenter Systems Engineering, Rational DOORS, Serena Dimensions to support requirement management in shared digitalized environments [11]. In such software, XML file formats have been considered as standards for the requirement information between the different systems [11].

Requirements are generally being divided as functional and non-functional requirements [13]. Usually, functional requirements specify the function or behaviour of a product [13]. Non-functional requirements at the other side specifies how the system should behave e.g. in terms of performance, reliability and usability [13].

The theoretical localisation of the requirements setting, and management process can be shown as in the V-model below [14]. It can then be seen that the requirements come as a second step in the project definition. In the right axis after implementation, it becomes important with verification and validation of both the requirements, and the follow up process of the designers. However, because of much iteration, many stakeholders and sometimes unclear working process, the V-model in reality gets much more erratic and can lead to e.g. unclear requirement ownership structure [2].

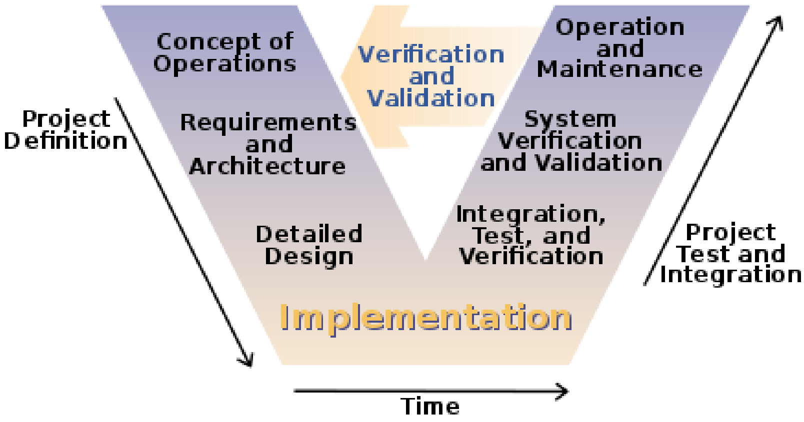

Figure 6. The V-model, illustrating the correlation between project definition and project test and integration in time, as shown in the horizontal axis [15].

It will in this project become relevant to study the working process at the department of ergonomics, in order to analyse the requirement management process [8]. The results are further described in chapter 5, in the empirical context section, where the working process is described as a result of a number of interviews and observations.

2.2 PLM

Product lifecycle management has several definitions in literature, in this report it is referred to as “the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of” stated in “Product Lifecycle Management: 21st Century Paradigm for Product Realisation” written by John Stark [16]. Before PLM was widely adopted, the management of product information was divided by separate processes in different moments in the product lifecycle. For example, product development and product support were often separated in companies, despite the fact that they managed the same product. Companies rarely had an explicit plan for how product information should be managed throughout the product lifecycle [16]. Furthermore, there were no standardised methods of documenting and managing product information throughout the lifecycle. The absence of PLM led to many complications such as contradictory versions of the same document, overlapping networks and duplicate processes. The end result was lost revenue and higher costs [16].

PLM emerged to solve many of the above mentioned problems. Advances in technology also enabled the change to happen. Contrary to the previous methods of managing products, PLM has a holistic approach. In practice this means a complete overview of product information, not only product specifications. PLM includes products and data but also processes, people and working methods. Thereby PLM brings together product aspects that was previously separate creating an important overview [16].

Table 1. Different practices and disciplines involved in PLM [16].

Products	Services	Structures	Activities	Processes
People				Equipment
Skills		**PLM**		Standards
Applications				Practices
Systems	Data	Information	Knowledge	Techniques

In its essence PLM is a process of storing and managing product data throughout the product lifecycle (Figure 7). The PLM process is mainly used to separate the lifecycle stages and work with them separately and then analyse the whole cycle [17]. PLM also has some eventual advantages in shortening innovation lead times and reducing costs [17].The scope of the product lifecycle can generally be described in five stages (see Table 2) [16]. Firstly, the imaginative state where the product is still in the idea stage. Second is the defining stage, specifying the product more closely to a detailed description. In the realisation stage the product is produced and prepared for market. Then in the use/support stage the product is consumed by the customer. Finally, the product will reach the end of its lifecycle and get recycled or disposed by the customer. Another common definition of the product lifecycle is in three main phases: Beginning-of-life (BOL), Middle-of-life (MOL) and End-of-life (EOL), (see Table 3) [16].

Table 2. Five steps describing the product lifecycle [16].

Imagine	Define	Realize	Use/support	Retire/Dispose

Table 3. The three phases in PLM [16]

Phase	Beginning-of-life	Middle-of-life	End-of-life
Description	Imagine/define/realise	Support/maintain/use	Retire/dispose

The responsibilities often vary during the product life cycle. A product is especially difficult to manage in its imaginative state [16]. This is not surprising since it is not yet a physical product. Among other difficulties is the fact that information regarding a product often moves between different departments at a company. Information and responsibilities regarding the product might for instance at some point be relevant to the engineering department while later be of interest to the marketing department. The goals and aspirations of these departments could also be in conflict. Furthermore, product information often travels from one enterprise to another which can often lead to further complications due to differences within the company structures. A major challenge for PLM is to handle all these factors in a consistent matter [16].

A successful implementation of PLM can lead to several benefits. It can reduce the time-to-market as the data management will become more streamlined and time efficient. Another potential benefit is increased productivity as less time and effort is spent on finding, coordinating and controlling product data. It will likely also contribute with better company control and overview since it makes product data more accessible. The ultimate goal of PLM is to reduce product-related costs, increase product-related revenues and ultimately create more value to customers in current and future products [16].

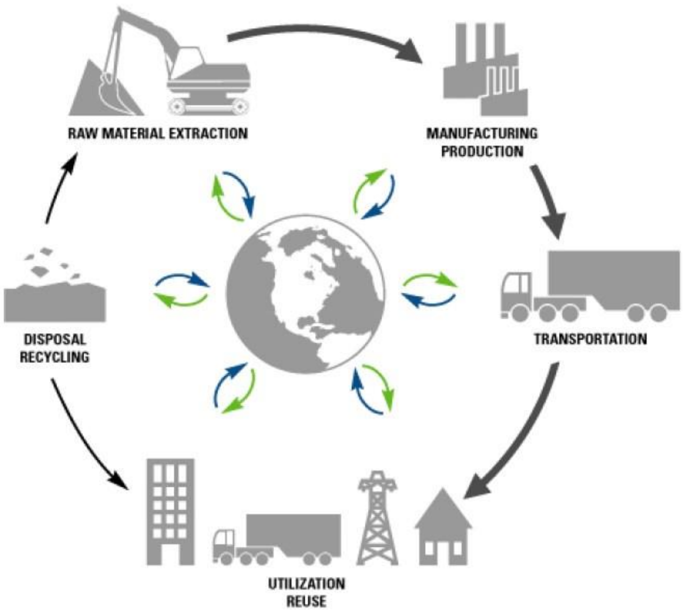

Figure 7. Schematic picture of product lifecycle [18].

PLM has several challenges that is known to have caused problems within companies previously [16]. Loss of control of some or several parts of a product can lead to serious consequences. If control is lost in the BOL it may lead to a delayed time to market or an exceeding target cost of development. A loss of control during MOL may be even more serious as the customer will be directly affected. This could also lead to repercussions to the company image and loss in revenue to competitors. It is difficult to identify the sources of these problems as companies rarely share that kind of information. However, some information becomes public. John Stark (2011) has identified the following problem areas and issues listed in Table 4.

Table 4. Identified problem areas within PLM [16].

Problem Area	**Issue(s)**
Products	Incorrectly, or unclearly, defined products
Data	Data out of control; data in silos; different definitions of data; incorrectly structured data
Processes	Processes not defined; unclear processes; conflicting processes
Applications	Islands of Automation; missing applications, ineffective application interfaces; unaligned applications leading to manual data re-entry and errors
Projects	Project status vague, unclear project objectives; too many projects

Equipment	Machines and software licenses under-utilised or not used
People	Specific skills missing; lack of training
Organisation	Working methods not defined; Differences between the organisational structures on different sites

While the above-mentioned problems can be prevalent in businesses working nationally within one country, challenges become even greater for companies operating globally. For instance, various regulations and conditions in an individual country needs to be considered. Furthermore, companies operating globally needs to provide technical information regarding parts, product and service to many different locations. The launch of a product also needs to be adapted to the global market where pricing could vary substantially depending on country [16]. In summary it can be concluded that PLM is essential to organize data in large industries. Data and information in an organization exists in several different formats, stored in different systems. To support and manage such information, a PLM approach is useful. The underlying knowledge about PLM and how PLM is useful motivates the practicality of this Master Thesis project.

2.3 Current trends within PLM

In manufacturing industry, it is becoming increasingly important to be able to manage large quantities of data. The increasingly large quantities of data in product design is mainly due to technical advancements in Internet of Things (IoT and big data analytics [19]. Consequently, some current trends within the field of PLM can be recognised in current literature. In "Semantic data management for the development and continuous reconfiguration of smart products and systems" the authors propose a new method for developing and configuring smart products (SP) [20]. The proposed approach is called "semantic data management" (SDM), it considers the technical advancements in microchips, sensors and IT technologies [20]. The emerging technologies enables internet-based services to be integrated in the smart product functionality. Mechatronic components and internet-based services are becoming increasingly prevalent in smart products such as self-driving cars. Several competencies are required to develop and configure SPs and such competencies may not always be available to the manufacturer. The authors of "A product traceability and authentication framework for verifying genuine products in the product lifecycle" conclude that three main types of information are necessary in order to develop SPs. The three different types are "architectural information" "component information" and "SP usage information" [21].

The greatest task regarding management is to integrate all of the above-mentioned components in the development of smart products, especially within large corporations [20]. It is especially in this regard that "semantic data management" can prove useful [21]. According to Abramovici et.al no such complete PLM solution where the relation between it services and smart products is fully addressed, exists today. SDM covers the product lifecycle both of the physical product and its virtual component [21]. It is in this context that the term "digital twin" is often used. Digital twin has been previously defined by Glaessegen and Stargel as "digital twin means an integrated multiphysics, multiscale, probabilistic simulation of a complex product, which functions to mirror the life of its corresponding twin". A digital twin can be divided in three main components: physical product, virtual product and the linkage between the two [22]. The virtual product is usually represented in some CAD or 3d modelling software [19]. In "Digital twin-driven product design framework" the authors present a new method for digital-twin driven product design (DTPD).

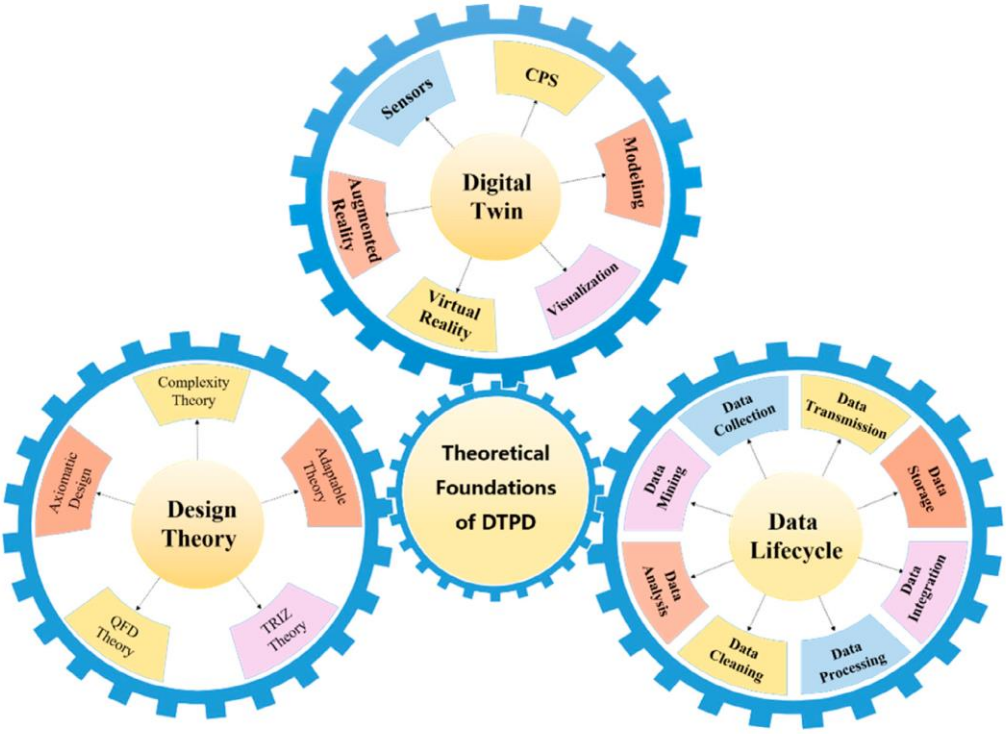

Figure 8. Theoretical formulation of DTPD [19].

The method consists of a closed loop of information between the physical product and the virtual product. The product information should be able to get back and forth between the virtual and physical product. In other words, a two-way transmission process. The method in its whole is a framework that could potentially guide manufacturers in utilizing the benefits of a digital twin in their development of smart products. From a management point of view, it could be very practical to monitor the virtual twin to get important feedback on the development process [19]. In summary, previously mentioned emerging technologies, change the way industries develop their products. Software being used to develop products needs to be adapted to handle smart products. In the context of DTPD, this Master Thesis project is focused on the virtual product, which needs to be adaptable to correspond its physical counterpart.

2.4 PDM Systems

In order to facilitate PLM in an organization, a product data management (PDM) system is needed to store and manage product data [23]. PLM and PDM systems are closely related. However PDM systems principally store files and database-records [23]. The data usually consists of product specifications such as manufacturing details, material specifications and other data regarding the product development such as CAD models [24]. The PDM system works as a repository of a specific product and data relating to that the product can be traced and analysed by stakeholders relating to the product [24].

However, as many various database systems are being used in the process of product development, such as PDM systems and requirement management systems, a lot of problems in interaction occurs [25]. Using only one of the database systems is also difficult as they've been implemented at a company and as they have different functionalities [25]. The problems in interaction very often result in problems with duplicate data and problems in managing traceability [25]. More on traceability in chapter Traceability.

There are many reasons as to why companies use PDM systems. It is effective in regulating and controlling the access that users have in different parts and stages in the product development process. Furthermore, existing components that is a part of a complex product structure can be effectively organized and structured in different classes and subclasses. Similar or identical parts can for instance be classified with specific attributes, making them recognizable. From an engineering perspective PDM systems becomes very relevant when it comes to handling changes and updates that are represented in CAD models. The impact that a design change will have on the involved actors can be administered by the PDM software [24]. For instance, if a specific design change needs approval by another actor.

Part of many PDM systems is what may be referred to as Requirements management applications which are specifically used to handle product requirements. Many different types of requirements may be included such as business, technical, functional, user, process or regulatory [16]. In summary, PDM systems store information. Furthermore, information needs to be accurate and accessible in the right context of a given scenario. To conclude, there are different types of PDM systems storing information. A basic understanding of PDM system is essential in this Master Thesis project since it will focus on the information flow between a requirement management system and a PDM system.

2.5 Geometry-based Requirements

The published material regarding geometry-based requirements handles mostly geometric requirements (i.e. requirements for specific geometries) in design and modelling. In turn, the material handling geometry-based requirement connections was scarce. Some sources handled standards and requirements on modelling and geometries, and how surface data, material data, shape and space data should look etc. [26]. In addition, some articles were exploring the areas of geometry-based parametrization methods for different types of modelling, and how geometries in general can be used for visualisation [27]. However, another study conducted 2017 by Holder, shows a concept of "geometry-based requirement management" implementation in e.g. requirement collection according to their presented cycle stages in Figure 4. Their study proofs the concept of increased flexibility in modelling using geometry-based requirements [11]. In addition, multidisciplinary design optimization (MDO) has been presented in many research articles as a technique for improving concurrent design and engineering [28]. A use of knowledge-based engineering would also contribute in achieving design automation and reuse which has in many companies led to using high level CAD templates [28].

An article related to this subject with the title “Configurable product views based on geometry user requirements”, written by Freddy Fuxin, at that time an industrial PhD student at Volvo Truck Corporation and now active in the field of “Geometry Based Product Information” [29]. The research examines an approach where geometry-based requirements are used to define product views at the company. The paper aims to “improve reuse of geometry by providing relevant geometry-based product information [29]. According to Fuxin (2004) most firms in the mechanical industry relies on so called engineering design processes. Geometry models plays in these processes a main role in e.g. product visualization and modelling and has replaced old physical mock-up models [29]. A problem that occurred in this transition was the lack of digital equivalence in all places, e.g. in the requirement management area this transition to geometry models came very late [29]. That is a result of that most product lifecycle research has been focusing on physical products rather than virtual models, although the big data-driven product development area has increased [30].

In the early phase, the product development process is driven by many ideas and much iteration. Therefore, right geometry-based product information is needed, which also needs to be generalized sometimes to be capable of handling many product varieties and new upcoming product complexities [29]. At the same time model requirements needs to be specific and not only e.g. defined as the model should be flexible and robust [28]. According to Fuxin (2004), the key for success is then to have insight and knowledge to what is the relevant product information which can be used in geometry-based models and be automated and later reused. These models can then be created and viewed in different ways, where some are company defined (e.g. modular structure) and others can be traced back to e.g. functional views [29]. Fuxin (2004) mentions also that such geometry models not only takes a role in redefining requirements (e.g. text based) and product information, but also stimulates for new technical solutions.

2.6 Traceability

Traceability is enabling users to see relationships between software and design artefacts, within and across different systems. It can help users with information on how and why a specific action will contribute to fulfil a requirement. Traceability will also contribute with an insight in the reasoning behind decisions that has been made in the development process previously. As a guarantee of quality, traceability is often mandatory in the implementation of a new standardized process [31]. The lack of traceability could have many negative impacts in an organisation working with development. Ensuring quality is at risk when there is a lack of traceability within the system. Loss of traceability will lead to some loss information. That information could be crucial in decision-making and communication [32]. Research has concluded that systems of traceability needs to be situation-specific, adapted to the specific aims of the context [32]. Traceability is essentially very important as decisions and changes in an organization needs be traceable in order to be understood.

2.7 Change Management

Several models of change management currently exists in literature. A model of explaining change management in an organization is illustrated in Figure 9, it was developed by David Nadler and Michael A. Tushman [33]. It is developed on the belief that an organization can be viewed as a set of several sub-systems. As illustrated in Figure 9, these sub-systems are informal organizations, formal organizations, work and people. Inputs such as strategy, resources and environment goes into the organization, resulting in an output of individual, team and organizational performance.

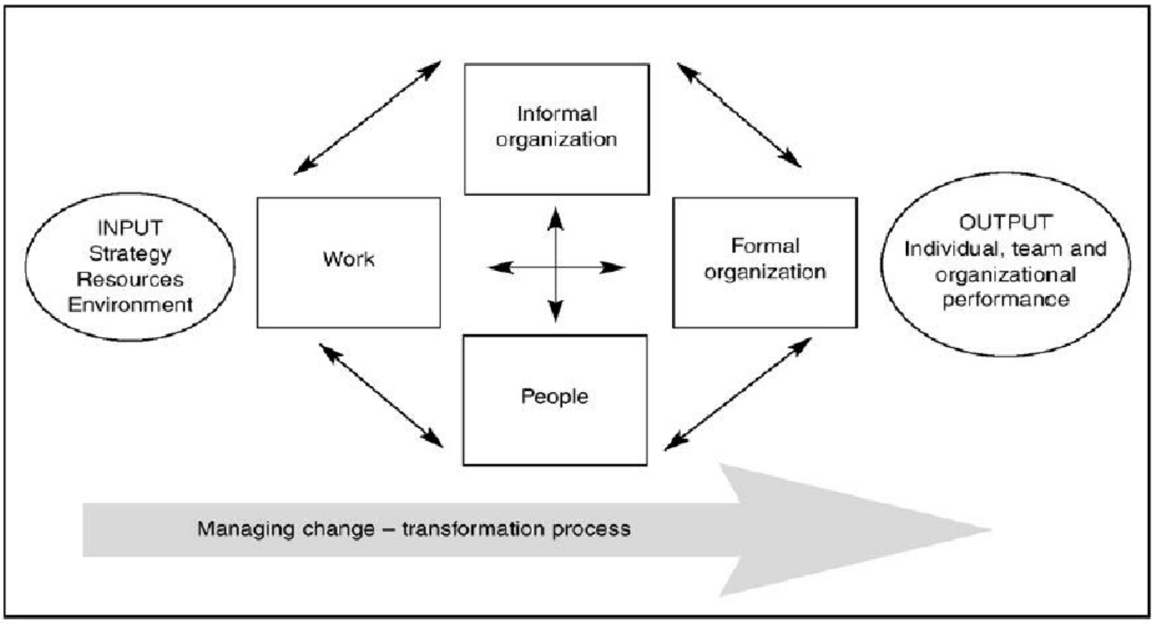

Figure 9.Nadler and Tushman congruence model [33].

Changes of requirements in the automotive industry occurs due to a number of reasons. Stephan Volker and Gabriela Prostean have listed some of these, separating proactive and reactive changes. Proactive changes are made to ensure success on the market upon product launch. Furthermore, changes are sometimes required to ensure a robust design [34]. Design changes should commonly be implemented as soon as possible [35]. Some reactive requirement changes include insufficient or faulty function description of the specification and software or hardware implementations being faulty. In summary, organizational changes are not only a matter of strategy. Practically it is also a result of people changing the way they work and perform tasks, such changes require change management. In the Master Thesis project, working tasks of people working at VCG will be closely examined and changes will be proposed in the final concept.

3. Method Theory

This chapter contains a description and theory of the different methods and tools used in this Master Thesis. The use of each method or tool are also motivated in the context of this Master Thesis project.

3.1 Semi-structured Interviews

One of the most common research methods in qualitative research are interviews [36]. Some important advantages with semi-structured interviews are flexibility and adaptability to the current situation [37]. Furthermore, the interviewer is able to improvise interview questions depending on previous answers. Previous knowledge in the interview topic is often required from the interviewer. A framework for the development of a qualitative semi-structured interview guide is presented in "Systematic methodological review: developing a framework for a qualitative semi-structured interview guide" [37]. The guide was developed in an attempt to create a uniform set of guidelines of how such interviews should be performed. The framework includes five phases that together contributes to the trustworthiness of the study. In this study, interviews will be essential in the data gathering stage since the final concept will rely heavily on the users working at VCG.

3.2 Empirical studies of software practice

Studies of software practice are often qualitative rather than quantitative according to Segal, Grinyer, and Sharp [38]. As software engineering concerns real people in real environments the actors and practitioners must also be studied using the software [39]. Robinson, Segal, and Sharp have put together some findings after carrying out several studies on "the adoption and evolution of software quality management" [40]. Firstly, the team examined effects on introduced software quality management systems. Organisational factors such as customer pressure and market pressure were identified along with individual factors such as charismatic leaders and individual pressure which effect standards documentation within software development [40]. The above mentioned organizational factors are considered in this study since "real people" working at VCG are the recipient of a proposed solution process.

3.3 SWOT Analysis

The SWOT tool is a powerful tool in examining both the current and the future situation in a company and project. The first two pillars in the tool, the strengths and weaknesses focus more on the internal aspects, while the opportunities consider more some of the external aspects [41]. However, the tool as whole, is considered to focus more on the internal environment which is more relevant in this master thesis case [41]. The strengths and weaknesses pose relevant questions like, what could be improved, and should be avoided. It also considers the advantages a company or project group may have, and for example what people the external market sees as your strengths. The last two aspects look e.g. into eventual opportunities and trends that can be spotted. In addition, it is also important to examine how far for example competitors has come, and what obstacles that can be seen [41]. The method will be used to assess and analyse the current situation at VCG in the context of this Master Thesis.

3.4 PEST Analysis

The PEST analysis is to give the big picture of the situation regarding four aspects; Political, Economic, Social (or Socio-Cultural) and Technological aspect [42]. It is mainly a tool for examining the wide perspective of the external environment [42]. Similarly to the SWOT analysis, the PEST analysis will be used to analyse the current situation at VCG.

3.5 Areas of Relevance and Contribution diagram

As suggested in the book “DRM, a Design Research Methodology”, relevant topics of research and examination can be explored using this method [43]. Such relevant topics are summarized in an “Areas of Relevance and Contribution” diagram (ARC diagram). The diagram displays the main topic of examination in the mid circle. The main topic is surrounded by subcategories of topics which are further broken down in smaller categories. Furthermore, the different areas are divided on their importance to a project. The three categories of division are: essential, useful and contribution [43]. An ARC diagram will be of relevance in this Master Thesis to visually map relevant topics of research for the project. Furthermore, the diagram will support in prioritizing different aspects of the project as topics are divided in categories depending on importance.

3.6 Brainstorming

Brainstorming is a method, originally created by Alex Osborn [44]. It is a method for problem solving that can be performed on an individual or group level. It is a creative approach to solve various design problems. A main prerequisite is that the problem or question being addressed is well defined prior to the brainstorming session. In the brainstorming session participants will attempt to generate solutions to the problem. At this stage creative ideas, both realistic and unrealistic are encouraged. Criticism of ideas between participants are to be avoided to create as many solutions as possible. In the following step, different ideas may be valued and prioritized on their ability to solve the problem in a realistic and likely manner [45]. The Brainstorming method is an important tool in this project to creatively address problems in the concept generation stage.

3.7 Black Box

When faced with a conceptual design problem, large amounts of information can become a challenge to manage and put to practical use to the designer [46]. In order to assemble relevant information and construct a new idea of a working solution the black box design method can be used [47]. A black box can be created on the premise that inputs are known, outputs are known and the function is also known. However, the internal mechanisms are unknown. Furthermore, a prerequisite is that the problem is known and well defined. Visually, a black box is set up with a set of known inputs going in to the black box. Inside the box are the internal mechanisms that are defined to the extent that they are definable. Lastly, the known outputs are going out from the black box [48]. The Black Box method will be used to summarize the most important aspects of the problem definition.

3.8 SIPOC Diagram

The SIPOC diagram is a tool originating from the SixSigma methodology [49]. It was developed to identify different elements that is part of a process. The SIPOC abbreviation is constructed of the different aspects of the process that should be considered. The "S" represents the suppliers of the process, the "I" stands for inputs and the “P” is the actual process. Furthermore, “O” is the outputs and finally, “C” stands for customers. These five aspects of the process are typically listed in a table of five columns in the corresponding order [49]. The SIPOC tool will be used to illustrate the requirement management process in a simple manner.

3.9 Scenarios

Scenarios is a method of capturing different use cases or scenarios in which the user may want to interact. Creating use cases is useful to foresee and understand what is required of a process or a product, which enables designers to creatively approach a problem with new ideas. More importantly, it will ensure that designers can identify key interactions required of the product or process. Scenario mapping is particularly useful when different alternatives of interacting may be applicable depending on outer circumstances. Practically, the different scenarios can be visualized to illustrate the different use cases [50]. Different Scenarios has in this project mainly been considered in the concept generation and evaluation process to get a final concept covering all possible scenarios. The scenarios method will be used to consider all possible aspects of the solution process.

3.10 Pugh Decision Matrix

The Pugh decision matrix was developed by Stuart Pugh. The matrix has been further developed and applied for concept screening and selection by Karl Ulrich and Steven Eppinger [51]. The method is developed to compare different product concepts against each other in the relation to different selection criteria. A column of selection criteria and a row of concepts results in a matrix where concepts are compared on each selection criteria. The different concepts should be compared on the same level of complexity and evaluated objectively. One concept is usually selected as a reference representing an approximate standard. The other concepts are rated in relation to the reference, either with a + (better), - (worse) or 0 (same level). The selection process results in a net score, where concepts can be compared in rank. The Pugh Decision Matrix method will be used to evaluate and compare different concepts objectively in the concept generation.

4. Pre-study

This chapter contains the preparatory work that was done before the development of concepts was performed. Firstly, a mapping of the different stakeholders of this project is performed, along with Business Strategy and Technology mapping found in Appendix C (Business Strategy and Technology Mapping). Furthermore, a SWOT and PEST analysis has been conducted presented in Appendix D (SWOT Analysis and Appendix E (PEST Analysis. The next section called “Methods and Software for geometry-based requirements”, is a summary of the software being used for geometry-based requirements management, to fully understand the circumstances at which the deliverables of the project are aimed. Following this, the different processes to manage and change geometry-based requirements are presented. After comes a brief presentation of how the ergonomics department works with requirement geometry. A geometry-based requirements model was created within the project, it is presented in the following section. The model was created within the project to gain understanding of working with such models. Lastly comes a functional analysis, where gathered data is analyzed using different tools to identify the preconditions and requirements needed for the concept generation phase.

4.1 Stakeholders and Market Segmentation

Identifying the stakeholders and market segments gives the opportunity for an organization to find and classify different competitors as well as customers. With that identified, it becomes easier to put targets and focus on specific market segments and stakeholders.

As this is not an identification of the stakeholders of an organization, and rather for a process solution, the main stakeholder segments are defined in terms of partners, customers, providers and suppliers and owners. The owners are considered to be the development team itself (CAD & Mechanical Development department), who leads this project and contributes with the development of it along with the customers. The customers in this case, are the internally affected departments. In this case it is the ergonomics department along with other requirement owners at VCG. A group considered to be the end users of the final concept are the designers as being the main users of the requirements. What can be considered to be a both partner and provider is the SystemWeaver department working with SystemWeaver implementation and learning at VCG. Therefore, the suppliers, becomes the providers of the used software, so mainly Dassault Systems (for CATIA V5), Systemite (for SystemWeaver) and eventually Microsoft (for eventual links to Excel) [52] [6]. All of these can be put into different market segments and categories as in Figure 10.

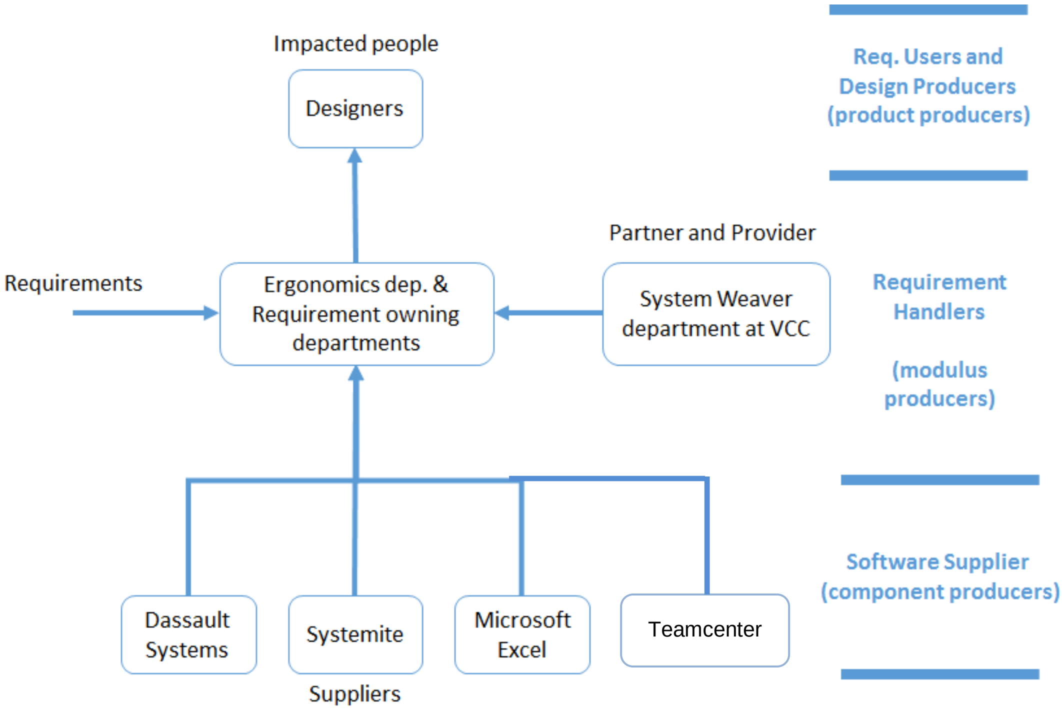

Figure 10. Showing the correlations between the different stakeholders as well as what can be seen as being different segments. SystemWeaver department at VCG provides with learning and tools for implementation at the company.

In the column to the right in the figure above, the different segments in this chain can be seen. It can be said that the software suppliers are the component producers (e.g. compared to a physical product). Then the ergonomics department along with the SystemWeaver department are the ones managing and taking care of the requirements, both as owners and publishers in the requirement management system. They can therefore be seen as modulus producers which will lead to the final process solution that can be used by the designers.

4.2 Methods and Software for Geometry-based Requirements

This section is a presentation of the methods and software that is currently being used at VCG in relation to geometry-based requirements. The methods and software presented is based on several interviews with people working at VCG. The main contextual aspects presented in this section are SystemWeaver, CAD models at VCG, Requirements & Ergonomics and finally a geometry-based requirements model. The first subsection present SystemWeaver in more detail than what is mentioned in the background. The next part gives an overview of how the requirement management is being conducted at the Ergonomics department, and how the requirement geometries eventually get connected to CAD models and templates. Finally, a brief overview of a geometry-based requirements model is presented.

4.2.1 SystemWeaver

SystemWeaver is a requirements management system created by Systemite AB based in Gothenburg, Sweden [3]. Within its PDM solution, the software has an integrated

Requirements solutions module. The Requirements solutions module includes several tools such as authoring and specifying different attributes of a requirement. Furthermore, SystemWeaver claims to have impact analysis, version management, and document generation, attribute driven specification and configuration to fit customer needs within the Requirements solution module.

VCG is currently implementing the SystemWeaver requirement solutions on a wider scale, expanding to more areas than active safety. The implementation was done gradually as different types of requirements were processed and translated into the new system in the year of 2017 [1]. Some of the main advantages and disadvantages with SystemWeaver according to Dahlberg (2018) are presented below.

Advantages:

- Highly configurable and customizable and supports rapid changed/updates.
- Supports ISO 26262 ensuring complete traceability within the software.

Disadvantages:

- No integration with geometry models.
- Server setup currently not scalable - number of users limited.

Figure 11 showcases the SystemWeaver software. All requirements of a car project are listed in the tree structure outlined in the picture. The requirements are divided in different subsections, where attribute requirements is one subsection. The attribute requirements are then further divided in smaller subsections. In Figure 11, the ergonomic level 1 requirement is cascaded. This level is further categorised down to the actual requirement. An overview of the requirement is displayed on the right hand side. The overview consists mainly of the most relevant data describing the requirement and its purpose. Other relevant data such as requirement status and requirement recipients can also be viewed by changing view in the roll down menu on the top left of the overview window.

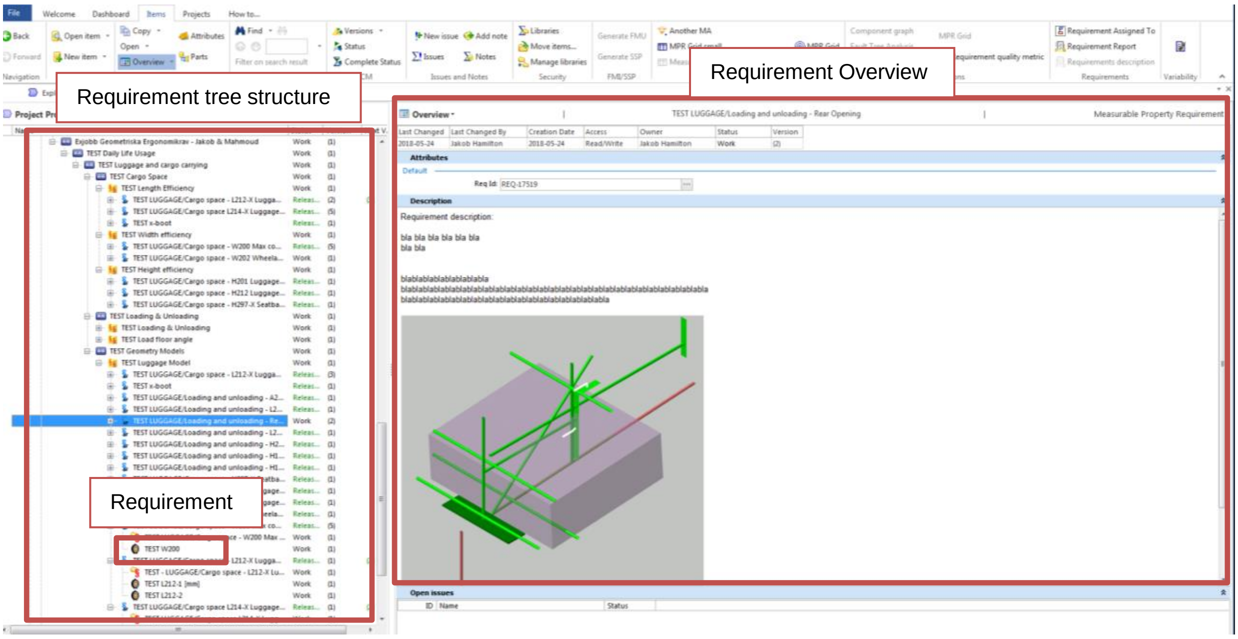

Figure 11. The SystemWeaver Software [54].

It is in the above mentioned way that requirement owners and requirement recipients are able to access and modify requirements in SystemWeaver. A requirement update is generally saved in a new revision, indicating that changes to the requirement has been made. Furthermore, old revisions can be traced and compared to newer ones to get and overview of the development process.

4.2.2 CAD Models at VCG

CAD models play an important role in many of the car development stages at VCG. An overview of the process in illustrated in Figure 12. In an early stage of development called the “Concept” phase, rough models are created to showcase the fundamental measurements and properties of the car [8]. As the development process moves on further into the “Engineering” phase, more detailed parts of the car geometry are modelled, which are continuously updated as new requirements on design, and aesthetic features are implemented [8]. In the engineering phase there are a total of seven “engineering blocks”, different subsections of the car illustrated in Figure 12 by different colours. After an agile development process in the engineering phase, the final design of the vehicle is decided in the “Part” phase and the final parts are modelled.

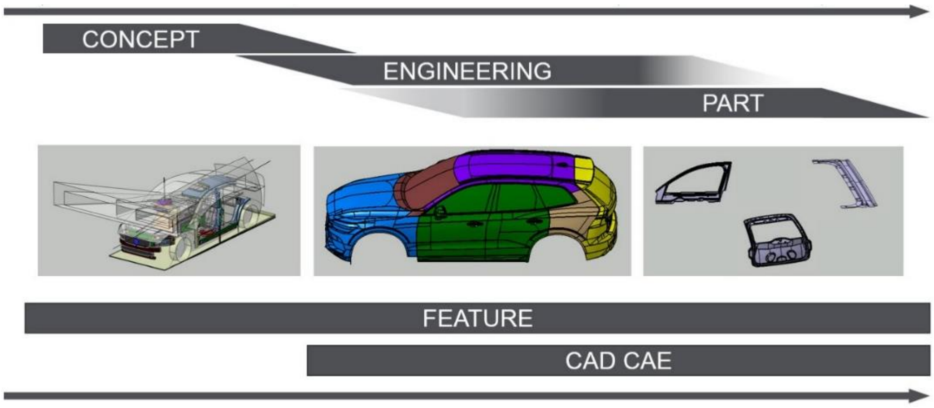

Figure 12. The working process in car development related to CAD models.

CAD models at VCG are created in the CATIA V5 software and most models are created according to a predefined methodology. In order to streamline the creation process and the product development, the department of CAD and Mechanical Development has created what is known as CAD Templates [8]. CAD Templates are a part or product structure in CATIA V5 where certain inputs, outputs and reference geometries are predefined and structured in a standardized way.

Standardizing the creation of CAD models in this manner comes with several benefits. For instance, the CAD Templates are modelled in accordance with the Flexible Modelling Guidelines which allows for an agile product development process where inputs and reference geometries can be redefined and updated over time [8]. This becomes a vital feature since the car consists of several models that need to coexist and relate to each other in the modelling structure. If a specific measurement in a CAD model is changed it might affect several other models which in turn also need to be updated. Furthermore, the flexibility of the models enables them to be reused and give input to future vehicle programs [8]. The predefined model structure has other benefits. In the case of one designer handing over his model to another there will be a common understanding of the model structure and design. Models can be very complex and difficult to interpret and the standardized way of creating them can save a lot of time.

Apart from designing specific components, CAD models have other applications in the development process. One is to verify geometry-based requirements. Geometry-based requirements have previously only been represented in text at VCG. However, as many physical requirements and measurements may be difficult for a designer to understand and interpret visual representations in the form of CAD models can be utilized. Geometry-based requirements can be put together in a model that is designed in accordance with the CAD Template methodology. With the CAD template properties, the requirement model can be placed in the correct design space and the geometry-based requirements can be verified visually by the designer [8]. Such a model has been created as a part of this Master Thesis, which has been designed to illustrate geometry-based car luggage requirements, see Figure 13. A complete description of the model is in chapter 4.2.4.

4.2.3 Requirements & Ergonomics

In this master thesis, the pilot case when it comes to requirements is limited to ergonomics requirements. More specifically, the requirements are related to a set of ergonomics car luggage requirements (see 4.2.4). In this case, all of the requirements are defined as measures and thereby parameters (see Figure 1). That means there are only parameters in the form of lengths, such as the length of the vehicle luggage compartment, or the height of it. Here, it is true that a lot of requirements for example come from marketing, but some of them also come internally, mainly from testing by the ergonomics department [2].

However, as previously explained, the situation today is complex and therefore they need concepts and solutions. The concepts should both be related to how to connect their new requirement management system SystemWeaver to geometry-based requirements, but also related to their working process [8]. One issue here, lies in that when a requirement is being approved, it is being distributed in several ways [2] [55]. In some cases, the requirements are therefore both uploaded to the requirement management system, SystemWeaver, and sent to the designers and other users via mail for example. Sometimes also other sources of distribution exist. It becomes then difficult to follow up whether the correct requirements are being used or not, especially when an update or revision comes up. That is because, the ergonomics department cannot ensure that the updated requirement has been used, as the requirement may have been updated in the PDM or requirement management system, but not in the document sent to the user. Then the failure and wrong specification follows until a later stage, when it becomes much more expensive and difficult to make changes.

4.2.4 Geometry-based requirement model

A geometry-based requirements model was created in order to get a better understanding of the requirement process. The model created in CATIA V5 is intended to be used by both designers and people owning the requirement at the ergonomic department in this case. The area of the car for the model is constricted to the luggage area. The requirements in the model were represented in different geometric shapes. Some as a set of measurements floating in space in the form of tubes, others in the shape of boxes to describe a 3D volume (see Figure 13. The Ergo Luggage model). More information regarding the model and its intended use can be found in Appendix F (Ergo luggage model).

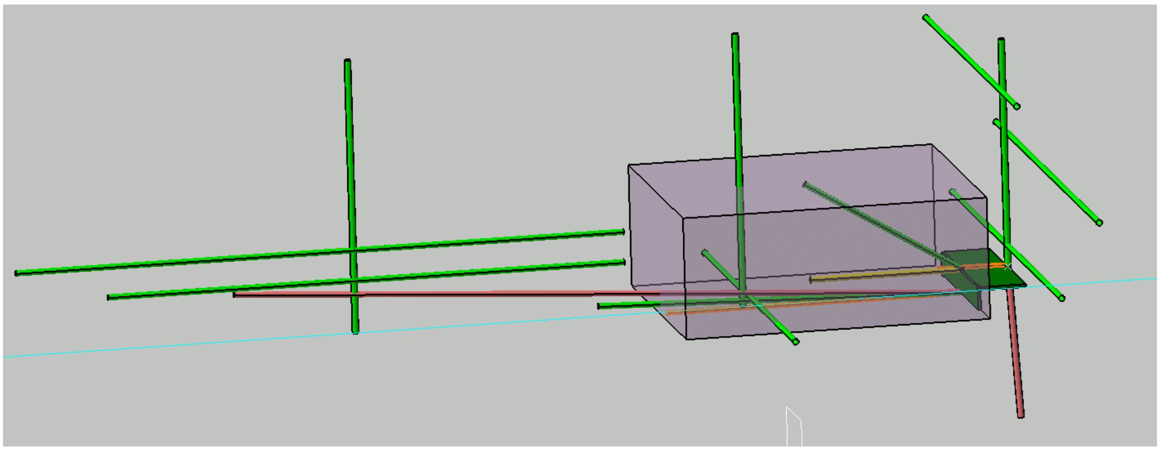

Figure 13. The Ergo Luggage model.

4.3 Processes for Geometry-based Requirement Management

In this section the different processes conducted at present to change geometry-based requirements are presented. The processes are presented as a result of interviews with people at VCG involved in the processes. The chapter is divided into three subsections, Requirement Management Process and Actors, Requirement Owner Process at Ergonomics, and finally Requirement Recipients. The first subsection gives an overview of the process and how requirements are distributed to requirement recipients and users. The last two subsections present in more detail the requirement management process, and how the work with requirements gets done.

4.3.1 Requirement Management Process and Actors

An attribute requirement at VCG is managed and passed along by several different actors before it is implemented in the actual vehicle design. Firstly, the requirement is created and administered by the requirement owner. The owner determines the specifics of the requirement with all the necessary data that is needed to successfully implement and verify the requirement. Once the attribute requirement is created it is typically assigned to its appropriate person or department which is the requirement recipient, illustrated in Figure 14. The specifics of the requirement determine the recipient. Requirements with fundamental properties of the vehicle is typically received by the "Concept" department. Many other requirements are received by the seven engineering blocks. Finally, some requirements will be received by a PSS (Product System Structure) area. PSS areas are smaller subsections of the car involved in the "Part" phase of development.

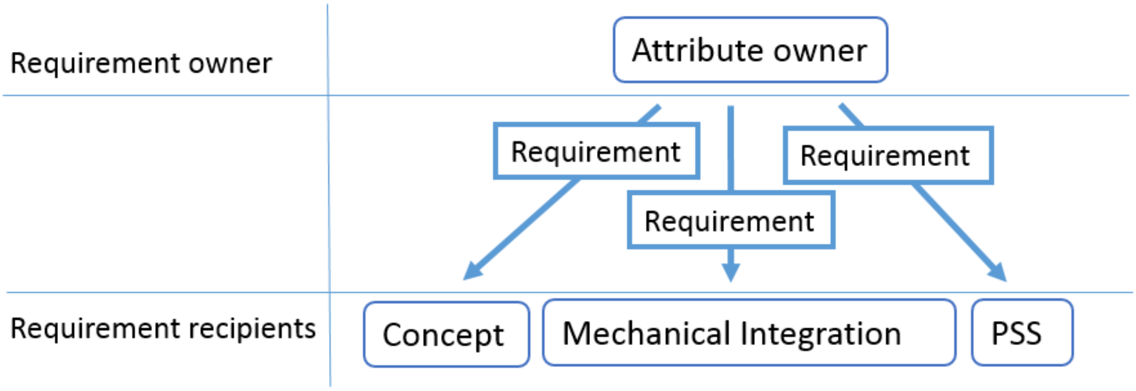

Figure 14. Requirement distribution, meaning requirements are sent from the attribute owners to the concept department, engineering blocks and different PSS areas.

4.3.2 Requirement Owner Process at Ergonomics

The ergonomics department owns and manages a large number of attribute requirements. In the early stages of development referred to before as project start (PS), the ergonomic requirements are managed internally within the ergonomics department. [2]. As presented by the ergonomics department, all ergonomic requirements are gathered in an internal list at the ergonomics department [2]. The list contains all relevant requirements and a brief description of their respective function [2]. Requirements will then be distributed to the development teams in different batches during different phases of the development process.

In the beginning of the car project, requirements are managed internally within the ergonomics department [2]. Some requirements are solely text-based while some have a geometric model connected to them. Today the requirements in these batches can be distributed and assigned in many different ways as has been previously explained, and when being assigned the requirement users can receive irrelevant requirements because the requirement owners do not always know who should be the recipient. The figure below is a conceptual illustration of the current requirement working process at the ergonomics department.

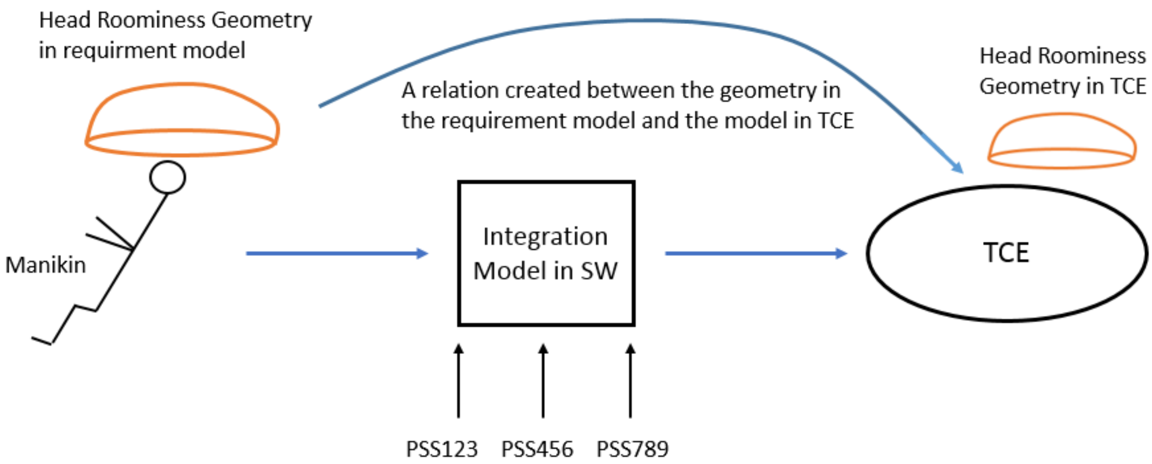

Figure 15. Illustration of the connection between the requirements in e.g. ergonomics requirements model (head roominess geometry illustrated by a helmet), the integration model in SystemWeaver, and the requirement geometries in TCE.

After this phase, all requirements are inserted in SystemWeaver. From SystemWeaver, requirements will be assigned to the destined department or block.

There are generally three types of requirements, Product System Structure (PSS) requirements, attribute requirements and design requirements. PSS requirements relates to the functional components of the vehicle and its design. Attributes relates to e.g. parametric requirements such as ergonomic requirements. Finally, design requirements relate to the outer physical appearance of the vehicle. As requirements are assigned, some will be assigned to the appropriate block and some will get assigned to the corresponding PSS area. This is dependent on the nature of the requirement as some might require collaboration between several actors while some will get fulfilled by one PSS alone. As these requirements are fulfilled they are ready for confirmation where they are set in a formal meeting.

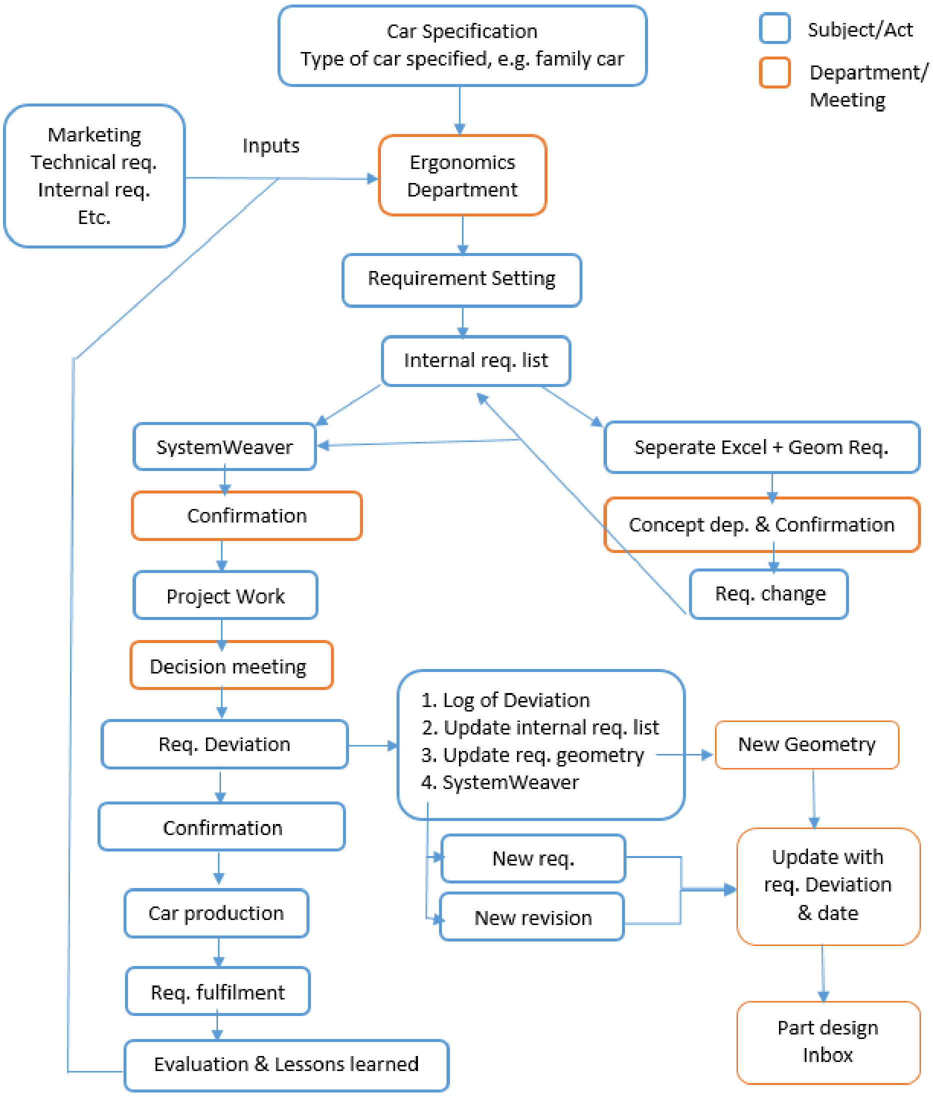

Figure 16. Conceptual illustration of current working process.

Following this, some changes can still be made to the requirements and they will in that case be referred to as deviations rather than an update or just changes [2]. A deviation of a requirement is processed in a specific manner. On a decision meeting the decision of a deviation is taken with both requirement owner and requirement recipient present. The requirement is later on being updated in SystemWeaver, either by the creation of a new requirement or by updating the revision depending on the specific circumstances of the requirement [2]. Furthermore, the requirement needs to get updated in the internal list [2]. This change might also affect requirement geometries which in that case is also updated. Along with this, when the affected requirement geometries have been updated they are being resent to the right PSS or block. The ergonomics department, then also have an internal excel sheet, where they log all the requirement deviations that has been done [2]. That is for the sake of documentation, and continuous learning.

After the process of managing deviations and implementing changes, the requirements goes through a confirmation stage where production readiness is confirmed for all cross-functional activities. Once all requirements are fulfilled, a lesson learned document is established. The document consists of useful insights that will give feedback to the next development [2].

Requirement owners often send out personal emails to individuals informing them about requirement geometry updates [2]. Sending personal emails is a time consuming task that requirement owners wishes to avoid in the future. Furthermore, requirement owners often open designs to check that the requirements are fulfilled. There seems to be a general uncertainty of when requirement updates are properly received and implemented after being sent.

4.3.3 Requirement Recipients Process

The receiving of requirement is carried out in different ways depending on the department. According to Per Bergener, designer in the concept phase of the vehicle (2018), the Concept department sends an excel sheet to the requirement owners with the requirements they need to fulfil their work. Once the correct requirements are received, the Concept department manages and updates the requirements in the excel document throughout their development process. Since requirements in this phase is usually very similar, the excel matrix is applied on all car projects. [56]. The requirements are finally verified by the requirement owner.

Some of the engineering blocks works in a similar manner. Oscar Rasmussen is working with the integration of the vehicle after Project Start (PS) in one of the engineering blocks. He executes and leads the compatibility process and verifies geometric requirements throughout the engineering phases. The people working at his department, gathers all of their requirements in a requirement checklist [57]. Inputs from the requirements is then managed in CAD template models. Some models have custom made parameters to control specific requirements. Therefore, much of the requirement work is made in CAD through visual inputs from reference geometries. Rasmussen does not have any personal interaction with SystemWeaver. The SystemWeaver process seems to be managed by the requirement owner. Similarly to the Concept department the engineering blocks are not responsible of verifying requirements.

Verification of requirements managed by engineering blocks is typically verified by either the attribute owner or a PSS department [57].

An interview has been conducted with people working with mechanical integration in early stages of instrument panel development in the vehicle [58]. Their work involves many geometrical requirements. All the geometric requirements requisite to his department is gathered in an excel sheet, similarly to the above mentioned examples. The excel sheet is a Master Checklist to keep track of the status of the many different requirements and their implementation. Different requirements are implemented at different times of the development process, which is also reflected in the excel sheet. The actual geometries are gathered in a specific folder in Teamcenter. Designers can access the folder and view the geometries in CATIA V5 in order to visually verify requirements. There is some uncertainty of who is responsible for verifying the geometric requirements. The responsibility lies either on the requirement owner or the recipient of the requirement. However, uncertainty causes some requirements to be left unmanaged at times. Such forgotten requirements will eventually be brought to attention, often later in the development process. Another mistake that commonly occurs is that both the requirement owner and the requirement recipient sometimes do the same work on requirements since there is a lack of communication stating who should do the work.

4.4 Functional analysis

The tools that were used in order to get a deeper understanding of the problem and the several functions are presented in this section. Firstly comes the Areas of Relevance and Contribution diagram, then comes the black box tool which was used in order to get an overview of the main function. Lastly the SIPOC tool was used, as a more detailed tool in order to finally end up in a requirement list which in the end can be used as a check list for validation and customer needs fulfilment.

4.4.1 Areas of Relevance and Contribution diagram

The ARC diagram (see Figure 17) outlines the identified important aspects of this thesis project. Some aspects are examined in the literature study, others such as information communication are examined using various methods. Furthermore, the topics in the diagram are divided according to their importance to the Master Thesis project. The division consists of three categories. Beginning with the most important topics the division consists of: essential, useful and contribution.

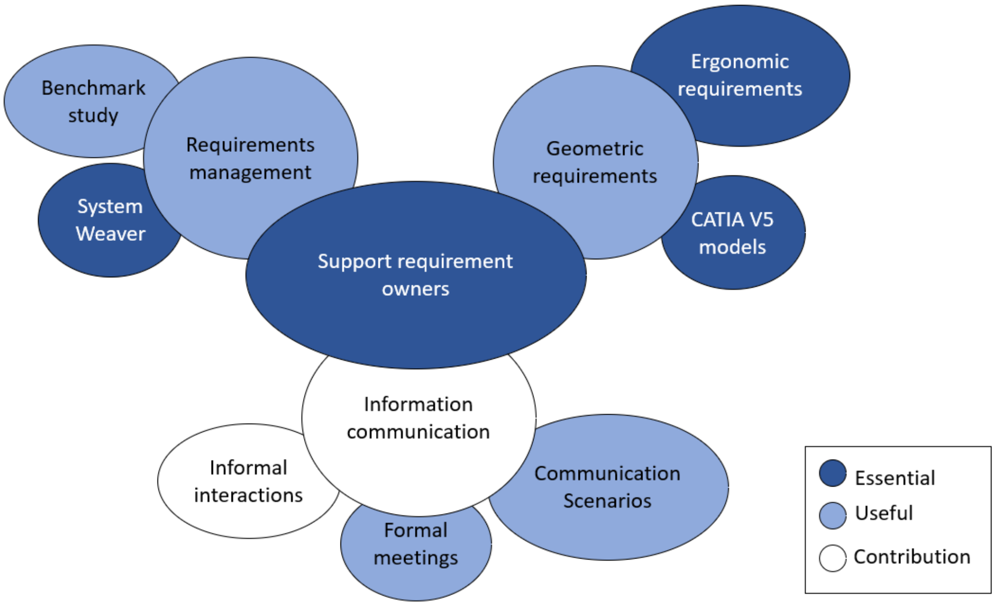

Figure 17. Areas of Relevance and Contribution diagram

4.4.2 Black Box

Here, the black box tool was used in order to direct the project group towards the main function which is stated in the box. Along with the main function, the main inputs and output are stated. When defining the inputs, usually the time aspect and other circumstances are also defined as inputs. However, in this case the inputs are not dependent of any time aspects or other circumstances.

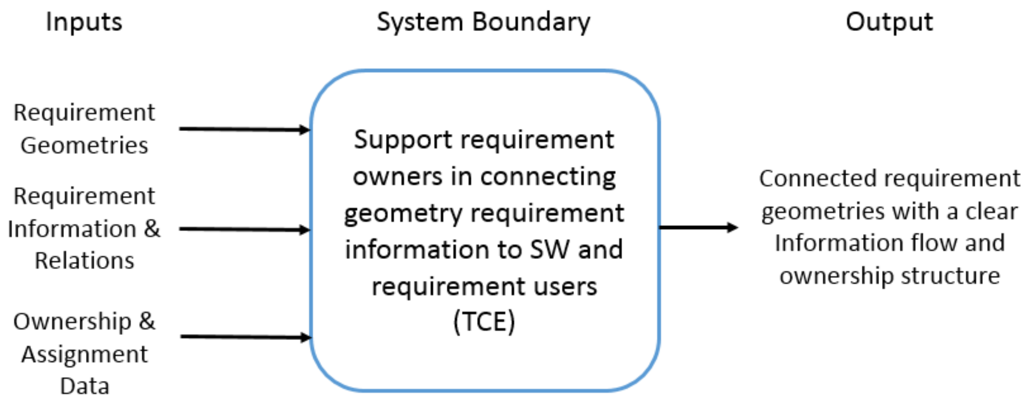

Figure 18. Black Box, showing inputs, main function and output.

As can be seen in the figure above, the main inputs are the Requirement Geometries, Information & Relations, and Ownership & Assignment Data. All these inputs pass then through the main function to get the output with connected requirement geometries in SystemWeaver and Teamcenter Engineering, TCE (where the geometry-based requirements can be loaded from Teamcenter). This includes a clear information flow and ownership structure. The information flow needed, mainly contains information about requirement and parameter relations to know their dependencies as in e.g. integration models. The ownership structure then comes as a result of the input related to Ownership & Assignment Data. This is based on that when a requirement is being received it should have a clear owner and be assigned to clear recipients. In most cases today, the problem is not with the owners as it is a part of their job to own requirements [2]. The most common problem is in not having a clear recipient, instead the requirement owners just send a huge list of requirements to a lot of departments and stakeholders [2].

4.4.3 SIPOC Diagram

To understand the process of geometric requirement management at VCG, a SIPOC diagram was made (see Table 5). It was constructed using analysed data from the interviews. As can be seen in Table 5, the requirement owners are the suppliers in this model. The inputs to the process are obviously requirement geometries but also requirement information and requirement owner data. The fundamental process can be described as "Connect geometry requirement information to SystemWeaver" and "Connect geometry requirement information to TCE" which has been conceptually described previously in chapter 4.3.2. The process results in the outputs seen in Table 5. Finally, the customers are seen in the last column. It should be noted that in some cases as the one of this study, the supplier and the customer can be the same person. At the ergonomics department the requirement owners commonly are also responsible of verifying their own requirements. For the sake of understanding the process however, it is important to differentiate the two different roles.

Table 5. SIPOC diagram of the geometric requirement management process

Supplier	Input	Process	Output	Customer
Requirement owners Designers/Users Decision meeting/ Project leaders	Requirement geometries Requirement information (version, status, & recipient, relations) Requirement owner data	Connect geometry requirement information to SystemWeaver Connect geometry requirement information to TCE Ownership management Information management (version, status, & recipient, relations)	Requirement geometry version confirmation Geometry requirement owner confirmation Geometry requirement to correct recipient Geometry requirement status transparency Connected requirement geometry with clear relations	Requirement verification responsible Designer Decision meeting/Project Leaders

4.4.4 Requirements of final concept

The following list is a set of sub-problems that the final concept should solve. The requirements are gathered using information from interviews with different stakeholders and actors working at VCG. To clarify, these are the requirements for the actual process of managing geometry-based requirements. The information has been analysed and interpreted in the Black Box and SIPOC diagram, leading to a set of requirements for the final concept. The corresponding requirements and wishes for each sub-problem can be further found in the elimination and pugh-matrix in the concept evaluation chapter.

- Connection between requirement geometry and SystemWeaver, to synchronise requirement information including requirement linking as an own sub-problem. The requirements for the connection are requirement information synchronization, general adaptability and usage of available and standardized tools at the company. The linking problem requires direct linking, general adaptability at VCG, two directional linking (from SystemWeaver to Teamcenter and vice versa) and also usage of available and standardized tools at VCG.

- Clarification of requirement management process in terms of:

    - Revision update management and traceability, describing a standardized way of handling revision updates and requirement changes and deviations. It is also important to be able to trace and find the history of requirements and previous revisions to e.g. see previous values. The requirements set based on interviews are that each link should reach to correct target or revision, copies of data needs to be avoided, a history trace should be possible and with direct linking (directly from e.g. SystemWeaver to Teamcenter without additional steps to be made).

    - Requirement ownership structure. This includes a clear structure for who should own the requirements and models. Should it be the requirement owners or requirement recipients, or depend on time e.g. before and after project start. The requirements here are that requirement changes only can be done by the right people along with avoidance of requirement deviations from recipient side (only to be done by requirement owners).

    - Requirement recipient information, how the recipients should get information of requirement changes. Previously personal contact has been the main way. The requirements for this sub-problem are that a clear notification should occur, the solution should decrease the workload, it should be possible to access and trace history of notifications. In addition, requirement information should be easily interpretable.

    - Requirement verification responsibility, i.e. should the requirement owners be responsible for verification or the recipients as they verify while using the requirement geometry models. The important requirements are here that verification can be checked and that correct verification of requirements can be ensured.

5. Implementation and Results

The results chapter presents the findings of the project based on the Pre-Study and the tools used there. The chapter begins with concept generation, where the complete process of managing geometry-based requirements will be addressed. In the concept generation, a separate generation phase for each sub-problem will be carried out. This is followed by a concept evaluation phase and summed up with the final concept. The final concept section consists of a concept validation and concept description and impact.

5.1 Concept Generation

The main problem defined in connecting geometry-based requirements to SystemWeaver to have a continuous information flow, can be described in three different scenarios as have been understood from the interviews and been brainstormed. The connections can vary according to these scenarios which are, requirement setting, requirement change in both SystemWeaver and requirement geometry (and in turn in TCE), requirement change in one side (either SystemWeaver or requirement geometry).

<u>Scenario 1: Requirement Setting.</u>
Example: The height requirement H201 in the vehicle luggage compartment is set to be 100mm from ergonomics (set in SystemWeaver). The requirement is then set to that value in the requirement geometry, and uploaded to Teamcenter. This means an action and work is done once in SystemWeaver and TCE. A connection or link is made once at both places.

<u>Scenario 2: Requirement Change in Both SystemWeaver and Requirement Geometry.</u>
Example: The height requirement H201 is reduced to 90mm as 100mm is difficult to reach (decided in e.g. decision meeting). A new revision is created in SystemWeaver with the updated value. A new revision is also created in the requirement geometry with the new value, however no new link is required as the links goes to subsections and not to specific requirement revisions (as will be described as a concept later).

<u>Scenario 3: Requirement Change in One Side.</u>
Example: A description change needs to be done in the requirement description in SystemWeaver. Then a new revision needs to be created in SystemWeaver, but not in the requirement geometry as the geometry does not change. The requirement geometry only gets changed when the requirement value is changed. As in scenario 2, the links are not affected here either.

The existence of different scenarios has in the concept generation and idea gathering been important in order for the final concept to cover all possible situations. The final concept solution will be a sum and merge of the final concept for each sub-problem. The master thesis problem has therefore been divided into the connection problem between requirement geometries and SystemWeaver, linking between Teamcenter and SystemWeaver, Traceability

& Revisions, Ownership Structure, Recipient Information, and Verification Responibility. Every evaluated solution in each of these will form the package for the final solution.

5.1.1 Connections and links between requirement geometry and SystemWeaver

As a result of the three existing scenarios, a concept generation for the connection problem has been mainly based on the pre-study (mostly the interview results) along with brainstorming and usage of morphological matrix. Some of the concepts are partly implemented today by some departments, while most concepts relies on brainstorming and known solutions for connecting software.

The morphological matrix has been adapted to fit this project, and is made to show the eventual exporting and importing formats between the three actors, SystemWeaver as exporter, CATIA V5 and TCE as importers. SystemWeaver is then studied as exporter as it is wanted to be used as a master and first step in the process [1] [55]. It means that when a requirement change is to occur e.g. according to scenario 2, the change should begin from SystemWeaver and then be done in the other software e.g. CATIA V5.

Morphological Matrix		
Software Connections	Date: 08/03-2018	Last Modified: 20/03-2018
SystemWeaver	CATIA V5	Teamcenter
Exporting Formats	Importing Formats	Importing Formats
xlsx (Excel)	xlsx (Excel)	API/XML
csv	txt (Notes)	
xml		
C-Sharp/API	C-Sharp/API	
REST API	REST API	
	stl/stp/igs/CATPART	

Figure 19. Morphological Matrix of exporting and importing formats for studying connections.

In the matrix above, some exporting formats from SystemWeaver are stated. The formats xlsx (Excel), csv, xml are easily exportable and can all be converted and connected Excel documents.

C-Sharp (often written as C# API), is an API which Systemite provides today [1]. API stands for Application Programming Interface, and is code and script based and can be used to connect several software [1]. Such a solution can be said to be a way of defining a customized function for connecting SystemWeaver and CATIA V5. This connection process can be automated, but there is a risk of it being too specific and not general enough to be used for all types of requirements or for several types of connections [1]. Hence, a C-Sharp solution requires much maintenance and support, which is both expensive and time consuming for VCG (a lot of IT staff and resources) [1].

A similar IT solution is based on REST API (indicated by the last arrow in the figure). REST stands for Representational State Transfer, and is a solution which is accepted by the VCG Integration Centre who has the responsibility for how connections are allowed to be at VCG [1]. This solution is more web-based, where URL links are being sent between the applications or software [1]. This is being partly done today between SystemWeaver and Jira, which also has a REST API [1]. Jira is an issue and project tracking software, being used at some departments at VCG [1] [59].

The xlsx, csv and xml connections are not automatic as both API solutions. However these solutions may be applicable in the short term while the API solutions needs much time to be decided and implemented.

The list of concepts for connection then becomes as follows:

1. Export xlsx document from SystemWeaver and connect to CAD designtables in xlsx (or txt).
2. Export csv document from SystemWeaver and connect to CAD designtables in xlsx.
3. Export xml document from SystemWeaver and connect to CAD designtables in xlsx.
4. Use C-Sharp API scripts for connecting SystemWeaver directly with CATIA V5.
5. Use REST API (sends URL links to applications) for connecting SystemWeaver with CATIA V5.

5.1.2 Linking between requirement geometry and SystemWeaver

For managing the linking between the requirements in SystemWeaver and the geometry—based requirements stored in Teamcenter, a study of possible linking formats has been made. There are only two generated solutions as they must fulfil requirements such as “Usage of available and standardised tools at VCG” and “Direct linking”. Testing and experimenting different possibilities and concepts in the Teamcenter environment for how to create links, along with interviews resulted in these two ways of creating links:

1. Link to TCE via URL links placed as hyperlinks in SystemWeaver. In Teamcenter it should be done in the same way using URL links from SystemWeaver.
2. Link to TCE and SystemWeaver using requirement specific serial numbers to search for in each software.

5.1.3 Traceability & Revisions

Another identified key area and sub-problem is how to manage traceability and revisions. Some different alternatives have been generated. These are mainly based on the interviews and a brainstorming session to determine the various sub-concepts. The challenges revolves around how to trace requirements and their respective revisions in SystemWeaver as well as the requirement geometry in Teamcenter. If a requirement is updated and a new revision is created, it vital that the latest revision is clearly visible to all involved stakeholders. Furthermore, in order to monitor the changes being done to a requirement is important to have traceability. Requirement traceability implies a way to be able to track the requirement changes between new revisions.

<u>Sub-Concept 1:</u>
The first alternative is to keep a hyperlink to the requirement geometry in the SystemWeaver requirement description box. Once a new revision of the requirement geometry is released, a new link will simply be placed underneath the previous one. The hyperlinks in the description box ensures simple traceability of the requirement geometry revisions. Similarly a hyperlink to the SystemWeaver requirement would be placed in Teamcenter in the requirement geometry description. New links for each new SystemWeaver revision would be created.

<u>Sub-Concept 2:</u>
The second alternative is to link to each respective subsection in both SystemWeaver and Teamcenter. In the Teamcenter document catalogue, CATIA V5 files are structured in subsections. A part with a specific part ID will fall under its own section. Once a new revision is created, the new part file will be placed under the same subsection. In this alternative a link to the subsection is placed in SystemWeaver instead of the link to the actual part file. In this way, the user opening the link would get an overview of the requirement geometry revisions and open the appropriate file. Similarly, in SystemWeaver all attribute requirements are placed in “Attribute Requirement Sections” which in turn is a subsection under “Requirement Authoring Area”. While “Attribute Requirement Sections” may get updated with new revisions the “Requirement Authoring Area” remains. A hyperlink to the correct “Requirement Authoring Area” could be placed in the requirement geometry Teamcenter description. Such a link would ensure that the user always access the latest SystemWeaver revision when clicking the SystemWeaver link.

<u>Sub-Concept 3:</u>
A third alternative would be to make the SystemWeaver requirement revision number and the Teamcenter revision number, always be the same. This alternative would alleviate any uncertainty of using the correct revision as long as the numbers are the same. This solution is fairly simple. However, it can become quire impractical since small requirement description corrections such spelling and grammar would require a new revision of the requirement geometry to be made.

<u>Sub-Concept 4:</u>
A fourth alternative would be to refer to the serial number of the SystemWeaver requirement in Teamcenter. Furthermore, a serial number of the requirement geometry in Teamcenter could be referred to in the requirement description in SystemWeaver. The user would then use the search function in SystemWeaver and Teamcenter respectively in order to find the correct requirement information, which is an additional step.

5.1.4 Ownership Structure

Ownership structure is another important component that needs to be addressed in the final concept. The reason of this, is that SystemWeaver and Teamcenter requires an owner of the requirement and requirement geometry respectively. The owner has owner rights and is the user that has permission to modify the requirement information in SystemWeaver and the requirement geometry in CATIA V5.

The person creating the requirement is typically called the requirement owner. The requirement owner could naturally own the requirement in SystemWeaver and the CATIA V5 model that is the requirement geometry. This alternative would be beneficial since the requirement owner has a good overview of the requirement and could keep good control of the requirement information in both SystemWeaver and Teamcenter. However, this option is a workload on the requirement owner. Furthermore, if a designer or requirement recipient would like to modify any requirement information, it would have to be done via the requirement owner. Another alternative would be to let the requirement owners own the requirements, while giving the ownership of the requirement geometries to the requirement recipients.

Furthermore, one of the two systems must contain the governing version of the requirement. Practically this means that if a version update is made in the first system, the second must comlpy. At VCG all requirements are stored and governed in SystemWeaver. Consequently, SystemWeaver will be the governing system as there is no reason to make an exception for geometry-based requirements.

5.1.5 Recipient Information

Once a requirement is created by the requirement owner it is to be mediated in some way to the requirement recipient. Some different alternatives of sending requirement information between requirement owner and requirement recipient has been generated.

1. In the SystemWeaver software there is a pre-existing solution to this issue. The requirement recipient will subscribe to his or hers assigned requirements. With the subscription feature, the requirement recipient will get a notification in the SystemWeaver software once an update to a requirement has been made. The SystemWaever software also has a feature of comparing requirement revisions, making it easier for the recipient to detect requirement changes. However, this requires a direct link between the requirement geometry and the SystemWeaver software. Otherwise, changes in the geometry will not appear as a notification in SystemWeaver.
2. Another alternative is that the requirement owner will send out a personal email to the relevant people. While this may be a good solution since the recipient gets important information of the requirement change, it may also be too much work for the requirement owner. Some requirement changes are not necessary for the requirement owners to describe in detail.

3. A third alternative is that an automatically generated email is sent to the requirement recipients. This solution would require this functionality to be added to SystemWeaver. Since the email would be automatically generated it does not require much workload on the requirement owners.

There are some different scenarios when an information exchange as the ones described above might be useful. Firstly, once the requirement owner assigns a requirement to the requirement recipient. Secondly, when a requirement change is being made by the requirement owner affecting the requirement recipients. Third, once the requirement recipient is finished working with the requirement and believes it is ready to be verified by the requirement owner, which is being discussed in the next subsection.

5.1.6 Verification Responsibility

Lastly comes the verification responsibility part of the final solution. The interviews played the main role in defining the potential concepts for this part of the problem. Only two concepts were relevant and had potential in handling this issue as the verification responsibility only could be on the requirement owners or the requirement recipients and users. The verification responsibility part is only considered here in geometry-based requirement context, as there is no doubt that the requirement owners are verification responsible for other requirements as they own them. The only two possible ways of dividing the verification responsibility is then as below.

1. Requirement owners are responsible for verification. The recipients only use the requirements in balancing to fulfil the requirement parameters. However, the final responsibility lies on the owners, as they have most knowledge in how the requirements should be measured to be met.
2. Requirement recipients use the requirements but are also responsible for verification. In this way, no extra work is needed, and the requirement owners does not have to check the fulfilment of the requirements.

The verification responsibility part of the problem has been discussed with consideration to what is most suitable in time, before and after Project Start (PS). That is because before PS, the requirement changes are more flexible and can be made much easier [2] [56]. This may require a less rigid and formal way of handling the verification of the requirements. However after PS, all changes are considered as deviations which has to be more controlled and only be made in formal meetings [2] [8].

5.2 Concept Evaluation

This section begins with an elimination matrix, where only the concepts fulfilling the requirements survive. Then these concepts if more than one, continues in the concept selection process in a pugh matrix where they are being evaluated based on wishes.

5.2.1 Elimination Matrix

An elimination matrix based on the Pugh Decision Matrix method has been made to narrow the number of concepts. The matrix allows the user to compare various concepts on their ability of fulfilling pre-set requirements. The requirements of each concept set are based on the specific task relating to the concept, and on the interviews where customer needs were attained. Each type of concepts was performed with an individual matrix since the requirements of each type of concept is different.

In the elimination matrix, the concepts were listed in the left most column and the requirements in the upper row. The column and the row results in a matrix where the cells will have information of the concept ability to fulfil the requirement. The measurement of the elimination matrix is binary, meaning that concepts will get a result of "Yes" or "No". In some cells some additional comments are added to clarify the result. Concepts that are not able to fulfil requirements will consequently be eliminated from the further development process.

Firstly, screening was performed on the "Connection between requirement geometry and SystemWeaver" (see Figure 20). The first requirement "Synchronises requirement information" is considered fulfilled by all concepts. However, concept 1-3 requires manual work from the user to fulfil this requirement. In the screening, concept 2 and 3 was not enable fulfil "Usage of available and standardised tools at VCG" (xls/xlsx format is recommended instead) and are thereby eliminated. Microsoft Excel and xls/xlsx file-extensions are the most commonly used at VCG. Concept 4 and 5 are also considered standardised. However, these concepts will require further research of application at VCG.

Connection between requirement geometry and SystemWeaver			
Concepts	Requirements		
	Synchronises requirement information	General adapatibility	Usage of available and standardised tools at VCG
1. Export xls documents to DT (Excel)	Yes	Yes	Yes
2. Export csv files to DT	Yes	Yes	No
3. Export xml documents to DT	Yes	Yes	No
4. C-Sharp API connections	Yes	Yes	Yes
5. Rest API connections	Yes	Yes	Yes

Figure 20. Elimination matrix of concepts type: "Connection between requirement geometry and SystemWeaver"

The elimination of the linking concepts ended up in using external reference links (hyperlinks) for the final concept as shown in the figure below. The reason is that using serial number links would not be a direct link (need to search for each serial number in both software), hence also add workload and be an additional working step.

Linking between requirement geometry and SystemWeaver				
Concepts	Requirements			
	General adapatibility	Two directional linking	Usage of available and standardised tools at VCG	Direct linking
1. External (data) reference links	Yes	Yes	Yes	Yes
2. Serial number links	Yes	Yes	Yes	No

Figure 21. Elimination matrix of concept type: "Linking between requirement geometry and SystemWeaver".

Third, is the screeing of concepts for "Traceability and revisions". As can be seen in Figure 22, the third and fourth concept were eliminated. The third concept got eliminated since unnecessary copies of data was to be avoided. The fourth requirement got eliminated since it did not fulfil the requirement of "Direct linking" as for the previous sub-problem in linking.

Traceability & Revisions				
Concepts	Requirements			
	Reach correct revision	Avoid copies of data	Trace history and previous revisions	Direct linking
1. New link for every new revision	Yes	Yes	Yes	Yes
2. Link to subsections/folders	Yes	Yes	Yes	Yes
3. Always same revision numbers	Yes	No	Yes	Yes
4. Link to serial numbers	Yes	Yes	Yes	No

Figure 22. Elimination matrix of concepts type: "Traceability and revisions".

The fourth elimination matrix was for "Ownership Structure". The concepts were divided in two phases, "Before Project Start (PS)" and "After Project Start (PS)". This division was made as it appeared from the interviews that certain conditions change after PS. Therefore the ownership of the requirement owners became clear after PS, but needed more investigation for the case before PS as there was a theory of that flexibility could be increased.

Ownership Structure		
Concepts	Requirements	
Before Project Start (PS)	Enable flexible requirement changes (from recipients)	Requirement change permission only for relevant staff
1. Requirement owners owns the models but with free positioning	?	Yes
2. Requirement recipients owns the models	Yes	Yes
After Project Start (PS)	Avoid requirement deviations from recipients side	Requirement change permission only for relevant staff
1. Requirement owners owns the models but with free positioning	Yes	Yes
2. Requirement recipients owns the models	No	Yes

Figure 23. Elimination matrix of concepts type: "Ownership structure".

The fifth elimination matrix was for "Recipient information" as seen in Figure 24. Concept 3 was immediately eliminated since an automatic email that informs of a requirement change or deviation does not cover all required information. The recipient will be unable to get information of the actual change or deviation. The second concept was left for further investigation in the pugh matrix.

Recipient Information (when requirement changes/deviations occur)				
Concepts	Requirements			
	Get notified	Decreased workload (working steps)	Notification history and accessibility	Requirement information interpretation
1. Subscribe in SystemWeaver	Yes	Yes	Yes	(Information changes can be seen in SystemWeaver)
2. Personal contact (e.g. via e-mail)	Yes	No (Further research needed)	Yes	Yes
3. Automatic e-mail from SystemWeaver	Yes	Yes	Yes	No

Figure 24. Elimination matrix of concepts type: "Requirement information (when changes deviation occurs)".

The sixth and final elimination matrix was for "Verification Responsibility". As can be seen in Figure 25, the second concept got eliminated since the requirement recipient lack credible knowledge of the requirement, sufficient for verifying the requirement. The requirement owners are the ones creating the requirement and are also the ones who should verify the requirement in the further development of a final solution.

Verification Responsibility		
Concepts	Requirements	
	Verification can be checked	Ensure correct verification of requirements
1. Requirement owners verify, recipients are only users	Yes	Can verify as they are the ones defining the requirements
2. Requirement recipients are responsible for verification	Yes	Not the most knowledgable in verifying

Figure 25. Elimination matrix of concepts type: ”Verification Responsibility”

5.2.2 Concept Selection Matrix

As a second step of the screening process a Concept Selection Matrix based on a Pugh Decision Matrix was used to go a step further and decide which concepts should be further developed. In this matrix, the concepts where evaluated based on desires which has been previously put forth as a result of interviews with the main stakeholders. Also here, as in the elimination matrix the different “sub-concepts” has been evaluated separately as they handle different parts of the problem. Therefore, four pugh matrices were made, were the desires were listed in the first column, and the concepts in the column after. One concept was then put as a reference to be compared with the other concepts which got a plus (+) if better in achieving the desire, minus (-) if worse, and zero (0) if as good as the reference in achieving the specific desire. Lastly the net values of the amount of +, - and zeros was counted, and based on that the concepts got ranked. The only remaining concepts after the elimination matrix and which were further evaluated in this step were as below.

Concepts for Connection between requirement geometry and SystemWeaver:

1. Export Excel documents to DT (Design Tables in CATIA).
2. C-Sharp API connections.
3. REST API connections.

Concepts for Traceablilty & Revisions:

1. New link for every new revision.
2. Link to subsections/folders (in e.g. Teamcenter).

Concepts for Ownership Structure before Project Start (as the structure was clear after PS as shown in the elimination matrix). This only considers the ownership of requirement geometry models, and not the requirements themselves as the requirement owners owns them.

1. Owned by Requirement Owners.
2. Owned by Recipients.

Concepts for Recipient Information:

1. Subscribe in SystemWeaver (The recipients subscribe for the requirements they need).
2. Personal contact, e.g. e.mail.

The first pugh matrix made for evaluating the concepts for the connection between requirement geometries and SystemWeaver was based on 11 desires. The desires was mainly related to aspects such as time of implementation and readiness, level of standardization and customization, usability (e.g. in terms of user friendliness and time saving) and user complexity (e.g. usage of complex processes and tools difficult to maintain and modify), cost etc. An important aspect when evaluating the concepts based on e.g. level of standardization was to judge the eventual acceptance of implementing a concept. If something would be totally new, it would be difficult and maybe take more time to implement. Also the level of standardization focuses on using the right tools and software already existing at VCG, which also enables for using the right processes along with these tools.

No.	Type	Concepts for Connection between requirement geometry and SystemWeaver		
	Desires	Export Excel documents to DT	C-Sharp API connections	REST API connections
1	Ready to be presented and ev. implemented before project finish	Reference	-	-
2	A solution already standardized and being used		-	+
3	Level of workload and automation		+	+
4	Level of generalization (not only a customized solution)		-	0
5	User complexity		+	+
6	Required new software and knowledge		0	0
7	Can be integrated with existing software		0	0
8	Usability (e.g. efficient, intuitive)		+	+
9	Development potential		-	+
10	Initial cost and resources (IT)		-	-
11	Needed support and running cost		-	-
Results	Total +		3	5
	Total -		6	3
	Total 0		2	3
	Net Value		-3	2
	Ranking	2	3	1
	Further Development	Yes	No	Yes

Figure 26. Concept Selection Matrix 1 of 4, for evaluating concepts for connection between requirement geometry and SystemWeaver.

The first pugh matrix as shown above, resulted in further development of two concepts. The first concept was exporting excel documents which can be used in the design tables in CATIA V5. This concept would be able to be presented before project finish and as a part of the final concept. The second concept which got the highest ranking was the REST API connection concept. However, this solution would not be ready for presentation and implementation before the time limit of this project. Therefore, the concept will be a bit further developed and discussed, but mainly left as a recommendation concept for future work. Not only the time is the limit here, but also that VCG wants Systemite to create a REST API for SystemWeaver which could be connected directly to CATIA V5 [1]. That is mainly because VCG wants Systemite to take responsibility of the REST API, and eventual support connected to it [1]. The C-Sharp concept mainly fell on the desires related to the level of standardization and customization, as the C-Sharp connections usually are more customized and therefore many different connections would be needed for each specific case. Also, the concept is not standardized and has not been widely used at VCG, in contrary to REST API connections.

The remaining three pugh matrices were made in the same way. The second one resulted in creating a new link for every new revision, and only connected to the specific requirement geometry. That is mainly because linking to folders is considered to not be a consistent and most intuitive way of working, as each requirement should be directly connected to each respective geometry. The details are in the pugh matrix 2, Appendix G (Concept Selection Matrices).

The third pugh matrix was made for the remaining two concepts for ownership structure before project start, and whether the requirement owners or recipients should own the geometry models. As a result of continuous communication with the stakeholders, the evaluation ended up in an ownership by the requirement owners, see Appendix G (Concept Selection Matrices). Also, in the part of the problem, the second concept fell on the desires related to level of consistency and intuitiveness, as the requirement owners should have the final responsibility and final word in the models based on their requirements.

The final pugh matrix was made for the concepts left for solving the recipient information issue. The first concept was for the requirement user or recipient to subscribe for the requirements they need in SystemWeaver. The second concept was to rely more on personal contact e.g. via e-mails and as have previously been done. The first concept had a higher ranking in the matrix. However, after discussions with the ergonomics department and some users, both concepts were left for further development for being a part of the final concept. That is because even if subscribing in SystemWeaver is most desirable, personal contact is also needed in some cases for describing details and discussing issues. The ranking is in matrix 4, Appendix G (Concept Selection Matrices).

5.3 Final Concept

This section presents the final concept which is a package of sub concepts solving the six sub-problems stated in 5.1 Concept Generation and in the figure below. The first subsection in the chapter is validation and verification of needs fulfilment. The second subsection describes the final concept and what expected impact it will have. A delivery connected to the concept is some user guides describing the new corresponding working process according to the standard at VCG.

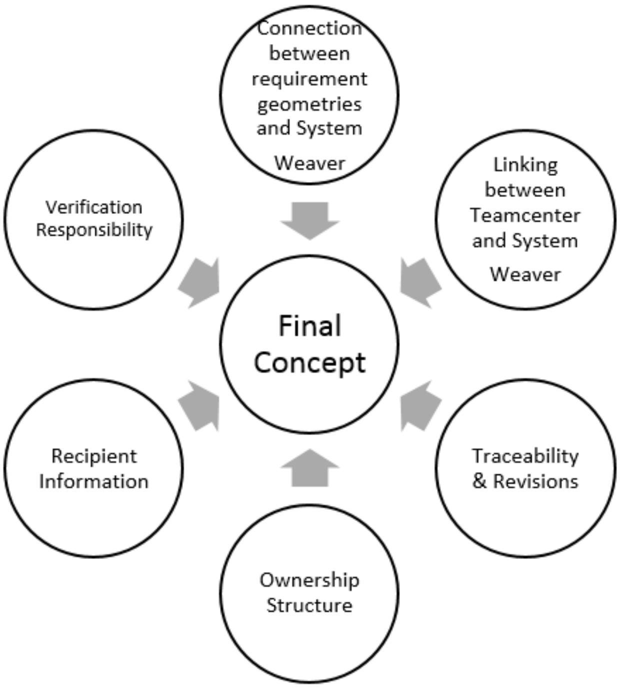

Figure 27. The package of sub problem definitions which all are a part of the main problem.

5.3.1 Concept Validation and Needs Fulfilment

An important aspect when implementing new concepts consisting of changes in working processes as in this case, is validation, more in 2.7. The validation is mainly to ensure the fulfilment of acquired needs as stated in 4.4.4 Requirements of final concept. The validation has mainly been made in collaboration with the ergonomics department at VCG as being requirement owners. The concept was tested and validated using different requirements and models, e.g. Ergonomics Luggage Compartment model, Head envelop roominess model, InEgress roominess model and Luggage compartment – Golf bag, a so called Generic model (i.e. same golf bag model in all projects) [2].

The aspects validated were mainly from a requirement owner perspective. The level of intuitiveness in usage, usability (in terms of effectivity), user complexity, workload, software integration and usage of standardized tools and processes at VCG. These validation aspects were similar to the ones in the pugh matrix. An addition step here was also the evaluation of the final concept as whole, not only the separate concepts solving each sub problem. The result of the validation was good and the working process was documented in user guides. However an important comment was stated. The issue was related to the concept for handling traceability and revisions by linking to each separate requirement revision. According to the ergonomics department, this concept would increase the workload as it adds many additional steps when creating links between Teamcenter and SystemWeaver [2]. The reason is that when the links are between each requirement revision, the links needs to be updated for every new revision. Instead the ergonomics department preferred linking to subsections and folders which is more flexible, which was agreed in a concept meeting for the project group and some stakeholders

[2]. This contributed to a revised version of the final concept as whole, which is presented in the next subsection.

In order to validate the final concept even further, the process should be integrated and used throughout a car project. However, with the scope and time of this Master Thesis this was not possible. A recommendation for further development is to test the final concept on other types of geometry-based requirements apart from ergonomics requirements. Furthermore, implementation in a car project will validate the "Requirement change loop" even further, especially from a requirement recipient point of view.

5.3.2 Concept Description and Impact

As was presented in the concept evaluation process which began with an elimination matrix and then a pugh matrix, each sub problem ended up in one concept (with one exception for recipient information). The final concept consisting of the six sub concepts can be described as in the following figure.

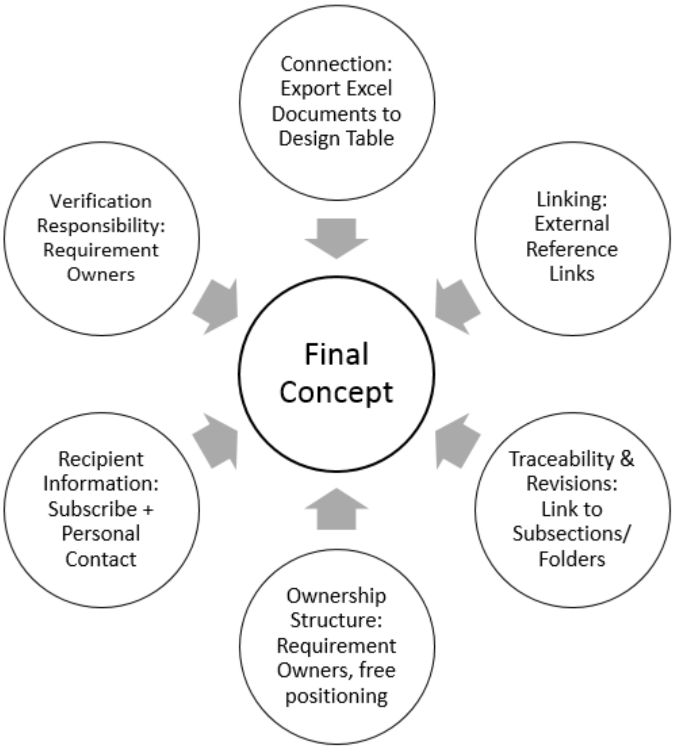

Figure 28. The package of sub concepts which all are a part of the final concept.

The concepts in the figure above does not all affect the way of working equally. However, each of them contains a lot of steps which needs to be performed in a specified sequence.

The new working process will mostly mean changes in connecting and linking the requirements between SystemWeaver and CATIA V5 according to user guides that have been created for step in the figure below. This part of the work affects the requirement owners and not the recipients. The delivered user guides explain the detailed working steps, the sequence and what to do in different scenarios and when using different types of requirement geometry models.

Figure 29 is the overall framework of creating and implementing geometry-based requirements. In the figure, some steps are outlined in a blue frame, these are processes that have been further described in detail, see Appendix H (Solution Concept Processes) (Solution Concept Processes).

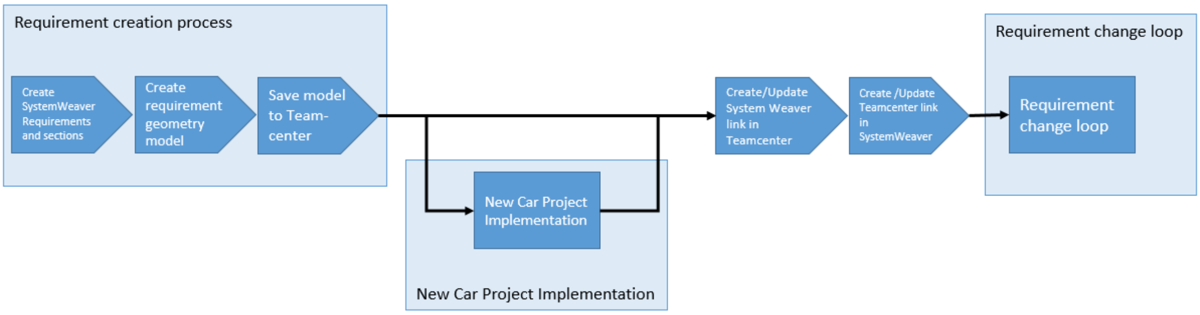

Figure 29. Illustrating the overall working process.

In addition to handling the connection and linking, the process means the requirement owners will own the requirements and their corresponding geometry models. However the models will need to have a free positioning so the requirement users can position the requirement parts correctly where they can e.g. be balanced and verified, as in the ergo luggage model, see 4.2.4. When it comes to receiving requirement information, the solution is to subscribe for the requirements needed in SystemWeaver. When any change occurs, the subscriber gets notified in the inbox in SystemWeaver (not externally e.g. via e.mail). In the beginning and in some cases where personal feedback is needed, personal contact can also be used to inform about changes. This will be a necessary tool sometimes, and as SystemWeaver has not been fully implemented and taught yet [2]. As has been decided the requirement owners will need to be responsible for verification, the requirement users will only be considered as users although they verify the requirements when doing their job. The reason is that the requirement owners are most knowledgeable in this area and need to have the final word in whether the requirements has been verified properly or not. For clarification, the following figure illustrates what should happen when a requirement change (or deviation) scenario occurs.

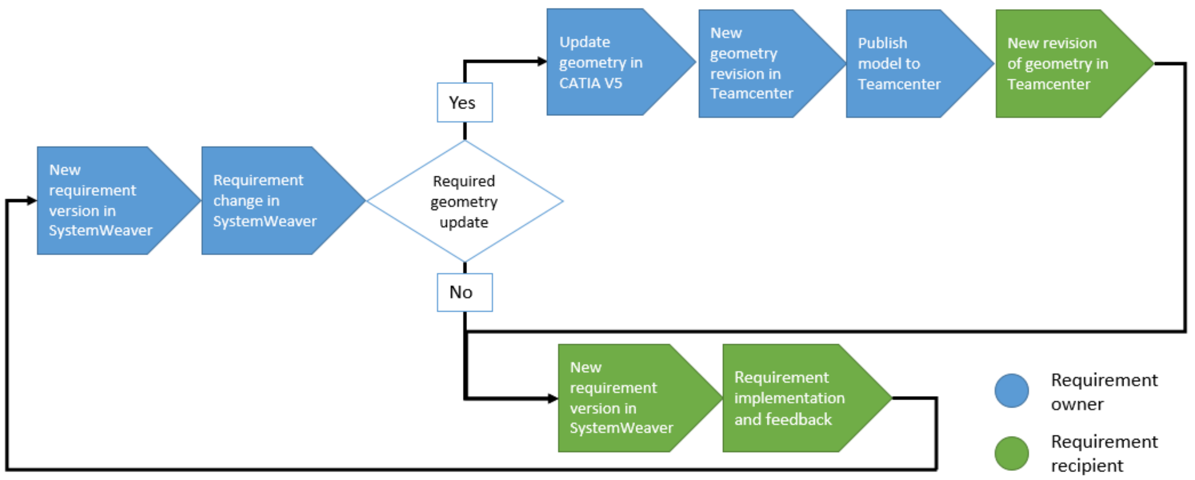

Figure 30. Illustrating the requirement change loop process, where a requirement change occurs.

The final concept and the process it brings is planned to have little impact on the requirement recipients. They will only get affected when ensuring that the requirement geometry is updated to the last revision. They will then need to open the link in Teamcenter, check the last requirement value and in that way use the geometry safely. This work will usually be made for a complete geometry model template with a set e.g. 19 requirements, and not for each requirement separately [2]. The biggest impact will thereby be on the requirement users. They will work with all steps mentioned in the final concept, all from connecting and linking the requirements to having responsibility for verification.

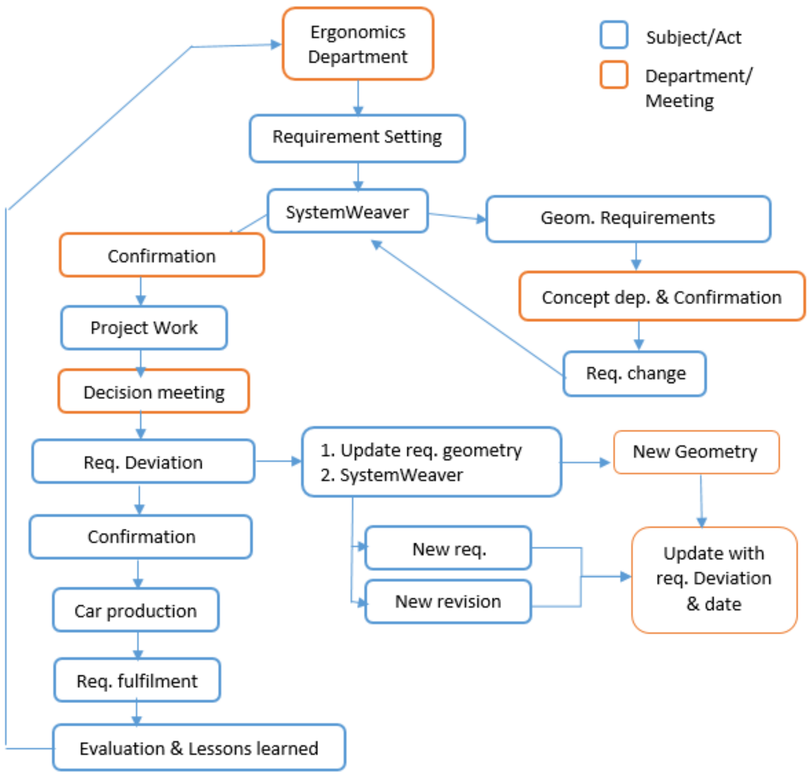

Figure 31. Illustration of the expected working process when implementing the final concept.

To illustrate the impact that the final concept will have when fully implemented can be described as in the figure above, resulting in less working steps and loops for e.g. the ergonomics department. Compare with the current working process in Figure 16. The biggest difference with the new process map is the elimination of the all working steps related to using additional documents such as internal lists in Excel and logs of deviations. In this way, not only the workload decreases, but double copies of information and data gets avoided. However, efforts will need to be put on convincing staff to stop using their old internal Excel documents. Therefore, such steps will need to be implemented stepwise as SystemWeaver get more implemented and as the users can see the benefits of it.

6. Discussion

The methodology of this master thesis has been developed to obtain a process i.e. the final concept. The process could be viewed as relying mainly on the people involved in the process and the technology and software it requires. When it comes to technology and software, they were predetermined by VCG. Thus, setting some technical boundaries of the project. Below follows a discussion of the master thesis project and summarizing answers for each research question (RQ).

RQ1: What eventual advantages and disadvantages are there with the current requirement management system, SystemWeaver?

Although all used software was predetermined by the company, information of these systems had to be obtained and properly understood before proceeding to finding and developing solutions. The reason is to benefit from each software´s advantages strengths and create solutions which are in line with its existing limitations and avoid its disadvantages. Such information was mostly acquired through interviews and having an ongoing dialogue of how to use software such as SystemWeaver according to the company's intention of use. However, some information was not presented in the report due to company secrecy and publication reasons, but these findings was the main contributor of exploring the REST API solution and that SystemWeaver was an object-oriented database. In addition, the theoretical studies contributed in giving the knowledge in how all processes and software should correlate, e.g. what is a requirement management system, PDM system and PLM. This enabled for sewing all concepts together into a final concept package, giving the knowledge of what problems to be solved in Teamcenter, the PLM software (e.g. the linking) and what to be solved in SystemWeaver, the requirement management system (e.g. the connection).

RQ2: How can geometry information be connected to SystemWeaver?

After answering the first research question and exploring each software knowing the possibilities and what can be done, collaboration with the stakeholders, mainly the end users took place. Much information was obtained from interviews and testing different concepts in different software from the perspective of the users and their needs. If the final solution would not be adapted to user preferences it would likely not be well received. The concept testing in the different software has only been explained briefly in the report due to secrecy and publication reasons, but covered mostly e.g. different ways to create links in Teamcenter etc. which contributed in generating concepts. All the other mentioned concepts have also been explained in the methods delivered to VCG, however not explained in detail in the report for the same reason. Keeping the end user in mind, the concept generation phase had two screening stages. The first relying on basic requirements of the concept to be fulfilled, mostly involving technical aspects. In the second evaluation phase, user preferences or "desires" was the final and determining factor. When the final concept was finished it was also validated from a user perspective to ensure both technical features and user satisfaction. In the concept evaluation stage, the variety of concepts being generated for each sub-problem vary. This is due to the requirements which narrowed down the number of possible concepts. These were even considered in the concept generation phase and had to be according to VCG's many standardised tools and procedures for working tasks. Hence, some unrealistic concepts where not considered already from the beginning. Furthermore, the solution process was complex and divided in 6 sub-problems and in some sub-problems such as "Linking between requirement geometry and SystemWeaver" there was not a great number of concepts to consider.

The final concept for connecting geometry information to SystemWeaver was as presented earlier, to export the requirement parameters from SystemWeaver (in Excel format) and connect to a pre-adjusted design table in CATIA V5. However, for other scenarios when having few requirement parameters or generic models, this would be done in a slightly different ways. Due to secrecy the detailed solution nor the different scenario processes has been explained in this report. However, this was the solution considering the project and company limitations. However, a recommendation for future work would be in the REST API area. As SystemWeaver is an object-based database, it can be customized which was a main reason of implementing it [1]. This means that a trend connection solution can be used, using REST API. Most software today has their own REST API which can be used for connections to other software. These connections are web-based and uses URL links for both sending and receiving information. The idea and future recommendation is then to use such REST API connections for sending URL links which CATIA V5 can receive for changing parameter values. A hypothesis is to connect the links to the requirement parameters directly without using any design tables. The design tables have in many companies been used for customizing functions that does not exist in CATIA V5, and which can be handled in Excel instead [8]. The REST API solution would even have an increased value if CATIA V5 would be replaced with CATIA 3DS with added functionality and smarter connections [60]. However, VCG are waiting for Systemite to create their own REST API to take the responsibility and support of it, this solution has been delayed although it is being in work in connecting SystemWeaver to Jira [1]. The REST API solution goes in line with the long-term vision of VCG IT group for gathering all software REST API into a gateway, where the different software can communicate and use information in a single standardized way [1].

RQ3: How can an information flow be created to ensure that the last geometry-based requirement revision is being used with a clear ownership structure?

As a result of having decided how to manage the requirement connections and linking, it became possible to create an information flow giving a clear way of how to handle revisions enabling traceability and also having a clear ownership. As the linking would be between items in Teamcenter and SystemWeaver, the decision was to create links between subsections and folders, mainly to minimize workload (as explained in 5.3.1. in Concept Validation). The ownership responsibility would lie on the requirement owners, but the geometry models would still have free positioning models to enable for more flexible use and requirement verification.

RQ4: How will a potential solution change the current process at the departments having requirement ownership?

See 5.3.2 Concept Description and Impact for more information, but in summary the solution can be said to have mainly avoided the usage of different copies of information. Previously the requirements were stored both internal Excel sheets and SystemWeaver. In addition, there were separate documents for logs of deviations and sometimes even personal documentation. This solution would now enable for a single standardized storing place of requirements. This minimizes the risk of using wrong requirement information, and thus all that confusion. In result, this also reduces the working steps in the requirement management process as the "surrounding" work with documenting in many different places disappears. The final concept also enables for a new mindset in having a partly automated solution. This can be a step towards a fully automated solution and integration of SystemWeaver and CATIA V5 using REST API connections in the future.

Other, limitations of final concept, recommendations for implementation and future work:

As the final concept has been adapted for a specific area, the solution has some limitations which needs to be considered for when to implement some of the sub concepts and not. For instance, there exists different requirement geometry models. Some models might consist of many requirements, thus usually controlled either directly by parameters or through design tables. However, most models consisting of few requirements are directly controlled by parameters directly in CATIA V5. In such cases there is no need to create a design table and use the connection solution in the final concept. Instead the requirement owner can just type in the parameter value manually. However, the later steps need to be used in all model types and cases, e.g. open the link in SystemWeaver to find the new requirement values and ensure that the last one is used in the geometry. It is therefore important to consider the number of requirements in a geometry model to determine if it is worth the parameter export connection solution using pre-adjusted Excel documents. Except fulfilling the needs stated in the previous chapters, a big advantage has been the level generalization (e.g. being able to link to different folder structures in SystemWeaver) of the solution. Also, all types of parameters which can be inserted in design tables and written in SystemWeaver can be connected, without any exceptions. In addition, connections and linking can be created for different requirement types as generic (same in all projects e.g. golf bags that should fit) and project specific requirements as they are parametrized in the same way (described in the methods delivered to the company.

In recommendation, before implementing the final concept at the company, the final concept needs to be further validated on more models preferably at other departments. It is also recommended to be tested in a real car project before scaling it up, in addition work by the company to define how it should be scaled up and who should be affected. Also surrounding requirement management processes for implementation are needed to be developed, for such a change in the organization to occur in the right way and based on previous lessons learned. From a research point of view as Holders (2017) mentions, an important field of research is what the impact of agile and lean principles to model based requirements engineering can be. These are some important principles and theories currently being implemented at VCG, and its impact on the processes of the final concept can be worth to study!

7. Conclusion

From the Master Thesis project, it can be concluded that the four research questions can be answered the following way:

RQ1: What eventual advantages and disadvantages are there with the current requirement management system, SystemWeaver?
Some advantages to SystemWeaver is that it is an object oriented and highly configurable software. Furthermore, it supports ISO 26262. A disadvantage is that the software does not support integration of geometry models. There is also a current limit on the number of users that can utilize the software.

RQ2: How can geometry information be connected to SystemWeaver?
In the final concept, a consistent connection and linking solution which could be standardized at VCG is illustrated. The solution avoids the risk of double data, thus minimizing the risk of using wrong data and information. It is a partly automated solution which is a step towards a fully automated solution and integration of SystemWeaver and CATIA V5 using REST API connections.

RQ3: How can an information flow be created to ensure that the last geometry-based requirement revision is being used with a clear ownership structure?
As mentioned in the previous answer the final concept illustrates a consistent connection and linking solution which could be standardized at VCG. Furthermore, a consistent way of being informed about requirement deviations (or changes), is presented (not in detail due to secrecy). Thereby, delivering a continuous information flow.

RQ4: How will a potential solution change the current process at the departments having requirement ownership?
In the final concept, reduced working steps in the requirement management process is presented. Furthermore, the final concept may result in an increased integration of SystemWeaver, depending on future testing (and validation) and implementation at VCG.

Finally, a recommendation for future work that can be concluded from the project is to further implement and test the final concept in a VCG car project. Further testing and application in practice, is required to fully evaluate the potential of the final concept. In this project, a virtual connection between text-based and geometry-based requirements has been done. The solution may however open up additional areas for future connections between requirements in the virtual and physical world environment!

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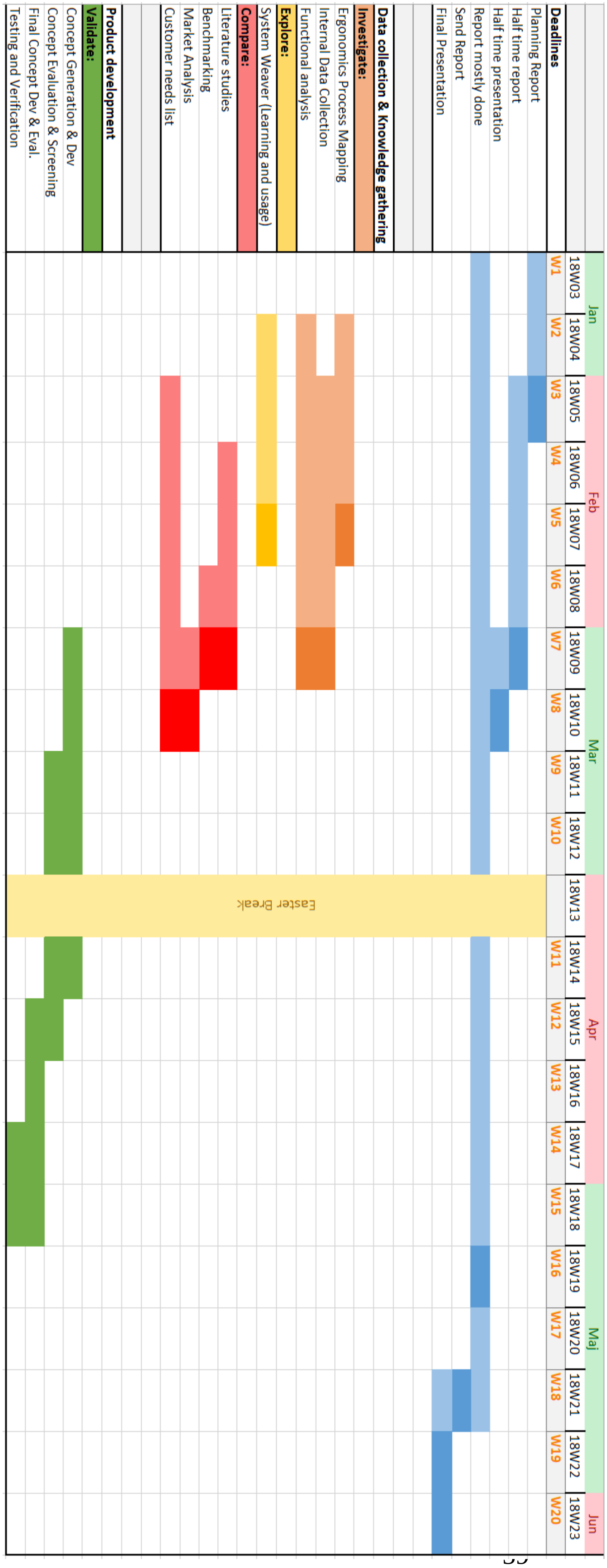
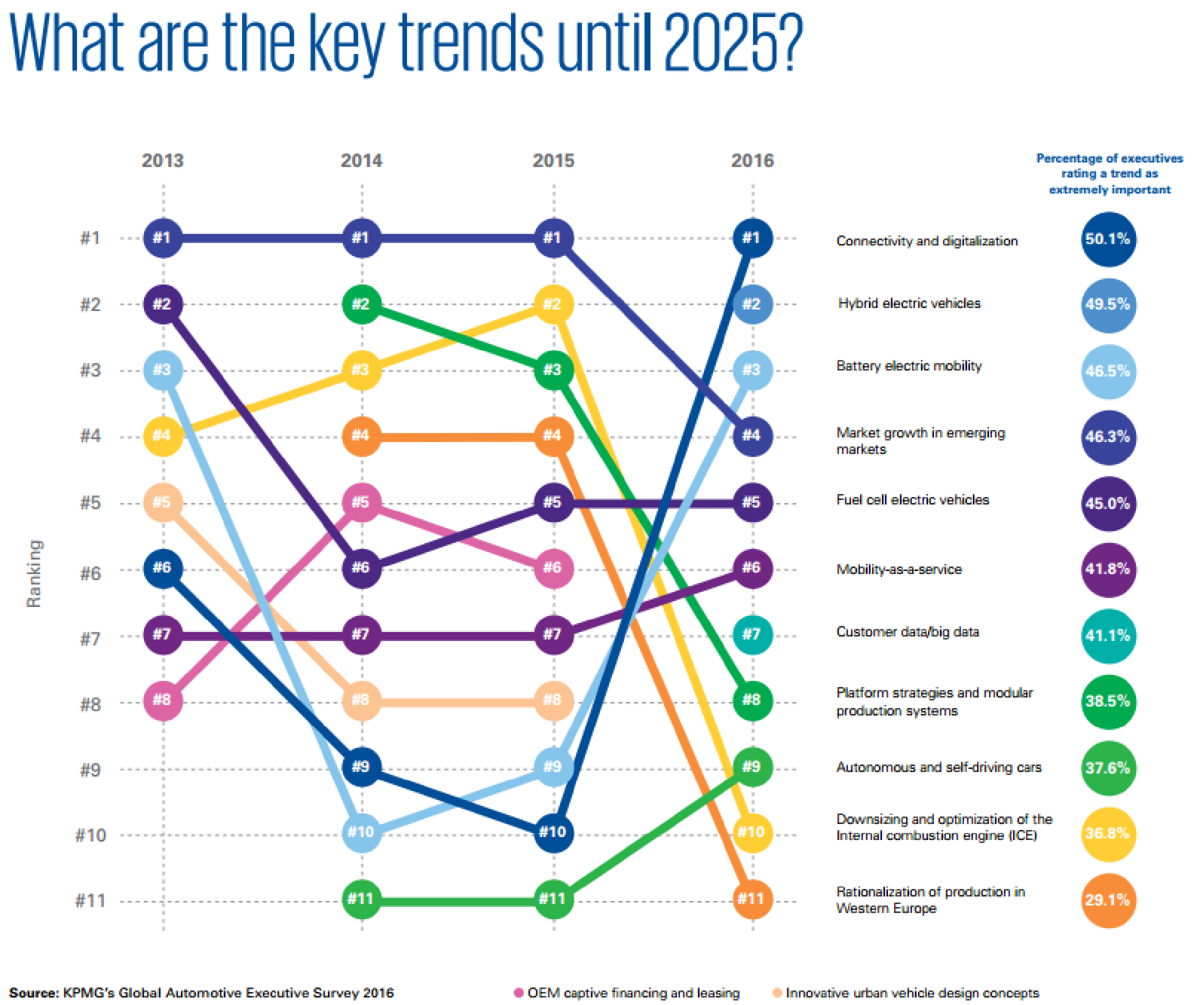
Appendix A (Gantt-Chart)



Appendix B (Key Trends)

This appendix shows some of the most important trends which may be expected until the year of 2025, with the time in the horizontal axis [61].



Appendix C (Business Strategy and Technology Mapping)

In all fields of business, there is a certain level of competition. This appendix presents some main market trends which affect the requirement management process in terms of e.g. handling more complex requirements.

On a global level, there are some big trends which has been commercialized. For example there are big trends towards self-driving cars, where the Volvo Car Group has come relatively far (level 2 out of 5) [8]. Known competitors as e.g. Audi has also come far, as they are almost on the same level as VCG [9]. These levels determines the extent of involvement needed for the driver to control the vehicle. Along with that, the system capability is also determined, e.g. whether the car can control the steering and/or speed etc. For example level 2, means that the vehicle is partially automated. The vehicle can then brake and accelerate, with some steering, but within a limited amount of circumstances. This still requires a high level of involvement and focus from the driver, especially in more “tactical manoeuvres” [62].

Other trends can also be seen in the global historical issue related to power and engines, as the Volvo Car Group stopped developing the Diesel engines since the summer of year 2017 [63]. Instead their intention was to focus more on hybrid cars, and more energy efficient petrol engines. That is because of the NO_x emissions, which has led to diesel engine bans in several cities as in Beijing and what is planned to happen in some zones in Stockholm [64].

In addition also large efforts are put into electric cars, using bigger and relatively efficient batteries. A lot of money and resources are being put here, not only from the VCG side, but also from other known companies and competitors as BMW (e.g. produced the BMW i3 car) [64]. This trend has encouraged many other companies to get in the business, as Tesla for several years ago, and now even companies as Google and many other Chinese car companies [65]. The combination of such areas and integrating autonomous drive, leads to new and more complex software, and mechatronic integrations [65]. An illustration of more expected trends until 2025 can be seen in Appendix B [61].

On requirement management level, the trends are heading towards management of more and more complex requirements. The aim is to develop both new systems, but also new processes for better requirement usage. This includes the requirement representation, as many companies including VCG are going from text based requirements to more 3D based requirements [8]. The idea is mainly to eliminate the errors from human factors [8]. The aim is also to increase the efficiency in terms of time consumption, as the verification of the requirements can be faster, and be done within the same CAD environment. The trends in PDM systems, goes towards systems which has to be visually more intuitive with more clear interfaces (e.g. similar to Windows or other known software) for both designers and requirement owners. The goal is also to have intuitive systems which gets updated along with the requirements, in order to minimize the risk of having different versions of requirements in different places and in different requirement management systems [1].

All this requires newer versions of PDM and PLM systems, along with mature processes to be used in order to get better interaction between different data management systems. As the car development gets more complex, the requirements also get more complex. There will then also start to come requirements of new types, which may be for example related to software end electronics. Taking the mind set of agile working into consideration, emphasizes the need of putting requirements into context in terms of e.g. functions, logics etc. This confirms the need of a general solution, especially for managing the information flow between the geometrical CAD requirements and SystemWeaver as the pre-chosen requirement management system at VCG.

Appendix D (SWOT Analysis)

INTERNAL FACTORS			
STRENGTHS (+)		WEAKNESSES (–)	
1	Good knowledge resources within department	1	Lack in know-how regarding project solutions
2	Good knowledge pre-requisits (from project group)	2	High bureaucracy, many meetings for decision
3	Close interaction with stakeholders	3	Long lead time for decisions and implementation
4	Open employee and colleague atmosphere	4	Dependent on main affected departments
5	Huge driving forces for solving the problem, stakeholder interest	5	Difficulties in conducting literature studies and benchmarking
6	Low investment needed	6	High uncertainty levels regarding System Weaver as newly introduced
7	Good acces to research made via supervisors from universities	7	Many current distribution channels of requirements (System W., Excel, Mail)
8	Good knowledge resources from supervisors from university	8	Lack of previous knowledge within the field of study
9	Students from outside the company, not locked into their perspectives	9	
10		10	

EXTERNAL FACTORS			
OPPORTUNITIES (+)		THREATS (–)	
1	Many stakeholders and people involved in project	1	Many stakeholders and people involved in project
2	Many people will be affected by the result of the project	2	Many people will be affected by the result of the project
3	Developing companies and competitors	3	Lack of communication sometimes between the departments
4	Knowledge in upcoming trends	4	Developing companies and competitors
5	Software support	5	New upcoming and more complex requirements
6	Find more market solutions	6	
7	No high risk of market uncertainty, stable market area	7	
8		8	
9		9	

Figure 32. SWOT matrix.

As can then be seen in the SWOT matrix above, the main strength and the key lies in the knowledge resources. Also the affected people are very positive to the project group and there is a huge stakeholder interest, as many emphasizes the importance of such work. At the same time it is a big advantage that the project group comes from outside, so they're not locked into the mindset at VCG. However, the weaknesses are also important in the sense that many of them are related to the lack of know-how, communication, and time as many people and departments are involved. This increases the complexity of the stated issue, and requires a large amount of data collection, especially internally at VCG in order to understand the working process. The data collection of the process should then include all phases from the beginning, requirement setting and "collection" by a requirement owning department, until they've handled it and "converted" it into a geometry-based requirement e.g. by using a CAD template, to finally upload it to SystemWeaver.

When analysing the external factors as the opportunities, it can be seen that as many people are involved and being affected, it is also an opportunity and not only a weakness or threat. The large number of stakeholder increases the level of seriousity and importance. A solution within this area would have big impact on many departments and would then contribute to many thing, as time savings and minimizing errors in e.g. distribution and ownership of requirements. Other opportunities lies in that the field of requirements is limited to some extent, and is considered to be stable in not having many trends and upcomings. At the same time, the knowledge in most areas exists within VCG but needs to be connected, and e.g. most software support is available. However, there are some external factors that may act as threats, such as new and more complex requirements. Therefore any eventual concept, will need to be as general as possible in order to cover all possible types of requirements, e.g. parameters (lengths, heights etc), binary requirements (of the type 0/1, yes/no).

Appendix E (PEST Analysis)

However, for this specific project the tool will be used to also include the internal aspects. So, for example the political aspect will not only consider external politics, but also the politics within VCG and all the driving forces for implementing e.g. SystemWeaver and how to connect it to geometry-based requirements. The same will be done with the social aspect, as the society outside VCG is irrelevant to some extent (if not considering SystemWeaver at other companies). Instead, the social aspect within VCG is examined, to understand whether they're for or against the new changes, e.g. introducing SystemWeaver as the new requirement management system.

PEST Analysis	
Situation being analysed : Geometry based ergonomics requirements	
PEST Analysis (Political , Economical ,Social ,Technological) assesses internal aspects within VCG, but there are external for the project group	
Political	**Economical**
A previous decision to go from TeamCenter Requirements to System Weaver.	An increasing market area, as new PLM systems and PLM solutions are being introduced.
All future requirements with a clear ownership structure	Expected trends in lower future adaption costs for PLM systems and solutions [18]
Clear process for requirements management	VCG putting resources into developing processes for requirements
Pressure towards only represnting future requirements as geometries. No text based requirements	
Social	**Technological**
Most affected people are positive towards this project as whole	PLM systems ev. entering and developing for new areas such as economy, e.g. circular economy, pull economy [18] [19]
Many people afraid of System Weaver, as it's new but also afraid to face the same problems as with TCR not being mature enough	Flexible data management in PLM, as the high level of customization has resulted in different needs in supporting different information [18]
Many thinks the new interface in System Weaver is better than what was in TCR	Fast PLM systems and information flows leading to fast communication [18]
	New and more intuitive interfaces and use processes [20]

Figure 33. PEST analysis.

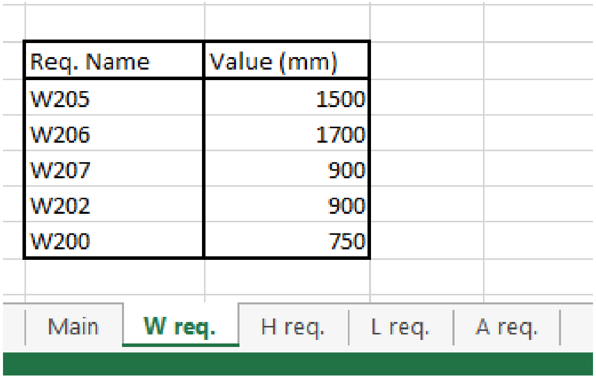
What can be extracted from the PEST analysis is mainly the economic and technological factors, as there seems to be growing areas both economically and technologically. From a technological perspective, new PLM systems and solutions are being established, which needs to be much more customized to support different management areas, along with being much faster [66] [67].

Appendix F (Ergo luggage model)

The model include the following ergonomic requirements:

Requirement number	**Description**
W205	Rear Opening Width Upper
W206	Rear Opening Width Maximum
W207	Rear Opening Width Lower
H202	Rear Opening Height
H212	Luggage Compartment Height
H297-2	Seatback to Luggage Floor Second
H201	Cargo Height
H193	Lift out Height
H196	Lift in Height
x-boot	Lift in/out measurement
L217	Lift in/out Length
L212-1	Luggage Floor Length First
L212-2	Luggage Floor Length Second
L214-1	Luggage Length First
L214-2	Luggage Length Second
L206	Rear Compartment Opening Length
A212	Luggage Floor Angle in Y plane
W202	Wheelhouse Width Minimum
W200	Compartment Width Maximum

The actual working process of the model is as follows. When the ergonomic department has generated L3 requirements, these are filled into an excel document (see Figure 34). The excel document is a so called design table which is a built in function in CATIA V5. The design table is connected to the length parameters in the model. Each length parameter is in turn connected to a requirement measurement geometry and determines its value. As the cells in the excel sheet is filled in, these values will then update the actual geometries in the model.



Req. Name	Value (mm)
W205	1500
W206	1700
W207	900
W202	900
W200	750

Figure 34. Design table excel document, connected to the CATIA V5 model.

Constructing the model in this way makes it very usable in the collaboration process when the ergonomic department informs designers of the given requirements. The ergonomic department will fill in the excel sheet and the geometry in the model will then be updated. The designer is then able to load the model and view the geometric requirements and the Part that he/she is designing in the same space. Furthermore, if the ergonomic department choose to update a requirement the designer can visually observe the corresponding changes that takes place in the model.

Another benefit of using the model is that the requirements is automatically placed in space through inputs from reference geometries. Misunderstandings of exactly where the requirements should exist in space are common if they are only text based. Automatic placement of the requirements alleviates the risk of misinterpretations from the designer. It should be mentioned that the exact position of most requirements cannot be done automatically. However, the placement and movement of the requirements are restricted in the best way possible to avoid mistakes.

Appendix G (Concept Selection Matrices)

Pugh Matrix 2:

No.	Type	Concepts for Traceablilty & Revisions	
	Desires	New link for every new revision	Link to subsections/folders
1	Ready solution before project finish	Reference	0
2	Standardized way of working at VCG		-
3	Level of workload		0
4	Usability (e.g. efficient, intuitive)		0
5	User complexity		0
6	Keeps all revisions tracable		0
7	Consistency		-
Results	Total +		0
	Total -		2
	Total 0		5
	Net Value		-2
	Ranking	1	2
	Further Development	Yes	No

Pugh Matrix 3:

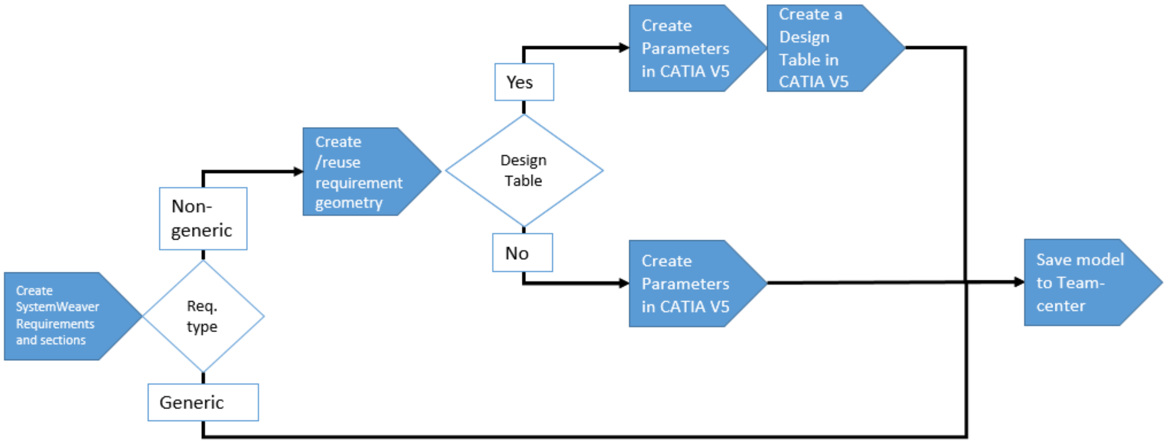
No.	Type	Concepts for Ownership Structure before Project Start	
	Desires	Owned by Requirement Owners	Owned by Recipients
1	Standardized way of working at VCG	Reference	-
2	Level of workload (for requirement owners)		+
3	Level of workload (for recipients)		0
4	Flexibility in requirement changes		+
5	Complexity in processing		0
6	Intuitive structure		-
7	Consistency		-
Results	Total +		2
	Total -		3
	Total 0		2
	Net Value		-1
	Ranking	1	2
	Further Development	Yes	No

Pugh Matrix 4:

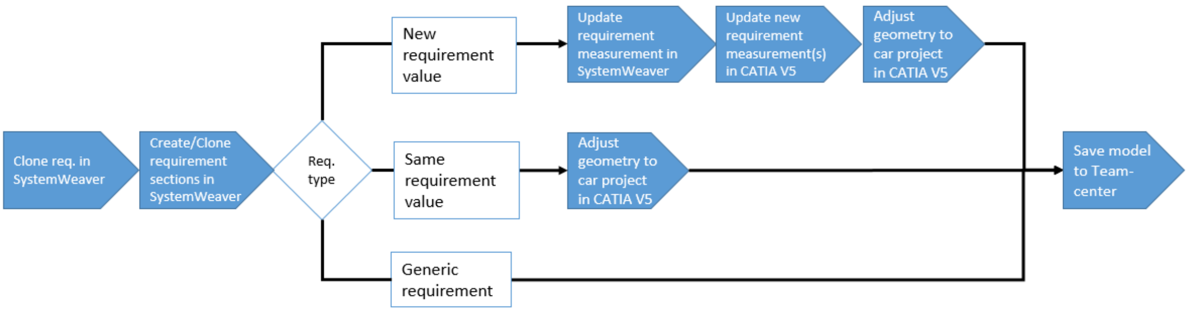
No.	Type	Concepts for Recipient Information	
	Desires	Subscribe in SystemWeaver	Personal contact, e.g. e.mail
1	Ready solution before project finish	Reference	0
2	Standardized way of working at VCG		-
3	Level of workload		0
4	Usability (e.g. efficient, intuitive)		0
5	User complexity		0
6	Recivement check		+
7	Development potential		-
Results	Total +		1
	Total -		2
	Total 0		4
	Net Value		-1
	Ranking	1	2
	Further Development	Yes	Yes

Appendix H (Solution Concept Processes)

Geometry-based requirement, creation process:



Geometry-based requirement, New Car Implementation Process:



Geometry-based requirements Requirement change loop: