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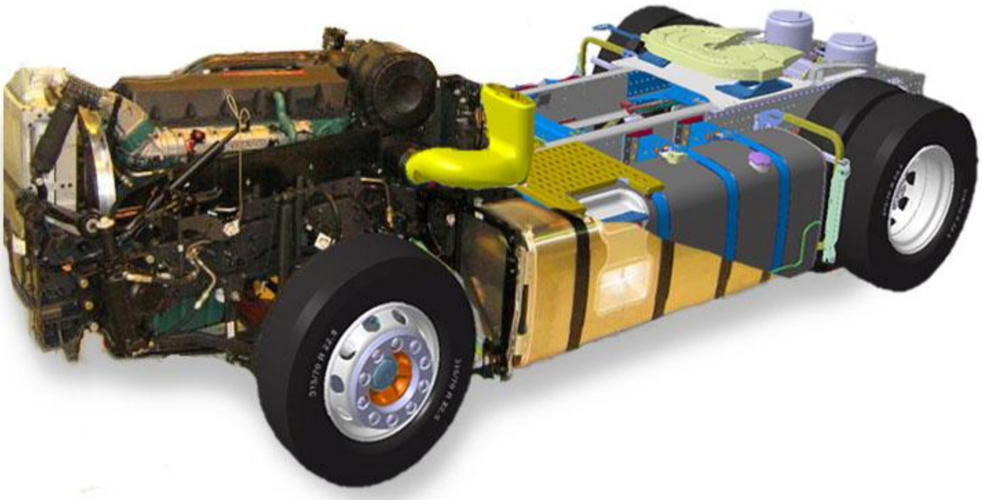

Concept platform for data transfer from virtual manufacturing to production preparation

Master of Science Thesis

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Cover:

A hybrid picture illustrating a 3D representation of a truck and a real photo of the same truck. Courtesy of Volvo Trucks.

Reproservice

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Abstract

To be competitive in today's market, effective use of virtual manufacturing tools are essential. It provides potential for shorter development cycles and less costly development since it reduces the number of physical prototypes. Along with other truck manufacturers Volvo Trucks have adapted mass customization and thereby have issues to address in the area of virtual manufacturing. This thesis have addressed three main questions: "Are there any complications in creating a concept platform connecting virtual manufacturing (VM) and manufacturing preparation?","Is it possible to realise a concept platform?" and "What benefits, if any, can be achieved by extended information transfer?"

A current situation analysis was performed to describe the current way of working at Volvo Trucks. Seven problem areas was identified: *variant richness*, *target vehicles*, *mismatch (between CAD part and real part), IT integration*, *multi factories*, *organisational boundaries* and *different product structures*. The problem areas were simplified to create a concept platform to transfer manufacturing preparation data from VM in Delmia V5 to SPRINT. Performing production preparation in VM makes it possible to use 3D representations of the product, which have been proved beneficial. It was seen that manufacturing preparation engineers at Volvo Trucks perceived the concept platform as useful. The concept platform in conjunction with the current situation analysis could be used to prove that it is possible to connect VM and production preparation as well as to create awareness within the investigated area.

Keywords: virtual manufacturing, bridging, manufacturing preparation, system integration, mass customisation, PLM, concept platform, demonstrator

Acknowledgements

We would like to give a big thank you to our supervisor Johan Sahlström for his knowledge and engagement. He was a very big help for getting hold of the right people and correct information. We also would like to thank our supervisor at Chalmers, Sandra Mattson, for the time she has invested in this project.

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1 Introduction

Gives a short background to the project and why it has been carried out. In the introduction the problem definition, purpose, goals and research questions are presented. The last part includes an overview of the report structure.

1.1 Volvo Trucks in a mass customized environment

According to Da Silveira et al. (2001), a substantial amount of companies today regard mass customization as a way to reach competitive advantage. In the world of heavy duty trucks there are a lot of variants as the customers require products that are highly adapted to their applications. Volvo Trucks have mass customization at the core of their business. In comparison to mass production, the goal with mass customization is to provide the customers with what they request but at near similar costs to mass production (Da Silveira et al., 2001). Another truck manufacturing company working with mass customization is Daimler. They are one of the world's largest truck manufacturers and state that all of the 120,000 trucks produced every year in their German plant in Wörth are unique (KPMG, 2011).

As stated, Volvo Trucks has a sales philosophy of offering and producing highly customized trucks according to the customer demands. The downside to this focus is that it becomes harder to optimize processes, resulting in lower efficiency. Scania, which are trying to reduce variant complexity by using modularization extensively, has around twice as high operating margin, compared to Volvo Trucks (Isskander, 2009). Having a sales philosophy of conforming to the customers' needs requires development, maintenance and ability to produce a huge amount of truck variants. This of course affects how development work can be carried out as well as manufacturing. Considering all variants in the development phase is in fact not possible at Volvo Trucks. Therefore simplifications are used where assumptions concerning for example manufacturability are made which later in the development to production chain potentially could lead to issues which are costly and time consuming.

Having well-functioning digital tools for Virtual Manufacturing (VM) is today necessary to conform to the ideas of mass customization (Iwata et al., 1997). The digital tools available have developed quickly over the last couple of years and competitors to Volvo Trucks are getting better at utilizing the advantages. Volvo Trucks are aware of this matter and want to improve the performance in the field of VM.

1.2 Problem definition

To work effectively with Virtual Manufacturing and mass customisation, several different softwares in the field of manufacturing preparation are used at Volvo Trucks. In the scope of this project, two parts of the process will be examined; virtual manufacturing and manufacturing preparation. The scope is highlighted, within the product realization process, in *figure 1*.

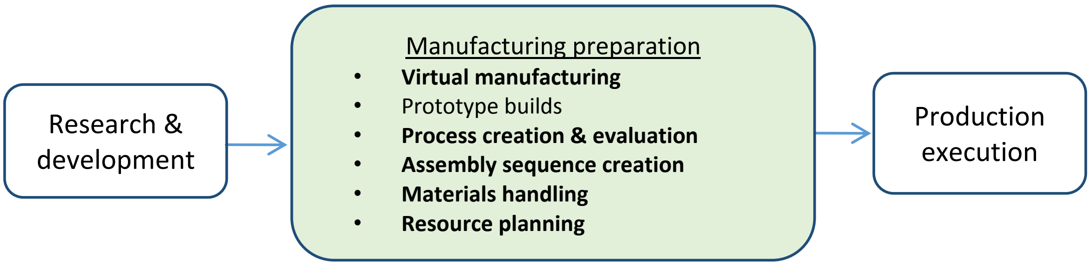

Figure 1: Project scope lies within a product realization process.

VM exists to verify research and designs (R&D) work and ensure the manufacturability of the trucks by creating virtual assembly processes. The product data available in this phase only covers a limited number of trucks, so called target vehicles. The virtual data, based on the target vehicles and created in VM at Volvo Trucks, is today not re-used in the manufacturing preparation and execution system SPRINT. This creates unnecessary rework and also implies that valuable information concerning manufacturability, established in the development phase, are not re-used when the product is prepared for production. There is therefore a wish to connect these two systems (and the development phases).

1.3 Purpose

The purpose of this master thesis is to investigate and explain why data created in Delmia V5 at Virtual Manufacturing is not re-used in the manufacturing preparation and execution software SPRINT, at Volvo Trucks. One way to solve this is to create a concept platform linking the VM environment (Delmia V5) and manufacturing preparation (SPRINT).

1.4 Goals

There are two main deliverables of this master thesis:

- A description of the current situation at Volvo Trucks explaining why data from Delmia is not re-used in SPRINT.
- A functional concept platform showing the data flow from Delmia to SPRINT. This includes a demonstration of the platform where it should be possible to develop a production sequence in Delmia and send it to SPRINT. The concept platform should use previously developed Lego trucks instead of real trucks to reduce complexity.

1.5 Research questions

The project's goals have been approached with three research questions:

RQ1 Are there any complications in creating a concept platform to connect Delmia and SPRINT?

RQ2 Can a concept platform be realized, and if so, how?

RQ3 What benefits, if any, can be achieved by an extended information transfer between these two systems?

1.6 Delimitations

The main focus is manufacturing preparation which delimits the manufacturing execution and logistics functions of SPRINT.

The connection done between Delmia and SPRINT need a detail level to connect the systems together in the context of the Lego models that are used in a previously developed Lego demo line. Therefore it is only necessary to create a limited concept interface between the systems. The Lego models are assumed to be a ready product in its final stage before production. Therefore the parts constituting a Lego truck are to be regarded to have the same and final level of maturity (the Lego models consist of 16 product variants).

The project should disregard unusual variants, e.g. special customer adaptations. The idea is not to create a complete coverage of all problems related to variants but to simplify and focus on presenting the main focus: the possibility of re-using information from virtual manufacturing (Delmia) in manufacturing preparation (SPRINT).

The development process examined only describes the case at Volvo Trucks, especially regarding final assembly.

1.7 Report structure

The three research questions are used as a connecting thread within the report. Chapter one, introduction, gives an overview of the project and present the research questions and goals. The theoretical framework, chapter two, helps the reader to understand the context of the master thesis and specific topics at Volvo Trucks. The methods and research approach is presented in chapter three. Chapter four describe how the project was carried out and how the results were attained. The results and accompanying discussion, connected to the three research questions, are found in chapter five and six. Final conclusions are given in chapter seven.

2 Theoretical framework

The theoretical framework presents the reader an understanding of the current situation analysis at Volvo Trucks. This includes the concept of mass customization, manufacturing preparation and virtual manufacturing.

2.1 Mass customization

Mass customization (MC) is a manufacturing strategy that aims to deliver customized products to a cost similar to mass-produced products (Coletti & Aichner, 2011). The production approach has evolved since about the 80's and lets manufacturing companies differentiate their product offerings and compete in competitive markets (Silveria et al., 2001). The development of IT systems for manufacturing and production is, apart from the competition, a necessity that has enabled the MC development.

Several levels of MC have been defined; in *figure 2* five the levels are illustrated ranging from no customization, to customization in the design phase (left to right), i.e. a completely unique product that is designed according to a customer's own specification. An example of low customization level is customized packaging of standard products. Bottled water having same content but different sticker is an example of such a case. The assembling of standard components into unique configurations is one widely used level that is followed by companies in several industries (Coletti & Aichner, 2011). Volvo Trucks is another example that applies customized assembly. To be able to maintain a high level of customization while reducing costs, modularization is growing fast. In the area of truck manufacturers, Scania is regarded to be the benchmark for modular thinking. Other subsidiaries within the Volkswagen Group (MAN for example) are also striving for more modularization. Daimler Trucks has the ambition to increase their modularization with non-variable parts from their current level of 50 percent to 70 percent. With modularization it is possible to reduce the amount of parts while still

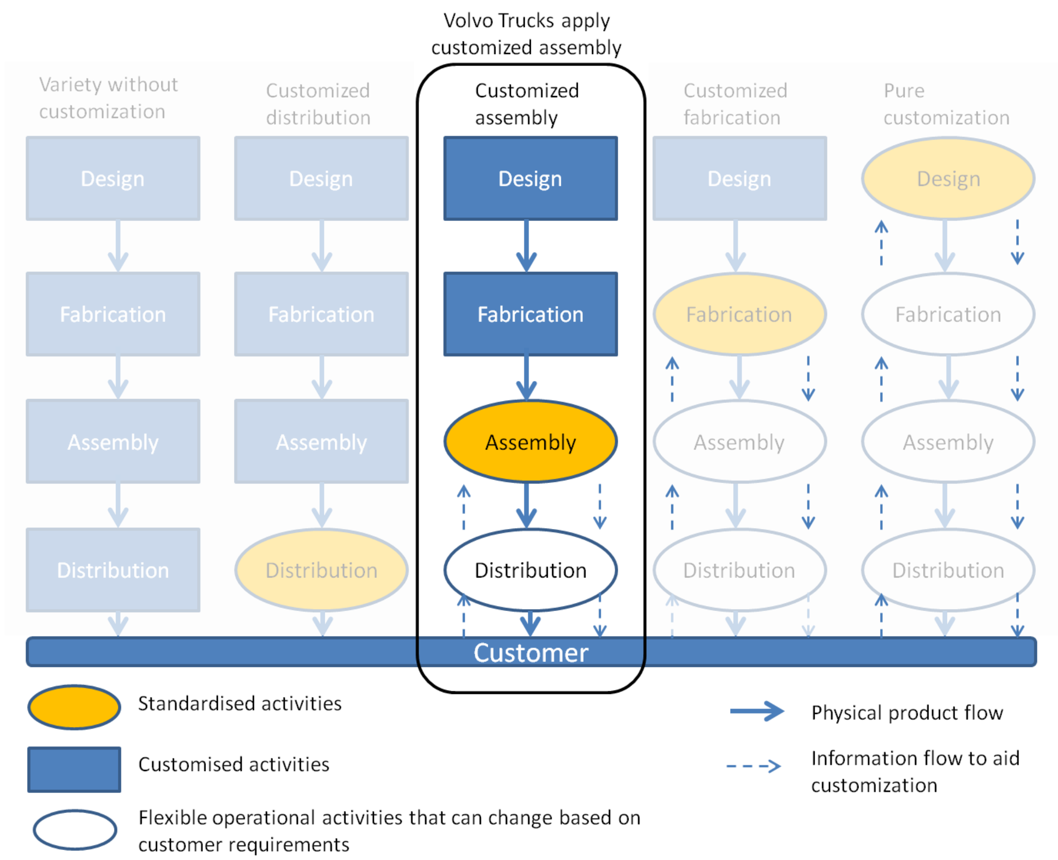

Figure 3: Levels of mass customization (Coletti & Aichner, 2011).

maintaining the required function and thus the customer value. By standardizing and modularizing electronics architecture and drive train components it is possible to create large positive effects since these components constitute around 60 to 70 percent of a truck's added value (KPMG, 2011).

2.2 The manufacturing preparation process

Manufacturing preparation means to prepare the product for production, taking consideration to product specifications as well as conditions existing at the manufacturing sites. In order for the process to work properly an appropriate transformation methodology as well as IT system integration is needed (Lee, Leem & Hwang, 2011). In the manufacturing preparation process the EBOM[1] must be translated into a MBOM[2]. One example of this is that some parts found in development can arrive pre-assembled to the manufacturing site, thus a translation and relation must exist between these different structures. This is a characteristics difference between EBOM and MBOM of the case generally described as "many to one".

When designing a product one usually use an EBOM where all the associated parts can be found. This is often structured so that it is convenient to use while designing the product. For example you need only to design a screw once even though you can use it in many places of a product. This screw can be categorized under for example "Fasteners" for easy retrieval of information during the design work. When you later finish the design work and move towards manufacturing of the product you need to translate your EBOM into a MBOM. The MBOM contains every single part that is going to be used when manufacturing the product. The parts are defined in the way they are bought or manufactured. Some parts from the EBOM might be pre-assembled when they enter the factory (PTC Help center, 2012).

Interrelated parts might also be distributed to several different places in the assembly structure. The same screw might be used ten times under "Rear axle" and four times in the category "Battery box". The MBOM contains a part list and a product structure that describe the relations between the parts.

When dealing with variants of the product, one could use an overloaded BOM, which contain all parts connected to a product class. Certain options or variant codes are then used to filter the overloaded BOM to represent a particular product (PTC, 2009).

2.2.1 Product, Process and Resource

The product, process, resource (PPR) concept is an approach of how to describe the elements required to manufacture any kind of products (Coze, 2009). Each expression describes a required cornerstone needed (another similar example is that there *have to be* oxygen AND fuel AND heat to make fire).

2.2.1.1 Product

Product contains the parts that make up the product. The product structure can look different during the different phases of development and production; the EBOM and MBOM structures are two common ones.

[1] Engineering Bill Of Materials reflects the product "as-designed", coming from design engineers.
[2] Manufacturing Bill Of Materials includes all the parts and sub-assemblies necessary to build a complete product.

2.2.1.2 Process

Process defines the operations, i.e. what actions that have to be done, and in which sequence they have to be accomplished to finalize the product. The process can also contain information about the time the operations should take.

2.2.1.3 Resource

Resource describes the required staff, tool, facilities, etc. required to carry out the process.

During production preparation it is common to work process-oriented, i.e. start with the processes definition followed by linking product parts to each process step where the part should be assembled, and finish with links to required resources. The PPR approach is used in the virtual manufacturing software at Volvo Trucks.

2.3 Virtual manufacturing

Virtual manufacturing (VM) is an approach to product and manufacturing development that propose the use of digital simulations and models to improve the process, i.e. reduce the time for development. In conjunction with virtual reality it also becomes possible to visualize and evaluate appearance of products before they actually can be built (Souza & Porto, 2006). It is a branch of the product development process, which has grown and evolved as the IT hardware, software and systems have improved. It is today almost necessary to use VM to be competitive on the market (Iwata et al., 1997). Using VM it is possible to perform production preparation with virtual models of the products, in contrast to physical builds.

There are several benefits with this approach. Shorter development times, higher quality and reduced costs are three main areas of interest. Coze et. al (2009) states that 80% of development costs are decided in the early stages of the development process. Some of the benefits are visualised in *figure 5*. The virtual tools are also used to prepare and verify the production process (Souza & Porto, 2006).

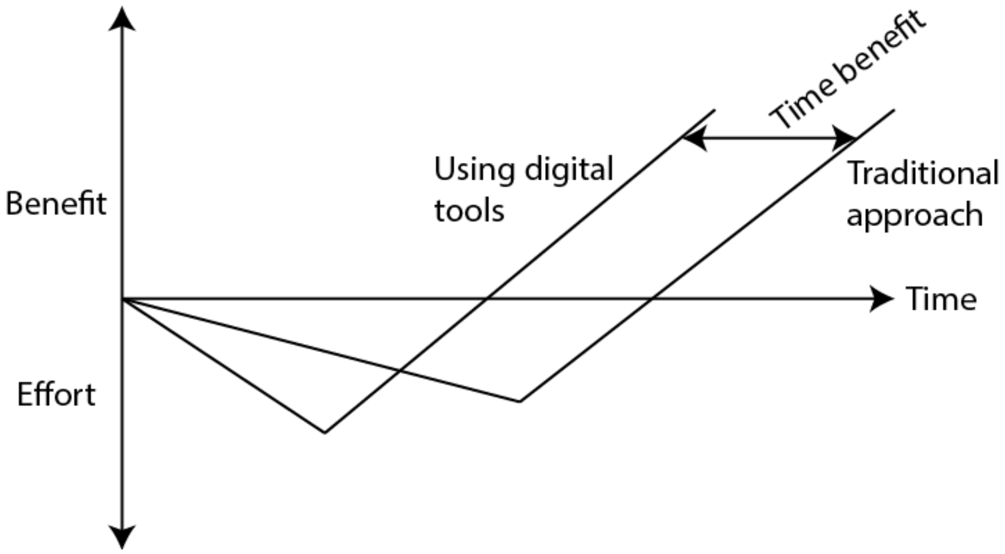

Figure 4: Using digital tools one can reach shorter time-to-market, reduced late-time error handling and overall lower effort (Coze et. al., 2009).

2.4 Volvo IT-systems

The Volvo group have many different IT systems from several suppliers as well as in-house developed systems. This section describes a few of them that are essential for this project: Delmia V5, KOLA and SPRINT are the three of greatest importance.

2.4.1 Delmia V5

Delmia is a software suite developed by Dassault Systèmes and is a tool for control, creation, planning and monitoring of virtual production processes. Delmia is an abbreviation for Digital Enterprise Lean Manufacturing Interactive Application. In the software it is possible to use 3D representations of products or parts. At Volvo Trucks version V5 of Delmia is currently in use.

2.4.2 KOLA

KOLA is an abbreviation for KOnstruktionsdata LAstvagnar and has evolved during several decades. The system is developed in-house by Volvo IT. KOLA is the core system where all information about the trucks is documented with references to and relations between parts, drawings and digital models. The information is organized in several structures that together make the whole system. In KOLA the business logics for the company can be found. In short terms the following structures build the KOLA logic structure: item, variant and item to variant structure.

Item structure

The item structure contains all parts that are needed to specify and build any valid and allowed truck. There are four items categories: part, drawing, digital model and interface. The structure also deals with the relations between different items.

Variant structure

The variant structure specifies all variant families and the variants in respective family. For example a variant family can be “fuel tank volume” and a variant might be “600 litres”. The variant structure is specified by the different variants together with a set of rules, authorizations, restrictions and exclusions. The rules describe how to deal with the variants from a technical, market and factory point of view.

Item to variant structure

The item to variant structure connects material from the item structure to variants from the variant structure. This is done to make a “bill of materials” for a specified vehicle. For every item there is a link to one or many variants for which the material shall be consumed.

All KOLA structures exist for material, i.e. the real items used in the factories, and for CAD parts and modules. However, the documentation in the CAD structure is not fully documented i.e. there is no information in KOLA about how and where the parts should be mounted or built. That information is kept in another system, SPRINT

2.4.3 SPRINT

SPRINT is an abbreviation for INTegrated Production System and it is a MRP II (Manufacturing Resource Planning) system. It is built up by about 500 tables that contain almost all production information. SPRINT is developed in-house by Volvo IT and the essential function of SPRINT is to ensure correct material, in the right time, at the desired place together with the associated assembly instructions. SPRINT is used both for manufacturing preparation as well as production execution, see *Figure 6*. The manufacturing preparation part is used before the product enters serial production and when the product changes during its lifetime. The system controls the manufacturing execution process and keeps track of material flows, operator instructions, tool data, factory structure, operator structure. All data in

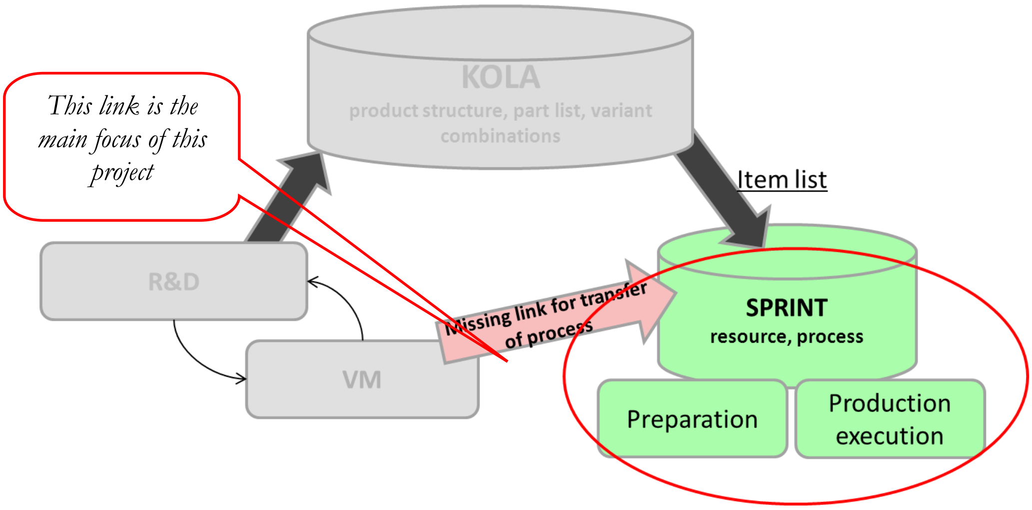

Figure 6: SPRINT handles both production preparation and execution.

SPRINT, except the material bills (which is fetched from KOLA), is entered by manufacturing engineers during the latter part of the product development process. Also, during the entire product lifecycle the data in SPRINT is kept up-to-date. Otherwise the production would not be able to run. In order to work in SPRINT it is important to be very familiar with the truck assembly structure as well as the factory layout because of the high detail level in needed in both product and factory structure. In the system there are no graphical representations of the materials.

2.4.4 AVP – Automated Vehicle Packaging

Automated Vehicle Packing (AVP) is a system that is used to build digital mock-ups (DMU, digital models of a complete vehicle) which is used by virtual manufacturing. The DMU is specified in the same way as an ordinary truck, using variant strings. The difference is that CAD parts and modules are used instead of materials and assembly parts. Certain CAD parts are generated based on the variant string, i.e. they do not exist before running the AVP order. An example of this is the chassis sides of the truck that has a unique layout for almost every truck. If certain item-to-variant links lacks connection to CAD-modules in KOLA, the AVP-generated DMU will lack that same information. KOLA is used to fetch the information necessary to build the DMU.

3 Methodology

This chapter describes how the results have been attained. This is done through the choice of approach, data collection methods and analysis of the data. Choice of approach describes the initially chosen way of working towards reaching the goal. *Data collection* gives a more in-depth description of how data was collected throughout the project and why the methods were chosen. *Analysis of data* formulates how conclusions and hypotheses were formed.

3.1 Choice of approach

This is the description of the originally chosen approach to answer the research questions given. To be able to do so, several methods were chosen. The overview of the research questions and the associated approach can be found in *table 1*.

RQ1 Are there any complications in creating a concept platform to connect Delmia and SPRINT?

RQ2 Can a concept platform be realized, and if so, how?

RQ3 What benefits, if any, can be achieved by an extended information transfer between these two systems?

<table>
<tr><th>Research questions</th><th colspan="2">How the question is answered</th><th>Aim</th><th>Data collection</th><th>Analysis</th></tr>
<tr><td>RQ1</td><td>Current situation analysis</td><td rowspan="3">Theory</td><td>To achieve understanding</td><td>Interviews, observations, literature studies</td><td>Grounded theory, triangulation</td></tr>
<tr><td>RQ2</td><td>Concept platform</td><td>Present a solution to the given problem</td><td>Interviews, literature (documentation) studies</td><td>Grounded theory, data mapping</td></tr>
<tr><td>RQ3</td><td>Usefulness analysis</td><td>Present the usefulness of such a solution</td><td>Interviews</td><td>Grounded theory</td></tr>
</table>

Table 1: Relations between research questions and used methods.

In the current situation analysis it was regarded important to have a good knowledge about the surrounding systems to reach the goal of creating a concept platform. Focusing only on the two systems to be connected (Delmia and SPRINT) would have led to unawareness of associated problems that occur in other places of the product development process. Such problems could lead to a badly adapted implementation of the concept platform as well as lack of knowledge when doing analysis of the use of the solution. The current situation analysis was to be conducted by performing interviews, observations and literature studies. It was regarded important to analyse:

- the different systems and their functions
- the connections between different systems
- which data formats that are in use
- what are the sources of information and data

To look at the topic of product data management from a larger perspective, a comparison between companies offering PLM (Product Lifecycle Management) solutions would be done. The three companies chosen were PTC, Siemens and Dassault Systemes. The reason for choosing these three was partly because they are among the biggest companies in their field and the fact that they all claimed to be able to offer Volvo Trucks a solution to the issues highlighted at Volvo Trucks. The comparison would be done to help identifying problem and improvement areas at Volvo Trucks.

Having good system knowledge about the two systems Delmia and SPRINT make it possible to perform a data mapping between the two as a first step in linking them. The data mapping would then serve as a basis when doing the actual programming and implementation. The usefulness of the concept platform and extended data transfer between virtual manufacturing can then be analysed by looking at the ready-made current situation analysis and concept platform. By using data triangulation, multiple data sources can be used to develop and strengthen results.

3.2 Data collection

Due to the nature of the project and the data required being collected, qualitative data collection methods were regarded more beneficial to use than quantitative methods. Qualitative research put focus on the achievement of deeper understanding and cause and effect rather than quantitative methods that focuses on statistics and confirmed results. According to Williamson (2002) qualitative data collection have less guidelines of how to perform the work compared to quantitative data collection. The importance is to perform the data collection thoroughly. It is also recommended to analyse the data directly when it is gathered. Doing so makes it possible to see when data saturation occurs and thus know when to stop the data collection (Williamson, 2002).

3.2.1 Strengths and weaknesses of the chosen methods

The methods chosen were regarded to be the most beneficial to answer the given research questions. *Table 2* presents an overview of why the chosen methods were picked.

Method	Main reason of use	Weaknesses
Semi-structured interviews	Good at handling complex subjects (as covered in this project).	Often includes non-value adding information.
Literature studies	It is an effective way of representing for example previous research studies.	Can be hard to find information directly related to the investigated subject.
Observations	Can quickly identify problem areas and can also be non-obtrusive.	Could potentially give a limited picture if the sample size is too little.
Questionnaire	Could present the view of many without the need of excessive data handling. It is therefore quite quick.	Generally requires simple and quantifiable questions.

Table 2: Shows the strengths and weaknesses of the chosen methods

3.2.2 Semi-structured interviews

Due to the complexity and width of the problem area, interviews were performed with system experts. Few, if any, had a general picture of the investigated areas. Therefore several experts were interviewed and their knowledge was correlated using grounded theory. Some questions was used as a base for the interviews but were followed up to match the knowledge area of the peoples interviewed. Interviews were performed until enough data was collected and data saturation was reached. The findings from the interviews were taken care of in the following way according to literature by Williamson (2002):

1. **Transcribing**
   The interviews were documented so they could be verified.
2. **Creating memos and summaries of interviews**
   This was done to be able to find relevant key points and get an over overview of each interview.
3. **Categorizing the interviews**
   Categorizing the interviews with key words and content.

3.2.3 Literature studies

Literature studies were carried out to find relevant information connected to the subject. The project used a systematic strategy like the one suggested by Sørensen (2004) when doing the literature studies to find accurate information. Studies done at other companies were investigated to find similarities or differences compared to the situation at Volvo Trucks. Documentation like manuals and guides concerning Volvo Trucks specific systems were also used. The sources and their content were critically investigated.

3.2.4 Observations

Some data were gathered through observations while investigating a particular topic. The observations were non-obtrusive. The observation style Ad Libitum described by Williamson (2002) does not focus on a particular subject or object and is beneficial to use when initially gathering information about a new topic. It was therefore chosen to be the main observation method in early phases of the project.

3.2.5 Questionnaire

Questionnaires are used to capture the perspective from a group of people regarding a set of particular questions of simple, quantifiable character. Using a questionnaire for these kinds of questions is preferable since it is less time consuming than an interview (Williamson, 2002). Results from the interviews were used as a base for forming the questions asked in the questionnaire.

3.3 Analysis of data

The project followed a Grounded theory approach which in short means that the theories and conclusion should be grounded in the collected data (Glaser & Strauss, 1967). The main focus in grounded theory is to use inductive data collection, developing theories from the collected data and later verify the theories by using a deductive approach. The perspective could also be seen as a bottom up-approach where patterns and relations are visible as you collect and analyse the data (Glaser & Strauss, 1967). Bottom-up means to form something bigger by connecting smaller parts. Information mapping and its principles about maps and blocks will be used to further understand and structure the collected data (Horn, 1974).

Data mapping is used when trying to create an interface between two data systems. Such a mapping specifies the relationships between two data schemas (databases). A data mapping is an important tool for integrating systems and transferring data (Chiticariu & Tan, 2006). Data mapping was mainly used when developing the concept platform.

3.4 Reliability and validity

The methods within this project were chosen to give as reliable and valid representation of the studied topics as possible. Having collected reliable data means that the information is consistent even if it is collected at different times. Reliability within this project was ensured by crosschecking data from different authors and resources. This way of working is called triangulation and can aid in validating data or finding correlations in the data collected and between different methods (Olsen, 2004). Inconsistencies will be followed up to gather the correct data or note that the data differs between authors or sources. The reliability is also aided by a thorough methodology description so that the same procedures can be reproduced and thus also, most likely, the same results.

Validity refers to how accurate the data collection was and that the collected information is relevant to the studied problem or area (Williamson, 2002). The aim of the master thesis was to give an accurate representation of the problem and that the collected data could be verified.

4 Implementation

The implementation is a description of how the project was carried out, how the methods were used to reach against the aims and also, if any, deviations from the originally chosen approach.

An overview of the three main parts of the project is illustrated in *figure 7*. The Current situation analysis serves as a foundation for both the concept platform and usefulness analysis. The Concept platform is a realisation and solution for the problem described. The Usefulness analysis relates data from the two previous parts to better evaluate the effects of creating this kind of solution.

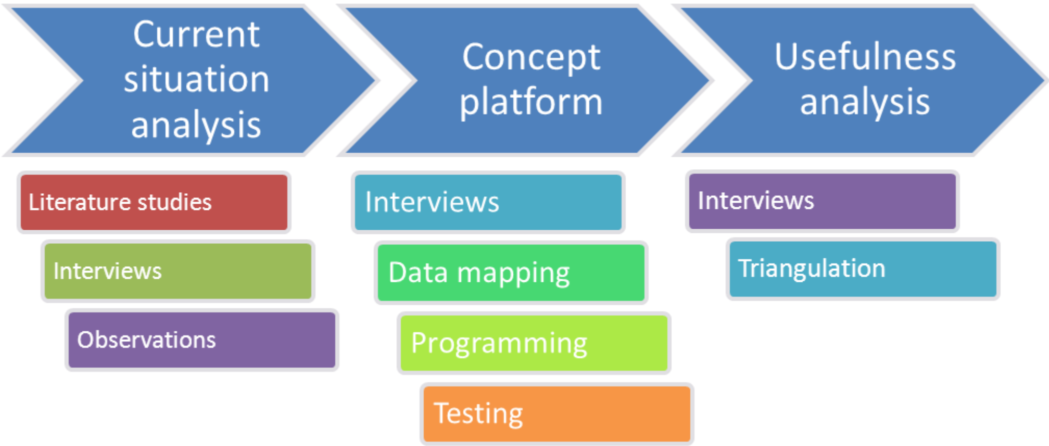

Figure 7: Shows the three main parts of the project.

Narrowing the scope

The first month of the project mainly consisted of data collection and grasping the problem. During this time a number of people were interviewed and the possibilities of creating a concept platform were investigated. The original plan was to extend the functionality of the now existing demo line built in a previous master thesis. Due to the complexity of the IT systems SPRINT and MONT (used in the demo line), Volvo IT could not deliver an interface between the two within the time frame of this master thesis. Therefore the scope of the concept platform was narrowed to only cover Delmia and SPRINT as shown in *figure 8*.

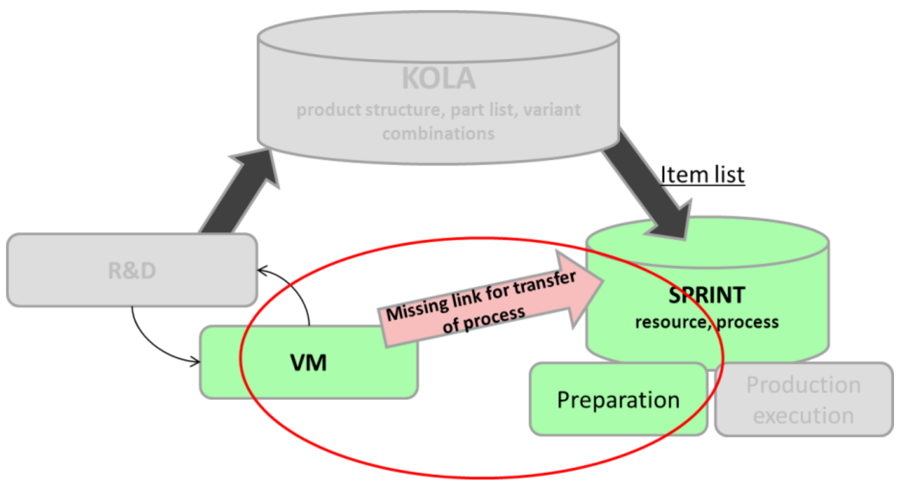

Figure 8: The focus area of the project will be the link between VM (Virtual Manufacturing) and Manufacturing preparation and execution represented mainly by the system SPRINT. But to do this in a good way, the whole system perspective has to be understood.

4.1 Current situation analysis

This project phase was done to gather the relevant information concerning possible problems and surrounding functions. Most time consumed was spent during the initial parts of the project. In this phase the manufacturing preparation process as a whole, the methods and the IT-systems was investigated. Issues related to BOM handling, variant handling and CAD to material links were identified here. The current situation analysis included: interviews, literature studies and observations.

Data collection was mainly done through interviews with people working at Volvo Trucks. An overview of the interviews, the associated keywords and interview questions can be found in *Appendix A – List of interviewees* and *Appendix B – Interview questions*. The people interviewed were mainly system experts or users in a certain area. Among these were people working with virtual manufacturing in Delmia and those working with manufacturing preparation in SPRINT. To get a wider and more complete picture, several interviews concerning the same topic were triangulated and compared.

Literature studies were performed to understand more about certain topics from an outside perspective to better see how Volvo Trucks related to these. The literature studies covered investigations from other truck manufacturers such as Scania as well as technical documentation at Volvo Trucks regarding system parts.

Observations were used to see how Volvo Trucks procedures and systems worked. Since much of the business logic is built into the IT-systems it was beneficial to test scenarios in these to understand how Volvo Trucks are working.

To highlight and be able to spot weaknesses and strengths in the current way of working at Volvo Trucks, other system solutions were investigated. This became a brief study of three companies besides Volvo Trucks offering PLM solutions. BOM handling, variant handling and CAD to material links were some of the topics investigated since they played a big role in solving the problems. All of them had in one or another way been partners to Volvo Trucks. The three companies were: PTC, Siemens and Dassault Systèmes.

To better understand KOLA, one of the core business logic systems at Volvo Trucks, a downscaled version of the system was developed using Microsoft Access. The user interface can be seen in *figure 9*. It has the same general functions as the real system but less functions in the user interface. It was only populated with data concerning the Lego trucks' variant structure. It was also built to have the possibility to be linked with the concept platform if it later was regarded beneficial.

Compared to the originally chosen approach, some ideas were more or less changed or left out. One of them is the idea about investigating what data formats that were used between the systems. It became clear that this was a too technical approach and had limited use for the final understanding. It was therefore generally omitted and used only were it was relevant for the understanding.

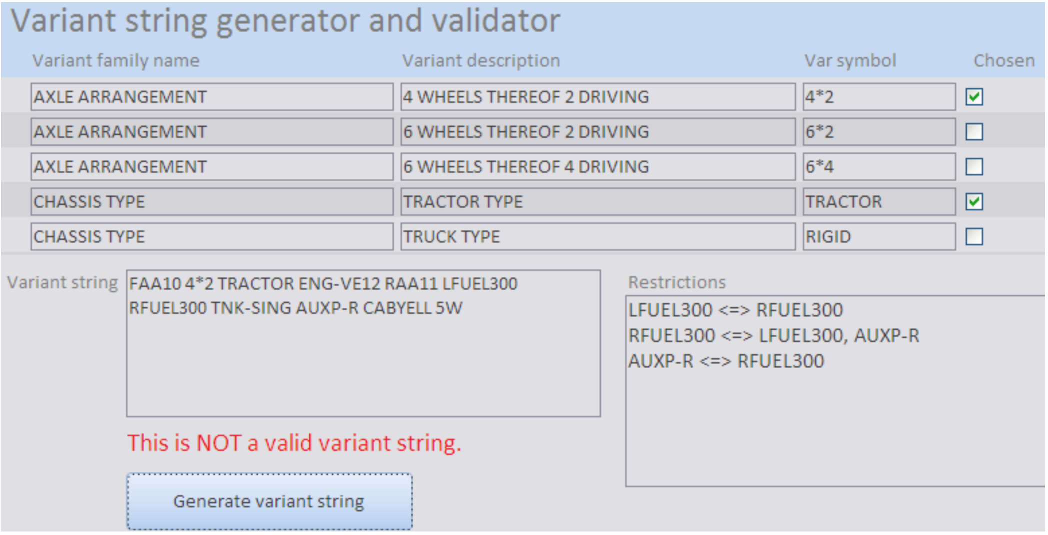

Figure 9: Shows the downscaled version of KOLA built to learn and understand the system better.

4.2 Concept platform

Creating the interface between Delmia and SPRINT served the purpose of showing that it was possible and also how it was possible. To be able to do this the identified issues needed to be addressed and simplified to a suitable level (to be able to develop the concept platform within the scope of the project).

Having narrowed the problem into this project's solvable proportions, a data mapping was done. This data mapping first identified what data was available and needed for both Delmia and SPRINT. Secondly a translation table was created where the two data structures were connected in theory. *Figure 10* shows an overview of the two structures and the starting linking between an operation step in Delmia and Core Instruction (CI) in SPRINT.

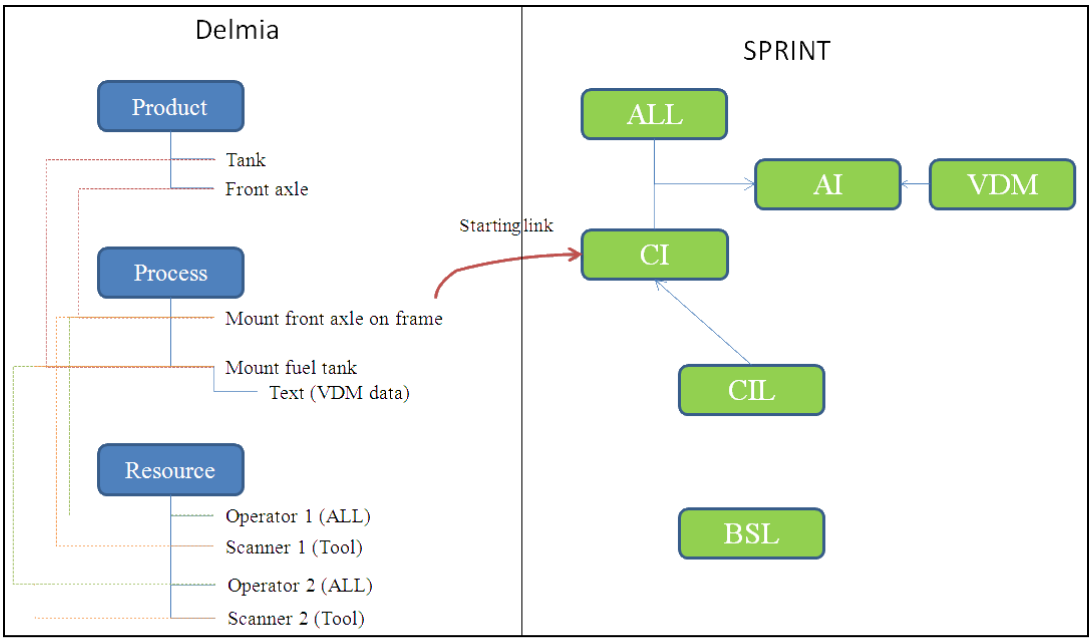

Figure 10: The two general data structures of Delmia and SPRINT were linked using data mapping.

With the data mapping done it was possible to work with Delmia and SPRINT independently. Since Delmia is a generally available system it has a built in function for writing Visual Basic Script (VBScript) to automate certain functions within the software suite. This ability was used to create a VBScript that could export the necessary data in the requested format. To make the Lego product structure in Delmia represent the modules in physical parts, an import script was written, in VBScript, to directly generate the right product structure in Delmia. The connection to SPRINT was done with the help of system experts from Volvo IT (they aided in creating the correct database connections according to the information found in the data mapping).

4.3 Usefulness analysis

An analysis of the results gathered in the current situation analysis and during the development of the concept platform, was done in order to see what problems the concept platform would solve and in that case, how well they could be solved. To investigate the usefulness from the perspective of the people working with manufacturing preparation a questionnaire was sent out. The questionnaire can be found in *Appendix C – Questionnaire for manufacturing preparation*. The questionnaire aided in the investigation of how common certain problems were.

5 Results

The results chapter handles the outcomes from the project. This chapter mainly consists of two parts: the current situation analysis and description of the developed concept platform.

As can be seen in *figure 11*, there exist data links between most systems and development phases, but not between the virtual manufacturing and manufacturing preparation. It is this connection the project actually is addressing i.e. that the assembly sequences developed by VM department in Delmia cannot be implemented automatically in SPRINT by manufacturing engineers. This has been questioned and in connection a host of related issues was discovered. The issues are presented in the current situation analysis (section 5.1), along with a product and process description. The presentation is followed by an explanation of the concept demonstrator (section 5.2) and what simplifications that was done in order to implement it. The usefulness analysis (section 5.3) documents the results gathered concerning the concept platform and how well it works.

5.1 Current situation analysis

The current situation analysis has resulted in a description of the product and process as well as seven identified problem areas and related issues. The resource aspect is not present because it was considered to have a smaller impact on the concept demonstrator compared to the product and process aspects.

5.1.1 The product

A truck is a complex product with high customer demands in quality as well as function and customization possibilities. Like most other manufacturers, Volvo Trucks is an assemble-to-order company, i.e. every truck that is built is already purchased. Volvo Trucks also share the mass customization (MC) approach with its competitors. However, the level of MC is very high at Volvo Trucks with a series volume of only 1.4. According to Coletti and Aichner (2011) the level of MC is in the middle on the customisation scale given that no new designs are made to customer demand but every product is assembled by standard components to form a unique, or almost unique, end product. The fact that Volvo Trucks are producing special customer adaptations is left out of this analysis.

During the development process, the product is treated by several peoples from different professions. Due to different needs the product is structured in different ways. During the product development it is logical way to group parts with similar functions together. When preparing the manufacturing on the other hand, the logical way is to treat the parts in a structure to match the sequence in which the parts are assembled. The development structure often refers to the EBOM and the assembly structure as MBOM, as previously described. Another difference between the development and VM compared to production is how assembly units[3] are treated. VM departments may form huge CAD modules that represent several parts or assembly units. These have to be split to smaller units for production when doing real production preparation.

5.1.2 The process

This section aims to describe essential information about the development and production preparation process at Volvo Trucks. This is made to make it possible to understand the following discussions. It should not be considered as a complete description of the process.

[3] An assembly unit is a purchased part, not manufactured in-house. It may consist of several subparts or subassemblies e.g. wheels that consist of tyres and rim.

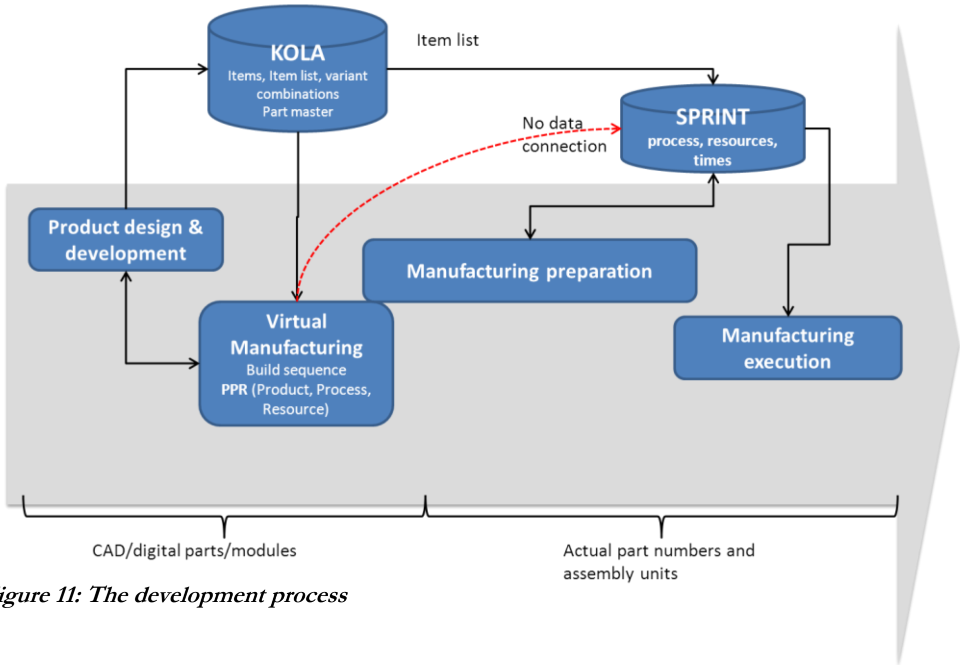

Figure 11: The development process

Figure 11 briefly illustrates the development process from Research & Development phase (R&D) to production phase. R&D is responsible for the construction and fulfilment of requirement specifications for any specific part. R&D collaborates with VM to ensure that the product can be manufactured and in a reasonable sequence. It is important to notice that R&D and VM make use of digital models in their tasks in contrast to production preparation where actual parts and assembly units are used. The virtual trucks used in VM are today created in AVP (Automated Vehicle Packaging, explained in section 2.4.4). Generating a truck with AVP takes time and users many times have to wait several days to get a virtual representation of a truck.

At a certain time in the development, the part maturity is enough to release part numbers and it is possible to order physical parts. During this phase, information about the process, like build sequence and resource needs, is added. The assembly sequence is developed partly by VM tools and partly by physical prototype builds. The wish is to decrease the amount of physical pre-builds and use VM instead because of the benefits presented in the theory part.

During the development process the IT systems KOLA and SPRINT carry the product and production information. KOLA is where the product structure and variant combinations are specified. SPRINT is fed with part lists and variant information from KOLA. In SPRINT the information concerning manufacturing and production process is added. KOLA contains information about both digital parts and real parts while SPRINT only treats actual parts for production purposes.

5.1.3 Identified problem areas

Within the current situation analysis seven areas with issues have been identified. These obstruct the creation of a seamless data transfer from VM to production preparation in SPRINT. The problem areas are illustrated in *figure 12*. The areas and their impact on the data transfer interface along with the impact on the overall process are hereafter described starting with variant richness and continue clockwise according to *Figure 12*.

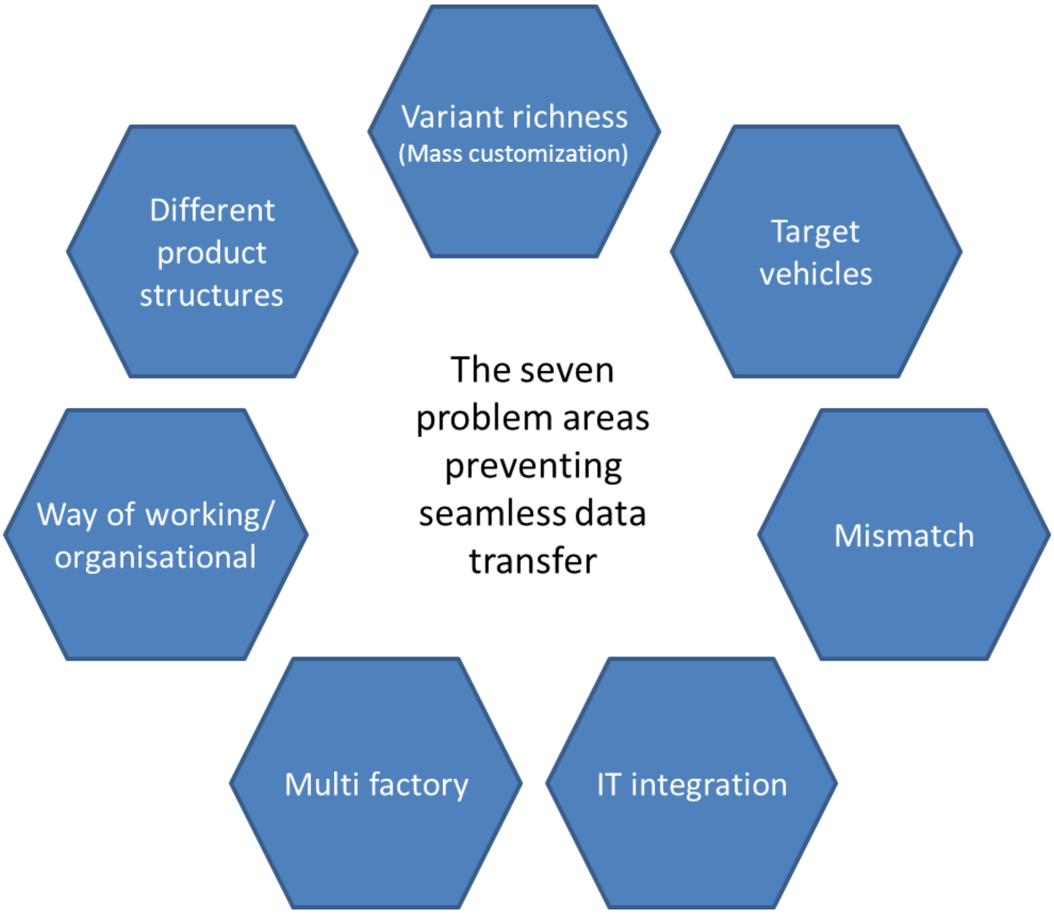

Figure 12: The seven problem areas at Volvo Trucks preventing seamless data transfer from Virtual Manufacturing to manufacturing preparation in SPRINT.

5.1.3.1 Variant richness

As described in the introduction, Volvo Trucks is offering highly customizable products to its customers. The customers have the possibility to specify the truck within the scoop of allowed variants from the variant families. The variant families specify areas where choices can be made and the variants are the possible options within the family. E.g. is fuel tank size a variant family and the 600 litres tank is one specified variant. Beyond the variants the customer also has the possibility to make a special order if no variant is suitable.

ISSUE 1: The variants themselves are not a big issue but the huge amount and the many possible combinations make it very hard to verify what can or cannot be manufactured and to what cost. It also obstructs other problem areas.

5.1.3.2 Target vehicles - Product simplification during development

As a consequence of the many possible variant combinations it is not possible to test build every variant combination, neither in VM nor in reality. The solution is to specify a reasonable amount of target vehicles that represents as much different variants and variant combinations as possible. Important to notice is that many (uncommon, but allowed) variant combinations will be untreated due to the high amount of possible combinations. The target vehicles are used both for virtual builds and processes evaluation along with real prototype builds. Though, virtual builds are possible to do in earlier phases of the development, before parts exists to build real vehicles.

During development of new products, before any real parts exist, the digital parts and modules is documented in KOLA with item to variant links only for the desired target vehicles. At a certain time the part maturity is enough to release it with a real part number. Now again, the real part is documented in KOLA, but this time for every possible and allowed variants where is can occur. The information regarding real parts gets fully documented but the CAD-module structure does not get updated at the same time.

ISSUE 2: The same part/module now has two different documentation levels: one possibly incomplete for the digital version and one complete for the actual part. This results in shortcomings when trying to build digital mock-ups of non-specified variants. If trying to transfer processes from VM to production preparation it might be materials left that have not been prepared because it does not exist in the VM, but in reality.

5.1.3.3 Mismatch

The mismatch problem area is strongly related to the difference in product structures, which is described in 5.1.3.7. As mentioned the truck can be described with digital parts and modules as well as with actual assembly parts and assembly units however, during the research it appears that a certain specified and assembled truck might not be possible to be fully described in terms of digital parts and modules. There are several reasons to this:

- The simplification with target vehicles during development results in an incomplete item-to-variant structure in KOLA for digital parts. It then becomes impossible to find item-to-variant links for others than target vehicle combinations.
- There is not always a one-to-one mapping between items in the digital part structure and parts in the materials structure see *table 3*. This will result in shortcomings if digital shapes are mapped to actual part numbers. Due to this it will also be problematic to transfer virtual processes to real ones because the process is described as digital shapes.
- It is a difference in how CAD parts are grouped to modules in VM compared to the assembly units that are used in production. This is partly because people working with VM do not know exactly what parts that are assembly units or not (Axelsson, 2013) and partly because there is no need to be as detailed in VM as in production.

- The links between digital and real parts are not fully documented. This makes it difficult to find out if, and what digital representation that belongs to a real part or vice versa.

The described reasons to mismatch can be sorted under the concept *bridging issues,* which describe differences in the structure. During the current situation analysis it was encountered that Volvo Trucks is running a project that is trying to resolve the bridging issues. This project will make suitable simplifications but preserve essential problems for demonstration purposes.

ISSUE 3: A valid variant string will not result in correct material from the CAD structure. This results in an incomplete or incorrect digital model.

ISSUE 4: A parts digital parent cannot be traced.

CAD structure	Materials structure	Description
		One CAD representation results in one material. One-to-one mapping is possible.
		One CAD representation results in several materials in the assembly. One example is tires that can be of different brands but is modelled with one digital shape only.
		Several CAD representations are needed to visualise one material part e.g. pipes or cables with different mountings in the assembly.
		Material may exist in reality but does not have any digital representation, e.g. oil.
		Several CAD representations results in one assembly unit. E.g. finished parts that is bought by suppliers, but individually represented in the virtual environment.
		There is no link between digital shape and real part.

Table 3: Differences between CAD and material structures.

5.1.3.4 IT integration

Almost all communication within the company is carried out by digital messages and data transfers between different systems. With today's computer power and network infrastructure this is the common way to exchange all kind of information. Due to different reasons (one is to keep business logic in-house) Volvo Trucks have several systems and softwares that are developed in-house by Volvo IT. These softwares are well adapted to their specific task. One drawback is that many systems are required to carry out what in these days could be carried out in an integrated business application. However, a decision to keep certain systems exists and others have to be adapted to be compatible. Observations and interviews (Granstav, 2012; Axelsson, 2013) showed that users have to use multiple-software simultaneously to find relevant information and solve problems.

Within this project's scope there were a wish to integrate the two systems Delmia and SPRINT. The desire was to be able to populate the SPRINT structure elements with data extracted from Delmia such as material routings, work orders, assembly sequence etc. The major IT issue in that sense is the lack of a suitable import function in SPRINT. In fact SPRINT gets material lists from KOLA, but the wanted import should be more flexible to handle different types of data. Along with the described issue a lot of other interfaces exists that communicate with the manufacturing process. However, these are not considered by this projects scope.

ISSUE 5: No suitable import interface exists in SPRINT.

5.1.3.5 Multi factories

The company has several manufacturing sites over the world and there is no standard layout so far i.e. one factory is not similar to any other one. The most optimal, but also unrealistic, would be identical layouts to make manufacturing preparation work universal for every site and minimize local preparation work. For the concept platform this will not be an issue because it is focusing on the Lego demo line as the only site.

ISSUE 6: Production preparation has to be done separately for each manufacturing site.

5.1.3.6 Organisational boundaries

The organisational boundaries relate to political issues and human behaviour. The two departments working with virtual manufacturing (in Delmia) and manufacturing preparation (in SPRINT) do not have an integrated way of working. The first issue lies in the fact that their main use, within the product realization process, is at different times. VM departments work in earlier phases and have less final information at their hands. Manufacturing preparation in SPRINT is carried out later in the development process and its main task is to prepare the product for actual production, industrialisation. One issue with this is that a lot of problems are identified late in the development process where they often are harder and more costly to fix. Bragsjö (2012) states that the CO-builds (physical prototype builds) are the first place where you can verify that the trucks are buildable. A lot of previously undiscovered problems are also identified here.

Next issue with VM and manufacturing preparation, being two disconnected departments, is that VM do not have to conform their work to meet the needs in SPRINT. Since VM gets most of their tasks from R&D they only need to work in a detail level needed to answers the assignments given by R&D. This detail level is today not sufficient for the needs of production preparation, in SPRINT. If one would assume production preparation being the immediate customer to VM, the level of detail in Delmia would need to be higher. VM do not have a management decision to directly support production preparation.

Having virtual manufacturing and manufacturing preparation separated and also working in different phases during the product realization process mean that there are big differences in product, process and resource knowledge. The people working with manufacturing preparation in SPRINT have a close relationship with the factories and therefore have better knowledge about these areas. Since much of this information is missing in the department working with VM, different approaches to solving a problem will be taken. One example can be how parts should be grouped. This leads to the product being described in different ways in the two departments.

When looking at having two separate departments decision-wise it often leads to sub-optimization. This is confirmed to be the case at Volvo Trucks as well. One example of this is R&D optimizing their work that leads to problems downstream in the product realization process (Stokke, 2012).

Data ownership is another identified issue. This is closely related to the product realization process and its progression. At a certain stage the data ownership is handed over to production preparation working in SPRINT. They then take the existing data in KOLA and use it to create assembly instructions and processes. At that stage they are adding information to the project which mainly only is usable within their area. VM can for example not use the added data even though it could be beneficial to do so. This leads to that the data found in VM is not updated and therefore an inaccurate description of the process. *Figure 13* shows an example how this looks over time at Volvo Trucks.

ISSUE 7: Departments are detached from each other and sub-optimized.

ISSUE 8: When data ownership is transferred to SPRINT at a certain time, the information added in SPRINT can later not be transferred upstream. This implies incomplete documentation in the upstream VM system.

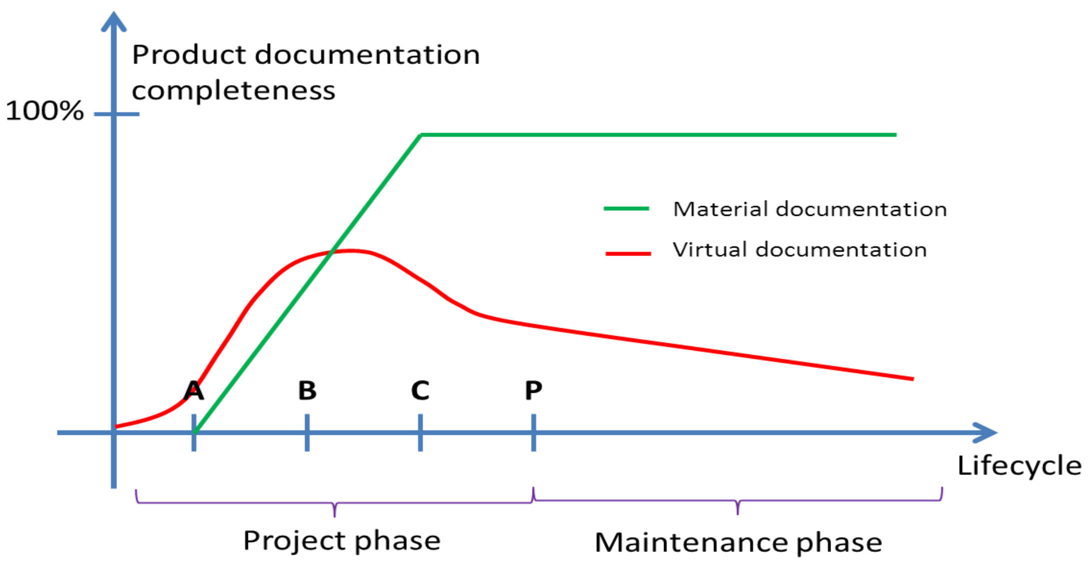

Figure 14: This graph represents how well the product is documented during different phases. Material documentation can among other places be found in SPRINT. The virtual documentation found in Delmia degrades over time since there is no demand to keep it updated (Köhler, 2012).

5.1.3.7 Different product structures

As mentioned in *5.1.1* the product parts is structured in different ways depending on its development phase. Development divisions organize the product according to different function groups, e.g. brakes or transmission (EBOM). In contrast, the production preparation division restructure the product and organize the parts in groups that are feasible for the assembly sequence (MBOM). These different views of the product are in fact the reason to the existence of the department for production preparation. The issue is how the translation between the product views should be done to keep all necessary information and enable traceability, i.e. the possibility to find the digital version of a real part.

ISSUE 9: There is no standardized way to translate the relation between EBOM and MBOM that preserve the links between digital and real parts.

5.1.4 Volvo Trucks in relation to available PLM solutions and research

To acquire some knowledge from outside Volvo Trucks about the approach to production management a brief review was done. The review aims to present the market leading solutions for Product Lifecycle Management (PLM) software. The connected IT systems at Volvo Trucks can also be seen as a PLM system but are not that integrated as many third party solutions are. Dassault Systèmes, PTC and Siemens PLM are the three market leading companies that offer complete solutions for PLM.

Siemens PLM

Siemens have businesses in many areas of manufacturing and production. Consequently they have a wide range of products. Siemens has coverage from product design i.e. CAD to production execution on the shop floor. Siemens has the strength in their experience from shop floor equipment and should be able to make a good connection to the development tools in design development.

Dassault Systèmes

Dassault Systèmes (Dassault) started in the aerospace industry delivering design tools for aircraft, thus have the strength in modelling surfaces. However the company have emerged as the largest supplier of computer assisted tools for design, manufacturing and engineering.

PTC

PTC has, compared to Siemens and Dassault, an overall narrower range of products but a comparable set of functions when considering the virtual development tools. PTC is not as established as Siemens and Dassault. The PLM solution offered by PTC is called Windchill.

Table 4 summarizes the key functions found in the Volvo IT environment and compares them with the equivalent in the third party solutions. Note that this is only a brief comparison of key parts of the different companies' solutions. The functions to compare were chosen as they were considered as key functions in the project and relates to the concept platform.

	Volvo Trucks	**PTC Windchill**	**Siemens Teamcenter**	**Dassault Delmia**
Variant handling	KOLA, Variant strings	Option codes, wizard	Variant codes	Variant codes
EBOM and MBOM handling	EBOM is used in CATIA which consists of function groups. No direct link between EBOM and MBOM.	MPMLink. Connected views. Regards EBOM being 70-80% the same as MBOM. Clear link between EBOM and MBOM	Integrated in Teamcenter. Clear link between EBOM and MBOM	Part of PLM solution
CAD to MTRL	No consistent links. Links exists sometimes exist to predefined CAD-modules.	Integrated solution	Integrated solution	Part of PLM solution
Creating DMU:s	Done through AVP. User needs to order with the help of a variant string. DMU not editable.	Dynamic and integrated viewing of parts and assemblies.	Dynamic and integrated viewing of parts and assemblies.	Possible

Table 4: Shows an overview of certain functions found in PLM solutions compared to Volvo Trucks way of working.

5.2 Concept platform

Within the given time, the concept platform was created and made functional. The platform is primarily based on Delmia and SPRINT. With the concept platform it is possible to transfer production data from Delmia to SPRINT and also conduct the same preparation work in Delmia that today is done in SPRINT. *Figure 15* shows an illustration of the missing link that the concept demonstrator is establishing between Delmia and SPRINT. To be able to create the concept platform, the identified issues in the current situation analysis have been addressed. The simplified or disregarded issues are stated hereafter.

ISSUE 1 - Variant richness

To reduce the amount of variants, the project only covered 16 different end products (Lego trucks). These Lego trucks originate from a previous project at Volvo Trucks where Lego were used to create module-based trucks for a small scale assembly concept (Johansson & Oliviera, 2011).

ISSUE 2 - Target vehicles, product simplification during development

In the real development process this problem leads to that all variant combinations are not being documented properly. In this concept it was assumed that the product is fully documented so that all items that exists in the virtual environment also exists in reality.

ISSUE 3 & 4 - Mismatch

In the concept demonstrator, the information needed to move between VM and real parts world was stored. The part had the same part number in VM as in reality. Physical assembly units were also found in VM, i.e. there are one-to-one mappings between all parts.

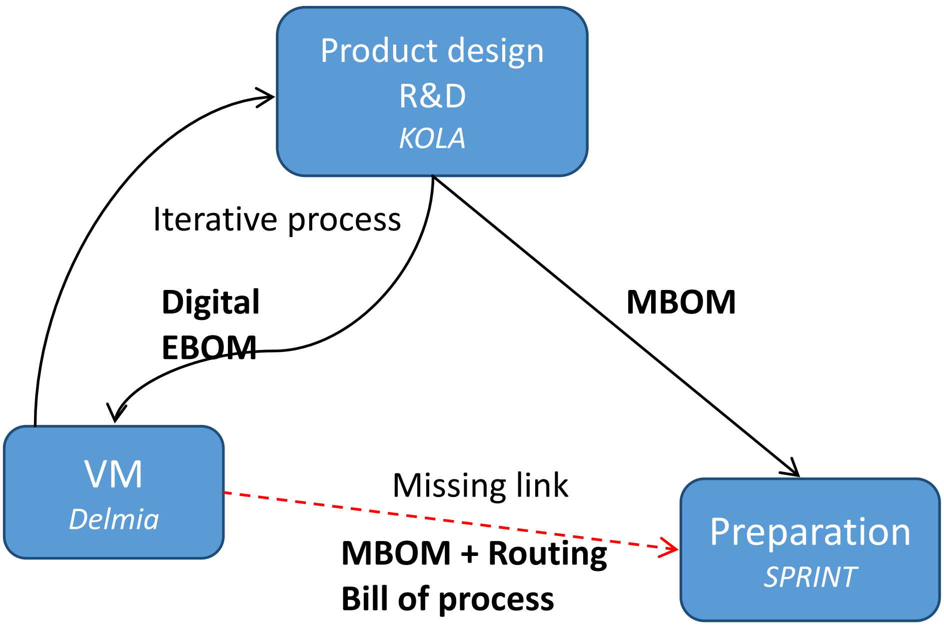

Figure 15: Shows the missing link that the concept demonstrator is establishing

ISSUE 5 - IT integration

Certain business rules found in the user interface of for example SPRINT were avoided to be able to link the systems and create the concept platform. One example is that BSL:s[4] are omitted (no KOLA connection) and only CIL:s[5] are used.

ISSUE 6 - Multi factories

In the concept platform it was assumed that the manufacturing preparation was done for one factory or a master structure. This closely reassembles the way of working with master structures as it is done at Volvo Trucks today.

ISSUE 7 & 8 – Organisational boundaries

The perspective of connecting Delmia and SPRINT took a broader view and focused on Delmia and SPRINT being a linked process instead of seeing them as individual instances, see *figure 17*. This means that these two were regarded to be one system or process (see *figure 18*) instead of two individual. What is done in Delmia is done to aid the work done in SPRINT.

Figure 17: In reality Delmia and SPRINT are considered to be two individual systems.

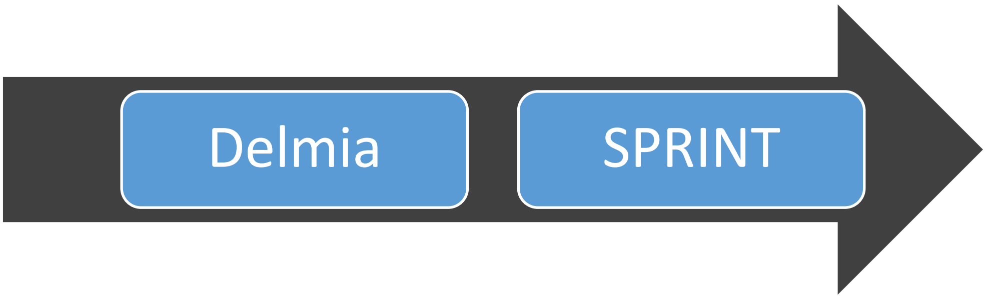

Figure 18: This project regarded the two systems to be one process to be able to merge them.

ISSUE 9 - Different product structures

This issue mainly lead to problems with traceability of items. For instance if manufacturing want to see how the development department have been working with a certain part it is often hard to find the same items in the different structures. In this project it is assumed that the items in the virtual environment have a clear and distinct connection to the parts in reality and therefore traceability is maintained even if the structures do not match fully.

[4] BSL: Basic Structure Line, is the smallest building block in SPRINT. The variant codes are assigned to the BSL's.

[5] CIL: Core Instruction Line consists of one or more BSL:s and describe the material needs for the operations.

5.2.1 Functional description

The concept platform has the ability to create a detailed preparation. Detailed in this context means that the preparation data needed to fully populate SPRINT concerning assembly instructions can be created in Delmia and transferred to SPRINT. The PPR-philosophy of Delmia makes it possible to create the necessary links between processes, material (products) and resources (for example tools and physical locations). The 3D functions in Delmia can visualize the product, which is an aid to identify parts, their orientation and location on the truck. *Figure 20*, page 30 shows how this process looks in Delmia.

Using the concept platform makes it possible to:

- Create a work plan consisting of process steps where sequence and work content is defined.
- Connect materials and resources to a process.
- Perform balancing of processes.
- Visualise products, processes (sequences) and resources.
- Visualise the process of building the truck.
- Add cycle times for processes.
- Import missing 3D product representations to aid in preparation.
- Transfer a complete preparation from Delmia to SPRINT.
- Visualise certain problem areas found in the current state analysis.

An important function of the concept platform is the use of variant codes when creating the process steps in Delmia. This is not something currently being used at Volvo Trucks. Connecting variant codes to each process step in Delmia mean that it is possible to prepare manufacturing based on variant codes instead of material as it is in SPRINT. This means that you need to care less about the material itself and more about the function. Doing so makes it being possible to perform manufacturing preparation at an earlier stage in the product realization process than today since the actual product or part is not needed.

Transferring data between Delmia and SPRINT is only done when the user request it. The concept demonstrator works by transferring all available data each time a data transfer is done. The concept demonstrator does not do incremental data transfers. Therefore, each time a data transfer is done the existing preparation data in SPRINT is overwritten. But it is possible to do a data transfer and then add additional preparation data in SPRINT to the data already transferred from Delmia. However, data added in SPRINT cannot be imported to update the Delmia environment.

5.2.2 Technical description

What the user sees in the concept platform is the graphical user interfaces of Delmia and SPRINT. This section describes the data connection between these two systems. Data from Delmia is exported with the help of a VBScript. This script first transforms and structures the data into a format usable by SPRINT according to *table 5*. After having done so it re-formats the data into SQL statements which, in turn can be inserted into the Oracle database structure of SPRINT. The connection between the VBScript and Oracle database is done through ODBC. *Figure 18* shows the overall functional description of the concept platform.

The Delmia instance is same used generally at Volvo Trucks. For this case, a separate project was created in parallel for the real manufacturing projects. The data is stored centrally in a PPR manufacturing hub. So the same tools that could be used for preparing real trucks were also available for the concept platform. The SPRINT instance used was a separate development database used by Volvo IT. This database was not populated with any process information, which made the implementation simpler since there were fewer factors to take into consideration when doing the technical implementation.

Delmia	SPRINT
Operation step (Process)	Core Instruction (CI)
Part (Product)	Core Instruction Line (CIL)
Resource (ALL)	Assembly Lowest Level (ALL)
Resource (Tool)	VDM Tool

Table 5: A summary of the most important linked data elements from the data mapping.

Figure 19: A functional description of how data is flowing within the concept platform.

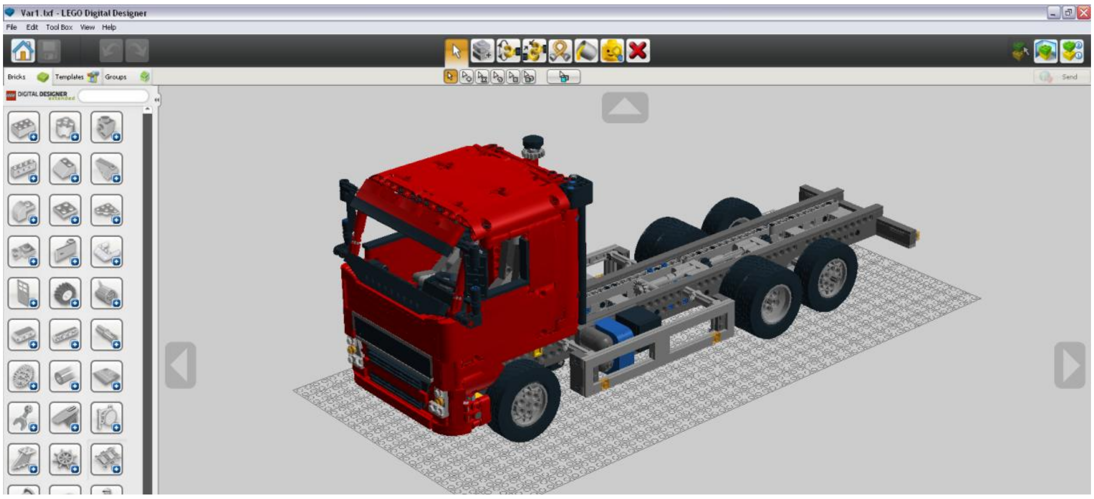

Figure 20: The Lego trucks used in the project where originally developed in Lego Digital Designer.

The Lego trucks used in Delmia have originally been created in Lego Digital Designer (LDD). LDD is a free 3D-based tool to develop Lego models by virtually putting parts together. These Lego models had already been imported to the manufacturing hub in Delmia before the project start. However they had been imported with a product structure that did not match the modular design of the trucks. Therefore a separate Lego module structure was created within this project. The Lego modules were exported from LDD one-by-one. A VBScript was created to import these Lego modules into the manufacturing hub of Delmia through the graphical user interface software Process Engineer. These modules matched the physical modules of the Lego trucks. These modules also represent actual part numbers when the data is transferred to SPRINT. Two examples of modules are the fuel tank and cab of the Lego trucks.

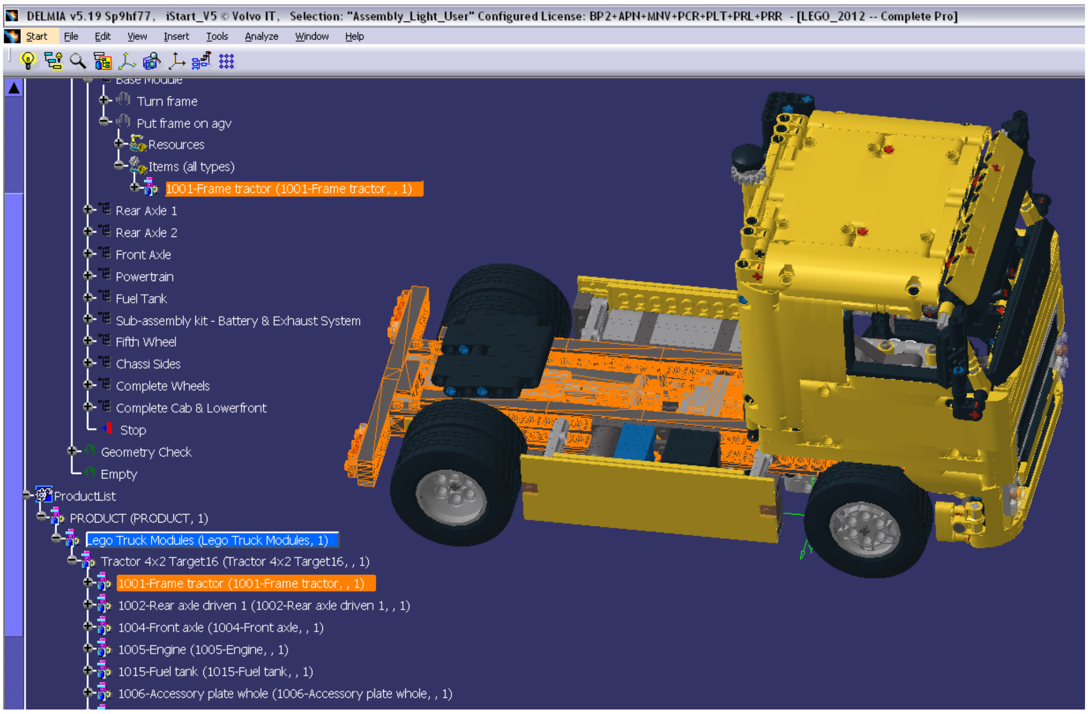

Figure 21: Shows a link between the process and product (part). The 3D representation highlights the chosen part on the truck to aid in identification and placement.

The SQL statements were developed using the software Toad, a database tool used to develop and maintain databases. The SPRINT database is a quite extensive database containing a lot of data and business logic. At the time of developing the concept platform the database consisted of 518 different tables but only a small number of them were needed to create the wanted functionality of the concept platform. Not all of these tables contained actual preparation data but acted as links between tables doing so. Therefore the necessary tables had to be identified by checking constraints and writing SQL codes conforming to these to make the data transfer work. The SQL codes used to populate SPRINT can also be exported to a .SQL-file for manual handling and verification.

The VBScript that export data from Delmia and generating SQL is highly customizable. Therefore new functions can be added in future implementations. It is also possible to only use certain functions of the export script. With the script it is also possible to transform or edit data on-the-fly.

The interface uses the same Unique Object Identifiers (OID) in both systems for identifying processes in Delmia and Core Instructions (CI) in SPRINT. These OID:s are made up by GUID:s (Globally Unique Identifiers) which conforms to the UUID (Universally Unique Identifier) standard. Having the same identifiers in both systems makes it possible to have traceability between processes in Delmia and CI in SPRINT. This makes it possible to implement incremental updates to the concept platform at a later time. The traceability also makes it theoretically possible to transfer data from SPRINT back to Delmia.

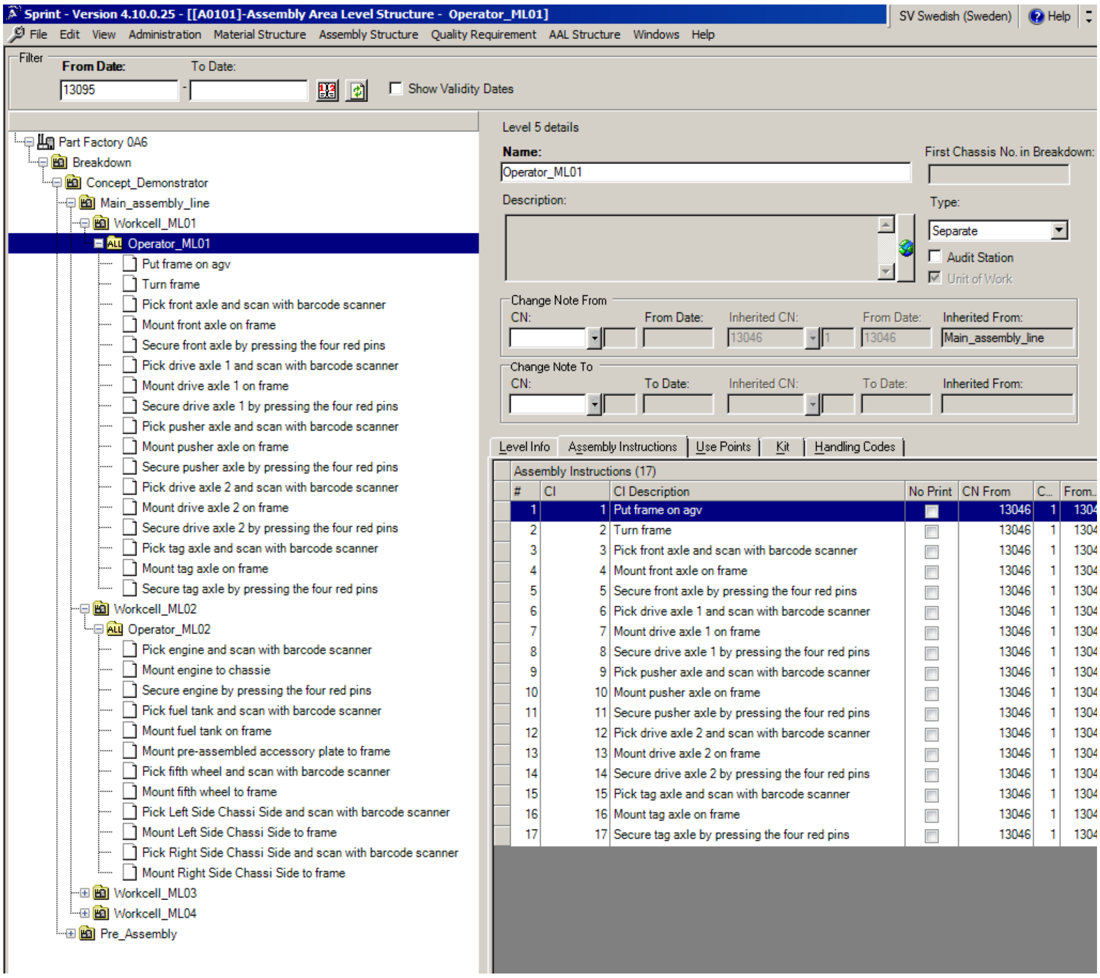

Figure 22: The downstream view of the concept platform showing SPRINT and the imported manufacturing preparation data from Delmia.

5.3 Usefulness analysis

The usefulness analysis aims to shed light on the usefulness of the concept platform. This part will answer how well it works and to what extent it can be used. It was seen that it is possible to do the same work in both Delmia and SPRINT but the approach and tools are different. Therefore both systems have benefits and drawbacks. Being a text and table-based software, SPRINT is efficient at handling text-based data. Delmia is on the other hand good at handling graphical representations. A comparison showing the main benefits and drawbacks of the systems can be seen in *table 6*.

Delmia	**SPRINT**
+ 3D visualization + Has the possibility of importing missing 3D objects into their context + Context (connected or surrounding objects) around an object is easily identified - Working with CAD objects which might not reflect products in reality	+ Fast at handling text-based data + Has a lot of business logic built-in + Has a good integration with downstream processes - Need external software to locate missing parts - Not beneficial to use for balancing - Need much experience of the product to be able to identify and group objects together (since it lacks visualization).

Table 6: An overview of benefits and drawbacks of Delmia and SPRINT as a manufacturing preparation tools.

The questionnaire served the purpose of trying to assess whether a data transfer from Delmia to SPRINT would be good, seen from the perspective of end-users. The end-users refer to people working in SPRINT that today makes the final preparation for the trucks before they are produced. Observations seen in the questionnaire is summarised in *table 7*. The full results of the questionnaire can be found in *Appendix D – Answers to questionnaire.*

After having created the concept platform, a demonstration video was created to showcase the functions and usefulness. This video was sent to manufacturing preparation engineers to comment on the usefulness of the concept platform. The result received from the users was throughout positive as can be seen in *Table 8*.

Observation	Observation based on	Comments
56 % of the people asked explicitly said they used 3D as an aid in their preparation work.	People stated they used a 3D representation tool.	The actual result might be higher since the people that did not explicitly say they used 3D might either use it or not.
45 % of the people could potentially benefit from easier access to 3D.	People noting that it is hard to get hold of graphical representations	Could potentially be higher.
100 % of the people asked encountered problems with not knowing what the part is, where it is located or oriented. Out of these the majority said it happened quite often.	People answering yes to question 2. Out of these people everybody also stated how often it happened.	More defined question gave more accurate answers.
People have different ways of finding information. No common or standardised way of working.	People stated different ways of finding information in question 3.	Seems to be a correlation between work experience and ways of working.

Table 7: Observations discovered in the results from the questionnaire.

Observation	Comments
100 % of the people asked regarded the concept platform solution useful.	Further investigations and head-to-head comparisons between Delmia and SPRINT could be beneficial to perform to additionally confirm this view.
All of the people questioned believed that the solution would aid them in their preparation work.	

Table 8: Feedback from manufacturing preparation engineers after seeing a demonstration video showing the concept platform.

5.3.1 Scalability

Scalability refers to how close the concept demonstrator can come a real implementation. The concept platform makes it possible to do a complete product preparation for a Lego truck in Delmia and then transfer it to SPRINT, which gets fully populated i.e. it is now possible to transfer all the work today done in SPRINT to Delmia. Consideration must be taken the simplifications done in the concept platform. The issues stated here are regarded the most important.

ISSUE 1 – Variant richness

Due to the nature of the concept platform to fully populate the SPRINT database on each run, a full truck with more parts would take a long to import.

ISSUE 2 - Target vehicles, product simplification during development

This issue would in reality need to be addressed by either doing more documentation work earlier in the process or work with the information available in Delmia to create the majority of the preparation work necessary.

ISSUE 3&4 – Mismatch

In reality it would be necessary to do one of the following:

- Have all parts available in 3D and thus having dummy parts for those who lacks graphical 3D representation. By doing this it would be possible to fully populate SPRINT.
- Have 3D modules available (as it is today) but have a translation between them and real parts when entering SPRINT. The missing parts (for example oil) are then added to processes in SPRINT. Therefore all preparation work cannot be done in Delmia.

ISSUE 5 - IT integration

To be able to link everything properly it would be necessary to also involve BSL (Base Structure Line). The concept demonstrator works around the need of having BSL:s representing CIL:s in SPRINT. This however requires more data mapping. KOLA needs to be more integrated in Delmia so that the information there can be used efficiently in SPRINT.

ISSUE 6 - Multi factories

Since it is possible to work with multiple factories in Delmia it would also be possible to transfer that data to multiple SPRINT instances. Therefore this issue does not limit the scalability of the concept platform.

ISSUE 7 & 8 - Organisational boundaries

The concept platform ties the two systems much closer since the work is totally transferable between the systems. It is therefore possible to seamlessly shift and decide how much work that should be done in either system.

ISSUE 9 - Different product structures

Having a clear traceability between digital models and real parts is a necessity if you want to move work between the two worlds. This is not something related and necessary for the concept platform to work but is needed for a larger scale implementation. Having a distinct connection between products in development and production more and more in focus at Volvo (for instance this comes in focus with the V-PDM project and RnD30).

6 Discussion

The discussion chapter aims to discuss the results and methods from different views. Was it good or bad? Is the result as expected and are there any new questions that have been raised. Proposals for further research are also included.

Mass customization is today required to be competitive in the field of vehicle manufacturing – also in the area of heavy trucks. Volvo Trucks have, as other truck manufacturers, adapted the concept since many years. VM, i.e. working with digital models in product and production development, is also considered to be almost required to compete effectively. VM should ease the mass customization work by enabling evaluation of products and processes in earlier phases than possible by previous methods, physical prototype builds and mock-ups. As can be understood by *figure 5, page 6,* digital tools implies that more effort can be put to earlier development phases, thus a shorter time to market can be achieved. It is also possible to detect possible manufacturing issues by simulating cases in the earlier phases.

There is much talk about how beneficial a data transfer could be and less talk about what risks or issues that might occur with it. Much literature and research points out that virtual manufacturing and early digital product models shorten the development time and thus cuts the development costs. However, an IT system or a method cannot alone solve any problem, no matter how good or effective might be. It is important to have in mind that it is the users that make the business run and can be influenced to start using new methods and systems. The outcome of the reasoning is that a data connection between Delmia and SPRINT probably will shorten and ease the development process. But the existing competence in the SPRINT areas most likely has to be spread to the VM departments and vice versa. The cause is the huge detail knowledge about the truck assembly that is required. This knowledge does not exist in VM today and simulation competence in VM does not exist in SPRINT areas. With a working interface and a prescription to move towards an extended VM preparation, a positive side effect will hopefully be an extended cooperation between the departments.

It can be understood from literature and experiences in other companies that mass customization can be achieved more effectively by using some module system to specify different functions (KPMG, 2011). Among others, Scania have proved that a module system can increase profitability. Though, Volvo Trucks have not adapted the modular way to specify their vehicles. One reason to this is the market demands in the American market where it is common to specify the vehicle very detailed. To be competitive Volvo Trucks have chosen to keep the detail variant combination possibility.

6.1 Current situation analysis

The identified problems are strongly related to issues that might question the concept platform between Delmia and SPRINT. To form the concept platform the identified problems have been addressed and either more or less simplified or even disregarded. The concept platform is further discussed in chapter *6.2*.

6.1.1 The product

As described, Volvo Trucks are manufacturing trucks in a mass customization manner and this approach is a necessity to be competitive on the market today. However the high customization level (amount of possible variant combinations) at Volvo Trucks can be challenged because it seems to approach an almost unfeasible level. During some interviews and discussion it was mentioned that the sales people couldn't know all product configurations. It might result in special variant orders that in fact could have been specified with an already defined variant or preconfigured truck. This implies that the products configuration have to be easier to understand and specify. The essence is that the product's complexity is an important variable when addressing the process for production and production preparation.

6.1.2 The process

The process description is quite brief but the aim was to achieve a general understanding for the complete view, enough to be able to grasp what the specific issues could be with a concept platform. It should also be mentioned that there are essential differences between the development of completely new products and updating of current versions where the latter one is the most common. This study has focused on the case with a new product class. A lot of the findings are applicable to both cases though. A considerable issue if working with updates is how to ensure that the most updated data are used because it can occur either in Delmia or in SPRINT. As is now, Delmia is not updated during the production execution phase while SPRINT is.

It is in the process description it is possible to distinguish the inadequate information transfer between different systems, especially Delmia and SPRINT. It has also been noted that the possibility to transfer data alone will not solve the information transfer issue. Also new methods and ways of working have to be thought of.

6.1.3 Problem areas

Seven problem areas have been presented and described. The areas are of different significance in how they impact the concept interface development. Several issues have been simplified and disregarded to make the implementation. Doing so however imply problems with scalability and applicability to reality (this was handled in part *6.2).*

Most likely the competence in VM departments will not be enough to make complete a production preparation. This is because that the resources and knowledge within the organization may need to be redistributed. Moving personnel from working in SPRINT to Delmia would actually be in line with Volvo Trucks' ambition to do more front loading[6] as defined in their RnD30[7] program.

Actually, body in white[8] at Volvo Trucks use 3D preparation and verification in Delmia for all of their work. This proves that there is a lot of knowledge about Delmia already in the company which could be beneficial if a large implementation of the concept platform is considered.

Today at Volvo Trucks all stakeholders cannot fully utilize virtual manufacturing since it lacks a comprehensive set of data to fulfil their particular needs. If there would be made more efforts to input data to virtual manufacturing, a natural response would be that more stakeholders could use and trust the systems. A practical example of this could be to strive for always having a digital parent to a physical part. There should also be a common understanding of the necessity of always inputting enough data to the digital tools to fulfil all stakeholders.

One issue that became visible during interviews and observations was that users had to manage several applications to solve a single problem. It was also clear that people have different ways of solving problems and finding information, which indicates that there is no standardization

[6] Front loading refer to moving activities upstream in the development process. Doing so leads to early detection of potentially problems which then are easier and less costly to address (Thelander, 2012).

[7] RnD30 is a product development process improvement program initiated to improve the overall efficiency with 30% (Thelander, 2012).

[8] At Volvo Trucks: Refers to the process of manufacturing the cab from raw material to welded cab but without assembly of loose parts.

way to work in these areas. According to principles in lean manufacturing; having a best practice, with continuous improvements, is in most cases regarded beneficial. Without standardisation there are limited possibilities of improving the processes.

6.2 Concept platform

As can be read in the result, the concept platform was developed due to that sufficient simplifications could be done. In the concept platform many issues were easy to handle because of the isolated environment. In a real environment though, it would not be possible to allow such simplifications. Using LEGO models in the concept platform serves a good purpose of bringing the complexity level low. Low complexity also makes it easier to focus on the core questions – if it is possible and what can be achieved with a working platform.

The possibility to use variant codes is an important function in the concept platform. The presence of variants in VM is in line with Volvo Trucks aim to move activities upstream in the development process. Having variant information in VM should also make it easier to develop the process and make it possible to reuse in SPRINT.

It is not possible to get a virtual representation of any arbitrary vehicle today (issue 2, described in section 5.1.3). One main issue that prevent is the lack in documentation of CAD parts and modules. The inadequate documentation may result in wrong parts or no parts at all or parts placed in wrong positions. The problem originates from the issue concerning documentation levels. No department have the incentive to do the documentation, it takes time and thus cost that otherwise can be used for development activities. A fully functional solution for achieving virtual vehicles should though ease work in later phases and also save time and cost.

Delmia is used as a VM environment in the concept platform because it is already in use at Volvo Trucks. It is therefore possible to adapt and supports several functions (many are not in use at Volvo today) like for example support for multiple factories and can handle several different layouts. SPRINT is used for manufacturing planning execution. It will be kept due to a strategic decision. Delmia V5 is however a slow and heavy software environment. Maybe next generation, Delmia V6 is improved. A large scale implementation should investigate other possibilities for the virtual parts of the platform. A real implementation also has to address whether the data transfer should be incremental or always complete, i.e. how updates should be handled and how to handle different versions of data.

6.3 Usefulness analysis

Undoubtedly there is a benefit of having 3D representations available when doing manufacturing preparation. This is confirmed by both literature and people interviewed within this project. Also, the industry shares the same view and is working towards realising it more and more. Therefore an implementation of this kind should be of high interest for involved people at Volvo. Showing the possibility to do preparation in the present systems, even if it is done in a small scale, is a good starting point for further discussions and development.

Having to disregard or go around some of the problem areas affect the scalability of the concept platform. It would therefore not be possible to directly implement the solution in full scale. With minor modifications it could be used for isolated parts of the actual preparation work. The concept platform actually addresses the currently existing problems preventing data transfer. Looking at how the problem areas were solved or circumvented might aid in showing what needs to be done in reality to be able to bridge the two systems. One should be aware that an implementation in reality would take considerable time due to the size of Volvo Trucks and the organisational overhead that exists. Doing such an implementation needs very good organisational support from all parties, including top management.

It is also essential to consider the cost for an implementation. Not only the initial investment but also the time and effort it takes to learn the new way of working. This study has not considered the effort to work in the different systems. Some tasks might be harder to perform in VM compared to SPRINT and thus should not be implemented in VM. An investigation of the total effort and resulting benefits should be done; this should include payback time.

An advantage is that it is possible to choose how much work to do in Delmia versus SPRINT. Having 3D representations available is always beneficial. It is also possible to argue about who has the final responsibility for delivering a fully producible truck. The research states that it is beneficial to verify that the product is producible early in the development. In that sense Delmia should be the system responsible to deliver adequate results to downstream processes instead of SPRINT, as it is today. The system having responsibility for data integrity should also be the system where the currently best practice of how to produce a truck can be found. Standardized work should be developed through continuous improvements and deviations from this standardisation could be used as a KPI (key performance index) to measure waste or how close factories are to the best practice.

6.4 Scalability

General technical problems should be possible to address with sufficient resources. More difficulty might arise in the issues related to organisation and way of working when people are involved. It is hard to force and convince people to change their way of working. Especially if one cannot realise any positive effects directly. It is also important to communicate with colleagues at different departments to understand what one can do to help each other.

It was possible to find people, knowledge and possibilities to create this concept platform. There were a lot of organisational problems hindering. Things took longer time than expected. But being a small project consisting of two people and still succeeding would probably mean that there are good possibilities in creating an extended implementation, if there is a consensus of doing so within the company.

6.5 Choice of methods

Using semi-structured interviews as the main data collection method have enabled detection of problem scenarios previously unknown within the project. This has worked well together with grounded theory to create new hypotheses, which then could be proved. In addition, observations proved to be an effective way to understand the core business logic present at Volvo Trucks. It also aided in understanding why people worked and reasoned in the way they did. In addition using literature studies to understand certain work methods or processes proved to be harder than expected since much of the literature studies available focus on a problem instead of having a descriptive character.

The questionnaire aided in gathering data from many sources in an easy-to-manage manner. The questionnaire was sent out by e-mail and the answers were received quickly. The downside was that all people answered not all questions. Another downside was that the people answered using different units of measure and interpreted the questions differently. Some answered the questions very thoroughly while others scribbled an incomprehensive answer. This could have been addressed by having more structured and defined questions in the questionnaire. However, quickly looking at the results from the questionnaire, several similarities could easily be identified.

The data mapping used when creating the concept platform was a good way of understanding complex data structures. Data mapping made it possible to quickly identify and isolate the key tables among several hundred in the SPRINT database structure.

6.6 Sustainability

There are three factors to sustainability – social, economic and environmental. The project has less of an environmental sustainability focus and more focus on the other two. But having a well-developed product realisation process will definitely aid in creating products and processes with less environmental impact. Supporting Volvo Trucks to improve their product development process will make them more competitive, which in turn leads to increased social and economic sustainability. Social sustainability can be increased at Volvo Trucks by being able to keep their employees, development and production in Sweden. Economical sustainability can be achieved by increasing the effectiveness of the company and by shortening lead times. Shortening lead times will make the company more agile and able to respond to the continuously changing customer demands. Being good at mass customization requires Volvo Trucks to benefit from well-developed and integrated virtual tools and methods.

7 Conclusions

The conclusion aims to answer the research questions in a short but clear manner.

RQ1 Are there any complications in creating a concept platform to connect Delmia and SPRINT?

The current situation analysis summarises the product and process at Volvo Trucks and out of this, seven problem areas could be identified. In the frame of these problem areas nine issues that impact the development of a complex platform were described. It was assumed that the issues could be simplified enough or even disregarded in some cases. The current situation analysis also visualized the information gap between virtual manufacturing in Delimia and production preparation in SPRINT.

RQ2 Can a concept platform be realized, and if so, how?

The concept platform that connects Delmia and SPRINT could be realised. The amount of simplifications implies that the solution should be considered as a concept. The platform makes it possible to do production preparation in the 3D environment in Delmia and transfer the process with links to material and resources into SPRINT, as desired. It should be mentioned that further implementation requires consideration to the problem areas that have been simplified. With the concept platform it is now possible to make use of the advantages with 3D models for production preparation in Delmia.

RQ3 What benefits, if any, can be achieved by an extended information transfer between these two systems?

Using good virtual tools is crucial in order to be competitive today and therefore this project can aid Volvo Trucks to become more economically and socially sustainable. In a longer perspective it might support in creating products and products with reduced environmental impact. Extended information transfer should also reduce unnecessary rework that exists today. It should tie different departments and professions closer.

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9 Table of appendix

9.1 Appendix A – List of interviewees

	Name and code	Role / area of expertise	When	Content and search words
1	Filip Hellman Code: A	Virtual Manufacturing (Delmia)	12-11-01	Target vehicles; CAD vs Part no; Link SPRINT - DELMIA; SPRINT; Delmia; VM; GDP; PPR; Protus
2	Henrik Köhler Code: B	Virtual Manufacturing	12-11-05	Virtual Manufacturing; CAD != Part no; Variant strings; AVP; Positionering; Bridging; Slow organization change; Simplification in manufacturability checking
3	Nicklas Bragsjö Code: C	Super user for SPRINT	12-11-05	SPRINT; KOLA; Physical prototypes; Pilot builds / contract builds; Target Vehicles; S-notes; Balancing; DCN; BSL; Manufacturing preparation
4	Björn Sterud m.fl. Code: D	IT SPRINT and MONT	12-11-14	Link between SPRINT and MONT
5	Daniel Björndahl Code: E	Siemens key account against Volvo	12-11-19	Siemens system solutions; Teamcenter; PMM - Product Master Structure; JT - Visualization; PLM
6	Filip Hellman Code: A	Virtual Manufacturing (Delmia)	12-11-20	Connections between systems; CAD vs Part no; AVP; DMU; KOLA; Item to variant; Virtual Manufacturing; CAD Vault; Item; V-PDM; Volvo systems
7	Jonas Östman Code: F	Dassault Systemés	12-11-22	Dassault; Routing; mBOM; eBOM; mBOR; Product Structure; Document Structure; V-PDM; CI (Core Instruction); Downstream (SPRINT etc); Volvo way of working
8	Gerd Stokke Code: G	KOLA System owner	12-11-22	KOLA; Item bridging; Sub-optimization; V-PDM; Joint calc; Overall problem
9	Jonas Östman Code: F	Dassault Systemés	12-11-27	eBOM; mBOM; Routing; Item master; Work plan; Article number; Overloaded structure (150% BOM); Product Class; Interface - Incremental vs full; 3D instructions; AVP; Work instructions; Volvo way of working
10	Pär Möllberg Code: H	PTC	12-11-27	PTC; Windchill; KOLA; BOM; eBOM; mBOM; Mapping resources; Overloaded structure (150% BOM); DMU; Variant strings; Item bridging; Volvo problems
11	Klas Thelander Code: I	Virtual Manufacturing system owner	12-11-28	AVP; Sales to order; Order to Delivery; Delivery to Repurchase; RnD30; GDP; Variants; Geometry and positioning; KOLA; eBOM; Release stages; mBOP; V-PDM; Improvement potential; Enovia; CAD vs Material; Bridging; Overall problem; Improvement factor; Volvo way of working

12	Sverker Nordlander Daniel Björnsson Code: J	Siemens System expert Siemens key account towards Volvo	12-12-05	BOM; eBOM; mBOM; Teamcenter; CAD; BOP; sBOM (service); Target vehicles; JT; Variant handling
13	Jonas Sand Henrik Köhler Filip Hellman Johan Sahlström Code: K	SPRINT and Delmia	12-12-17	SPRINT; Delmia; Bridging; BSL (Base Structure Line); CI / AI (Core / Assembly instruction); Function groups; Work cells (ALL – Assembly Lowest Level); Parts; Items; Operations; PPR; Linking; Organisational structure; DSM (Digital Shape Model)
14	Henrik Köhler Filip Hellman Code: L	Virtual Manufacturing at Volvo Trucks	12-12-21	CAD modules; K-parts D-parts; PPR; Delivery unit; Operations; Linking; Bridging; Lego case; EBOM MBOM
15	Jonas Östman Code: M	Dassault systemés	13-01-11	EBOM MBOM; Routing; PPR; Items; Organisational / Politics; Variant handling; SPRINT; SR801 Interface SPRINT→Delmia
16	Jonas Sand Code: N	SPRINT	13-01-15	SPRINT; CI CIL AI; Function groups; BSL; KOLA; Master Structure; VDM Variant Driven Module; CN Change Notice
17	Elisabeth Axelsson Code: O	Virtual Manufacturing and preparation	13-01-16	Manufacturing preparation; Graph; Pilot builds; Virtual Manufacturing; AVP; Product Structure
18	Henrik Köhler	Virtual Manufacturing at Volvo Trucks	13-01-17	Lego case; PPR; Delmia
19	Michael Voemel Code: P	SPRINT, IT	13-01-21	SPRINT; CI CIL AI BSL; KOLA; Bridging; Lego case; Delmia; SQL
20	Peter Granstav Code: Q	Manufacturing preparation	12-12-12	SPRINT; Preparation; KOLA; Delmia
21	Filip Hellman Code: R	Virtual Manufacturing at Volvo Trucks	13-02-04	Lego; Delmia; XML
22	Christian Velin Code: S	SPRINT, IT	13-02-08	SPRINT; Oracle; TOAD; Databases; Tables; Structure; Data mapping; Data; ODBC
23	Klas Thelander Filip Hellman Code: T	Virtual Manufacturing at Volvo Trucks	13-03-01	Concept platform; Master structure; variant structure; target vehicles; virtual manufacturing

9.2 Appendix B – Interview questions

Translated from Swedish.

Klas Thelander, system owner Virtual Manufacturing:

- How is the connection between Virtual Manufacturing and Product Design? How do these two departments communicate?
- Concerning information flows of CAD-data: AVP (Automatic Vehicle Packaging) is used to create DMU:s (Digital Mock-ups). How much information is transferred in this process? And how much data _could_ possibly be transferred?
- How well does it work with a CAD-vault built around PDMLink and Enovia?
- How does VM (Virtual Manufacturing) communicate with Tuve and the SPRINT-people? How well does VM know about how things are assembled in the factory?
- What are the future plans for VM? Will more work be transferred to this department? What is the dream scenario looking from the eyes of VM?
- How many parts are there in total for the new Volvo FH? One produced truck consists of about 20000 parts (correct?). Imagine looking at a part list which is not filtered for any variant.
- Why do you perform 9600 break downs in the AVP and not use all of them? What is the benefit of doing a break down in AVP and why do you want to more break downs?
- In what cases do you break down a truck in AVP and put geometry on all parts? Do you even do this?
- In an earlier meeting you mentioned the T3 target vehicle where 49% of the data were the same for KOLA CAD and KOLA Material. Could you show more of this study?
- When you do a break down in AVP, do you always get all associated parts/items with that variant? And if not – why? Is it because there is some missing item-to-CAD link in KOLA? Looking at geometry you do not get all information so therefore it may be applicable to item existence as well?
- VM test 20 target vehicles which in the end of the development process leads to VM having tested about 80-100 variants (correct us if wrong). How large coverage does that give when looking at all variants that can be produced?
- Which activities does VM perform (ergonomics, assembly testing etc)? Who use these results and how are the results documented and communicated?
- Who are customers to VM?
- Which tools are used apart from Delmia?
- What could be built virtually when looking at the development process?

Nicklas Bragsjö:

- What kind of work do you do in SPRINT and plan to do? What is SPRINT used for?
- How long time does it take to prepare a new truck for manufacturing in SPRINT?
- What limitations are there in SPRINT? And how do you get around them or plan to get around them?
- What are missing in SPRINT? What would you like to improve?
- How many people are working with manufacturing preparation (using SPRINT daily)?
- Where does the information going into SPRINT come from? And how is it entered into SPRINT?
- How does the integration between SPRINT and KOLA work?
- How much information in SPRINT concerning the old Volvo FH was possible to re-use when entering data about the new Volvo FH? And if it was possible, what kind of information was it?

Filip Hellman:

- In VM you test (validate) 20 target vehicles (between 80-100 target vehicles per product class). Could you explain the concept of target vehicles? What does it really mean? How much work do you actually do?
- Concerning Delmia supposedly being faster than SPRINT. You wrote: "If it is down to individual screw level it probably takes longer time. If it is the physical modules it may be possible to do it in one day. Ask someone who works with manufacturing preparation in Delmia."
  - Why would it take longer time to do it in Delmia? Do you have any names of someone working with manufacturing preparation in Delmia?
- SPRINT vs Delmia. How long time does it take to prepare a truck? Delmia: A couple of weeks but dependent on detail level of course. If it's the Physical Modules it may only take one day.
  - What does Physical Modules mean? Is it the same as the fish bone structure used (CAB etc) in assembly?
- Does Product Design also use Delmia? Since it seems that they already know that all parts fit together packing- and interface-wise.
- Is it VM that first find problems with for example variant combinations? Looking from a perspective of finding problems with assembling the parts (because the parts may fit together but you cannot assemble them).

Pär Möllberg, PTC:

- What kind of solutions does PTC offer? Please show how PTC works in the chain from product design, virtual manufacturing, manufacturing preparation and manufacturing execution.
- How does PTC manage the interaction between manufacturing preparation and MRP/ERP/MES. Any real world examples of this would be interesting to see.
- How does PTC relate to EBOM and MBOM? How is that taken care of in Windchill?
- How is the link between CAD parts, CAD modules and real physical parts taken care of?
- Do you have any examples of how other companies are working with these issues (even those who are not using your products)?
- Please show how you at PTC handle the problems associated with handling many variants. How were you planning to interact with KOLA? Were you planning to phase out KOLA? Please show us some real example of how it works with variant handling (for example using Michelin tires on the variant FH 4x2 and Pirelli on 6x2).
- You mentioned a wizard you could use to create variant links – please show us how this works.
- Volvo have very many variants (theoretically 10^67) but only build 20 target vehicles in product design. How is this problem handled in Windchill? Is it possible to document this data in some good way?

Daniel Björndahl & Sverker Nordlander, Siemens:

We are investigating how Volvo can get better at transferring and taking care of information between product development and manufacturing preparation and production. When we mention product development in this context we primarily mean virtual manufacturing. We would like to know what kind of system solutions there are and what Siemens' take on this is.

A part of the problem at Volvo is that product development creates 20 target vehicles. Virtual Manufacturing (VM) validates these target vehicles so that they are possible to assemble. In the end of development they have verified around 80-100 variants. But this is far from the theoretical 10^{67} variants that could be built. Manufacturing preparation has to prepare many more than the 80-100 variants that are validated. And today they cannot even re-use the information created by VM for the 80-100 validated variants. This mean that there are quite much re-work going on here. The question that arises – How can you integrate manufacturing preparation and virtual manufacturing?

And more specific – How does Siemens PLM handle variants?

Does Siemens have any counterpart to Volvo's SPRINT? And in that case – does it work in the 3D-realm? Is it well integrated with the rest of the chain?

How does Siemens handle the transition between EBOM and MBOM?

Examples connected to the variant problem and connection to CAD/Item/Variant

This example show how one CAD object is used and represents several different tires in reality.

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 3 - 6x4
Tire in CAD - generic	X	X	X

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Michelin	X		
Pirelli			X
Goodyear		X	

Next problem consists of having several different routings for electrical wires but only having one part number in reality.

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Routing 1		X	
Routing 2	X		
Routing 3			X

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Electrical wire	X	X	X

Jonas Östman, Dassault:

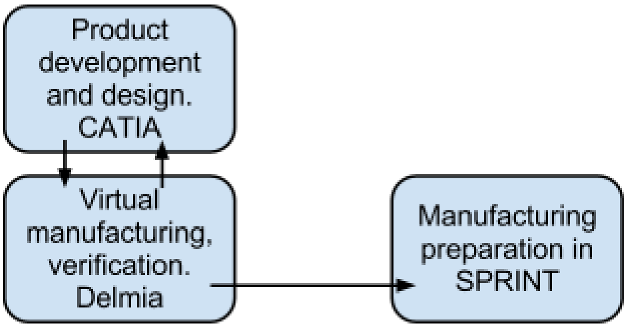
We are investigating how Volvo can get better at transferring and taking care of information between product development and manufacturing preparation and production. When we mention product development in this context we primarily mean virtual manufacturing. We would like to know what kind of system solutions there are and what Dassault's take on this is.

Please explain about the integration between manufacturing preparation systems and MRP/ERP/MES and your experience about this. Please tell us about the three examples you been a part of and deployed.

Please explain how Dassault relates to EBOM and MBOM and the connection between them. Also explain the link between CAD parts, CAD modules and real physical parts.

How does Dassault integrate with proprietary MES for example.

General questions asked to suppliers



Different software and inadequate handling of information between different instances creates problems at Volvo. How

- Describe your area of expertise.
- What product development solutions do your company / department offer?
- Looking from product design to production, what kind of integrated systems exists today? Does some company offer the whole chain? Are there real world examples of companies using these solutions? Do you have examples where your solution is used?
- What kind of industries are the focus for your company? (Mass-production of individual products, as Volvo trucks?)
- Volvo uses proprietary software for manufacturing preparation and execution. What are the benefits and drawbacks of that? Do you have any opinions about develop in-house/buy software?
- What do you know about Volvo's way of working and do you have any suggestions of possible improvements?
(Kanske lägga till en kort beskrivning av problemet. VM->SPRINT och att det är olika system som hanterar datan)
- What are the differences between the systems existing on the market today? Developed by PTC, Dassault, Siemens for example.

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 3 - 6x4
Däck i CAD - generic	X	X	X

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Michelin	X		
Pirelli			X
Goodyear		X	

Nästa problem består av att vi har flera olika eldragningar i CAD men endast ett artikelnr.

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Eldragning 1		X	
Eldragning 2	X		
Eldragning 3			X

	Variant 1 – 4x2	Variant 2 - 6x2	Variant 6x4
Elkabel	X	X	X

9.3 Appendix C – Questionnaire for manufacturing preparation

Translated from Swedish to English.

Questions to people working with manufacturing preparation in SPRINT

We are conducting a master thesis where we are investigating the possibilities of re-using data from Delmia in SPRINT. This questionnaire will help us understand your work tasks better and see it from your point-of-view. Please send to filled-in questionnaire to samuel.jennerhav.2@consultant.volvo.com. Thanks for your help!

Your name and e-mail (not mandatory):

1) When working with manufacturing preparation, are you missing any work tool or functionality?

2) Does it happen that you do not know where items should be placed on the truck? And if so, how often does it happen?

3) If you cannot find information about what an item is or where it should be placed, how do you solve that problem?

4) Does it happen that you encounter errors (for example invalid variant combinations from KOLA) that you cannot solve? And in that case, how often?

9.4 Appendix D – Answers to questionnaire

Ref. number	When working with manufacturing preparation, are you missing any work tool or functionality?	Does it happen that you do not know where items should be placed on the truck? And if so, how often does it happen?	If you cannot find information about what an item is or where it should be placed, how do you solve that problem?	Does it happen that you encounter errors (for example invalid variant combinations from KOLA) that you cannot solve? And in that case, how often?
1	Time overall. Time to work in Delmia	1 time / month	Contact technical preparation guy in charge	2 times / half year
2	* To be able to search and bring up complete modules. By other words part numbers grouped according to how they are assembled or come delivered from suppliers for example * Faster lead time for getting hold of a particular chassie no. Today it can take long time * Simpler user GUI	* Almost every day. Not regarding where the part should be but how the part should is related to connected or surrounding parts, for example clamping points and angles on nipples	* Search TR documentation firstmost * If it is an emergency I call the designer * Download the CAD-module and check	* Parts sometimes come incorrectly assembled from supplier. CAD not complete. Not possible to mount/assemble according to CAD/TR * It is usally solved through a special solution which has been given deviation approval from design (R&D)
3	*It would have been very convenient if it would be possible in SPRINT to see if a KOLA Link id was connected to a PROTUS * Faster communication with KOLA would have been good. Example: Clicking on a link id and it would open in KOLA	30 - 42,5% of all times I am looking at something "new"	I download a construction drawing of the detail either via KOLA or directly from RAPID I have been using 3D Cad more and more lately	The problem seems familiar but it has rarely happened for me. I only know about 2 occations. Both of these is due to KOLA being to generally divided. Both my cases where related to pressure tanks and circuit stickers to these.
4		Maybe once a week	Order a truck in AVP and check in Creo view	A couple of times per month
5	I miss clear instructions of common activities that should be done. For example cheat sheet (quick reference)	A couple of times per week	Asks or search in databases	Maybe once a week
6	It is hard to see the full picture of how the product looks when it is assembled in its context. How can I see the best assembly? How do I assemble it?	80 % of the cases. After a while you learn the "coding" in the link information in KOLA (if there is any)	One or several of the following: - Order and open the truck in product view * Open hole group information i KOLA - Open jointcalc-version in EDB to get a picture of how it is assembled in the chassie - Contact the designer - Ask a collegue	*1% of the cases have been invalid * In 80% of cases parts are missing, it is invalidly documented
7	To be able to connect/do splits on several BSL:s at the same time regardless of variant string / combination When doing preparation of hole patterns not having to first open all + BSL:s and then having to unmark +rows.	2-3 times out of 10 in average	* Look at a truck in Product/Creo view * Contact PD (Product design) * Write a protus	Yes. In 0.5% of the cases.
8	An easier way of bringing up pictures of details and how they are assembled on the truck would be awesome	Yes, quite often.	I ask intro technicians or some other collegue which might know	I don't think so
9	What I miss is that there are not pictures connected to all parts. It would make it much easier for me and when showing production what articles are affected when doing a change.	It happens quite often but I have only been here for 3 months.	Then I ask my collegues	Especially on trucks with "s-notes". It is often errors there. It also happens on other trucks and I feel that it seems to take quite long time to solve the errors.