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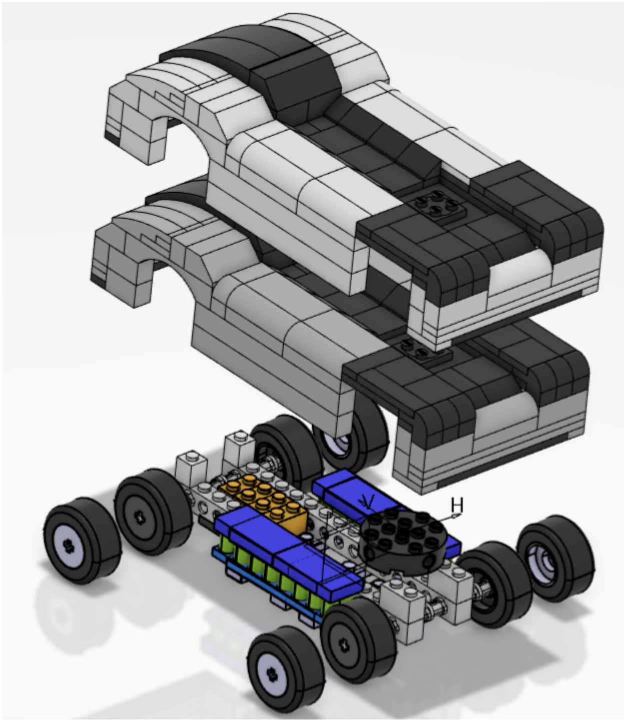

The need of flexibility in today's industry

A case study of variant management in a Product Lifecycle Management system and production system

Master's thesis in Production Engineering

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Cover: Illustration of the LEGO-made truck in an exploded view.

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Abstract

In today's industry, it is important to have production systems which are adapted to the companies' aims and to acknowledge how the production system can create value for the customers. Customers require customised products to fulfil their needs and the demand of such products are increasing. The project, Smarta Fabriker, has developed a new demonstrator, with the purpose to introduce variant management in their product to enable a flexible production. This master thesis investigates how a flexible production can be achieved and how variant management in production and Product Lifecycle Management (PLM)-system can improve flexibility. To investigate variant management in a PLM-system, ENOVIA from Dassault Systèmes was utilised. The performed thesis shows the importance of flexibility in the industry to be competitive in today's market, where flexibility needs to be aligned and included in an organisation's strategy. It shows utilising a PLM-system can result in a collaborative environment, creating a red thread throughout an organisation to work with customised products. ENOVIA provided the ability to visualise and overview the product's content and to illustrate customer demand's impact on the product. It enabled product configurations suited for different customer segments and their needs to be offered. Modularisation is identified to reduce the amount of unique articles and minimise the need of warehousing. Evaluating profitability of product variants and how entering new markets affect the profitability are identified as challenges when utilising variant management. Challenges with modularisation and product variety's impact on the production flow have also been identified.

Keywords: 3DEXPERIENCE, ENOVIA, flexible production, product lifecycle management, variant management.

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On the academic side, we also want to show our deepest gratitude to Henrik Kihlman and Per Nyqvist, our supervisors at Chalmers University of Technology. Both of you gave us new input, believed in us and gave us continuously support that has been valuable to be able to complete the master thesis. Lastly, a great thanks to Johan Stahre, our examiner at Chalmers University of Technology.

Robin Eriksson & Stina Wahlström
Gothenburg, May 2020

Contents

Acronyms

B2B Business-to-Business. 42, *Glossary:* B2B
BOM Bill of Material. 11, *Glossary:* BOM

CE Concurrent Engineering. 9, *Glossary:* CE

EBOM Engineering Bill of Material. 15, *Glossary:* EBOM
ERP Enterprise Resource Planning. 36

ICT Information Communication Technology. 9, *Glossary:* ICT
IoT Internet of Things. 13, *Glossary:* IoT

MBOM Manufacturing Bill of Material. 12, *Glossary:* MBOM

PLM Product Lifecycle Management. 1, *Glossary:* PLM

SCM Supply Chain Management. 9

UPS Unified Product Structure. 14, *Glossary:* UPS

Glossary

3DEXPERIENCE A business platform designed to link communities of cooperators socially with the aim to create effective products. 3

Available A relation alternative that is chosen when that relation will exist as a choice and is the main setting for all relations until being modified. 45

B2B Can be defined as a way of how to perform commerce, in this case a company that makes transaction with another company. 42

BOM A hierarchical structure of all parts included in the assembly of the product. 11

CAD-BOM Imports data from an EBOM of a product to ensure which components are needed and the desired quantity of them. 15

CE A methodology regarding how to design and develop products, where all phases of a product are considered. 9

Configuration management A process to establish and maintain product's performance and attributes during its life cycle. 14

Configured Engineering A process which defined the working procedure of configuration management and defining an Engineering Item Structure. 14

Default A relation alternative that is chosen when that relation will be preselected, although other possible relations can still exist and be chosen instead. 45

Demonstrator A small production system or cell. 2

EBOM A defined list where all parts in an assembly list are included, where information about assembly parts, e.g., quantities of different parts are included and described. 15

Engineering Item Structure The way the product is conceptualised, developed and structured and defined from an engineering perspective. 14

ENOVIA A virtual workplace in the 3DEXPERIENCE platform and is a PLM-system. 3

ICT Different technologies that are used to handle, store, share or exchange information. 9

IoT A system of computing devices in different objects used to receive and send data. 13

Matrix rule Defines the relations between combinations of product variants and configuration options. 45

MBOM Illustrates how the product should be assembled consisting of a structured list where different parts included in the product are illustrated. 12

Modularisation A concept connected to product development, where companies provide customers with products allowing high variation. 10

Module Represents using common articles instead of unique articles. 10

Native app An app located onto a device, which requires that the app has to be installed of a media locally. 47

Not Available A relation alternative that exclude a specific relation from being chosen. 45

On-premise Explains that the IT-servers are housed on a specific location, e.g., at the users computer. 9

Overhead cost Expenses that can not be directly linked to creating a product and can be related to running a business. 39

PLM A methodology or business strategy where product data across the whole product lifecycle are managed. 1

Product configuration Describes the product variants and their corresponding variant values ordered from a customer or defined by a company. 2

Product family An association of products which are derived from an identical platform of products. 10

Product variant A defined category of one or more choices which the customers can choose from. 2

Selected A relation alternative that is chosen when only that type of relation can be chosen, thus excluding other possible relations that exist. 45

UPS A structure which collects/can convert it to different kind of structures depending on the environment. 14

Variant value A choice within a product variant. 2

Variation Different customer requirements should be fulfilled. Variation and variety are used as synonyms throughout the master thesis. 1

Widget app A set of tools within a dashboard which provides services in an interactive window, e.g., displaying a status. 44

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1
Introduction

Throughout the introduction chapter, a description of this master thesis can be found. The background provides information about the master thesis' underlying problem, a description of the case study, aim, purpose, and research questions. Thereafter, a presentation of the master thesis' delimitations, followed by a description of sustainability aspects, and lastly an overview of the outline of the master thesis can be seen.

1.1 Background

The production system is seen as the basis to provide value to the customers (Qin, Liu, & Grosvenor, 2016; Bellgran & Säfsten, 2010). Hence, it is important to have a production system that is adapted to what the company does and how the production system can be used to create value for the customers. Furthermore, it creates a challenge, how can companies adapt their operation to what customers desire? Feldmann, Legat, and Vogel-Heuser (2015) explain, products where the customer can choose details or components of a specific product, also called customised products, are becoming more common in today's society. It can therefore be argued, it is important for companies to meet customers' needs and demand, to be competitive in their market.

It puts requirements on an organisation to work, mainly within the product development and production departments, with customer needs which are continuously changing. One way to work with variety in customer demand in a company is through a Product Lifecycle Management (PLM)-system (Saaksvuori & Immonen, 2002). Saaksvuori and Immonen (2002) explain, with a PLM-system, the whole lifecycle of a product can be managed and information connected to it. Moreover, a PLM-system can be seen as an attractive approach for companies due to it can reduce costs and time in all lifecycle phases (Zhao, Jeong, Noh, & Yee, 2015). In a PLM-system, it is possible to build product structures, but also managing variations of a product (Saaksvuori & Immonen, 2002). Variation or variety means that different customer requirements shall be fulfilled (Feldmann et al., 2015). In this report, variant management implicates both how to manage customised products in their physical form and how to manage customised products in a PLM-system.

According to Slack and Lewis (2015), capabilities are connected to an organisation's strategy, where these are needed for an organisation to sustain over time.

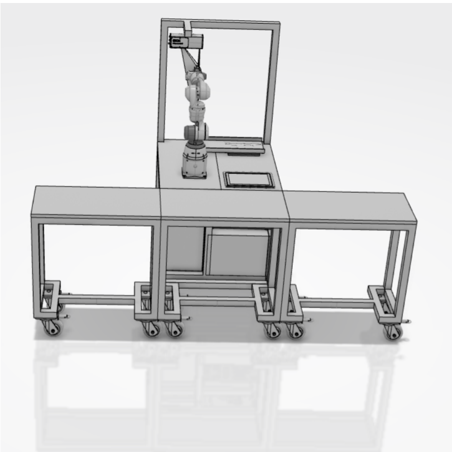
One of these capabilities is flexibility, which can be connected to the production system (Bellgran & Säfsten, 2010; Brettel, Klein, & Friederichsen, 2016). Hence, an analysis concerning the need of flexibility in today's industry, the relationship between flexibility and customers' demand, and how flexibility can impact product variation is of interest to investigate. Throughout this master thesis, the scope of flexibility concerns two parts. The first one concerns the ability to improve flexibility through variant management. The second one concerns what Slack and Lewis (2015) explained flexibility can be defined as and its importance to the production system. The authors explained flexibility as the ability to manage frequently changes in demand.

A project driven by Gothenburg Technical College, called *Smarta Fabriker*, is a collaboration between universities, companies in the industry and vocational universities (Smarta Fabriker, 2020). The aim of the project is described to create a social platform, where knowledge between industrial organisations can be shared. Moreover, the aim is to increase the attractiveness of technology and careers of companies in the industry (Smarta Fabriker, 2020). During the time period, 2017-2019, two different demonstrators were developed by students and collaboration with about 50 different companies (Smarta Fabriker, 2020). A demonstrator in this scenario represents a small production system or cell. One of Smarta Fabriker's demonstrators was developed to inspire, to be more digitalised, sustainable and automated in the industry, also called the *Smart fabrication* (Smarta Fabriker, 2020). It was adapted to produce one single product, VR-glasses in cardboard. However, since this demonstrator is only able to produce one single product, it was not flexible enough to enable an implementation of product variants, variant values and product configurations. According to Schuh, Rudolf, and Riesener (2014), a product configuration is a representation of how several parts can be combined and assembled to achieve desired abilities. It also describes product variants and their corresponding variant values ordered from a customer or defined by a company.

With this background, a need to create and build a new demonstrator have been established. The purpose of the new demonstrator is to analyse how to achieve a flexible production and collaboration between human and automation. During the year 2020, this new demonstrator, called *Production for Future*, will be developed and built by Smarta Fabriker.

1.2 Case study

Smarta Fabriker aims to increase flexibility in their new demonstrator, Production for Future. The aim with the case study is to analyse Smarta Fabriker's new demonstrator and product offerings. Currently, the demonstrator consists of three different workstations, where a LEGO-made truck will be assembled. The demonstrator in a virtual representation is illustrated in Figure 1.1a. Three operators will be assigned to assemble the LEGO-made truck, one at each workstation. All stations are possible to move, enabling a mobile production system. Furthermore, a robot is presented in the demonstrator and has the ability to move between the three workstations, depending on where the assistance of the robot is needed. The robot and operators will work in a collaborative environment, thus enabling both parties to work with one another without disrupting each other's work tasks. In Figure 1.1b, a physical and complete representation of the LEGO-made made truck is illustrated.



(a) A virtual illustration of the demonstrator.

(b) Illustration of the LEGO-made truck.

Figure 1.1: Illustration of the demonstrator, without any operator and the finished product that will be assemble in the demonstrator.

One company that is part of the project Smarta Fabriker is Dassault Systèmes. Dassault Systèmes provides software solutions to several industries and are known for their 3D-modelling and PLM-applications (Dassault Systèmes, 2020c). Dassault Systèmes has a business experience platform called 3DEXPERIENCE, which will be used to perform this master thesis project. Moreover, employees at the company will provide supervision and knowledge support regarding the 3DEXPERIENCE platform and Dassault Systèmes' PLM-system ENOVIA, as well as guidance for the master thesis project.

1.3 Aim and purpose

The aim of this master thesis is to investigate the need of flexibility in the industry and how a flexible production can be achieved through variant management.

The purpose of this master thesis is to investigate why flexibility is needed to be competitive in today's market and how variant management can improve flexibility. The purpose is also to investigate the benefits and challenges of introducing a product and its product variants in a PLM-system by conducting a case study. How this procedure can be executed for organisations currently not utilising a PLM-system, such as Smarta Fabriker, a step-by-step approach in the PLM-system ENOVIA will be illustrated. Moreover, how product configurations and their product variants, impact a production system will also be evaluated.

1.3.1 Research questions

By considering the presented background, aim and purpose, three research questions have been defined. These are:

1. Why is flexibility needed in the industry to be competitive in today's market?
2. How can customised products be managed to increase flexibility?
3. What are the main challenges when utilising variant management?

1.4 Delimitations

Delimitations aim to limit and narrow the scope of the master thesis project to provide answers and investigate the defined research questions. The delimitations are:

- The time frame of the master thesis will take place during 20 weeks, representing full-time studies by two students.
- The step-by-step approach, how variant management can be introduced, is only performed in one PLM-system.
- An investigation and comparison between other PLM-systems will not be performed due to the master thesis' scope.
- ENOVIA and CATIA are the only used virtual workplaces on the 3DEXPERIENCE platform.
- Data concerning the robot is only available for analysing the performance of the demonstrator at workstation two and three.
- The performed case study on the 3DEXPERIENCE platform is only evaluated from a product development perspective.

1.5 Sustainability aspects

Findings from the master thesis will culminate a discussion concerning sustainability aspects. According to Cubas-Díaz and Martínez Sedano (2018), the sustainability concept consists of three parts: economic, environmental and social aspects. It will be discussed if environmental and economic sustainability, whether or not are impacted by using a PLM-system to achieve a flexible production. The demonstrator's impact on these two sustainability aspects will also be analysed. Furthermore, other findings will be discussed regarding concepts that can be used to enable a flexible production. Due to the master thesis' scope, social sustainability is excluded from the discussion.

1.6 Outline of the master thesis

The master thesis consists of six chapters and begins with an introduction about the problem itself and the defined research questions. During the second chapter, the theoretical framework is presented, followed by a chapter about the methodology used to conduct this master thesis. Thereafter, is the result presented. In the discussion, the theory and result are combined and elaborated on. The master thesis ends with a chapter about conclusions, where the three defined research questions are answered.

2
Theory

In following chapter, the theoretical framework of this master thesis is presented. The chapter highlights aspects of a flexible industry and PLM. Then, the 3DEXPERIENCE platform is introduced. Lastly, the content from the platform utilised in the master thesis is presented.

2.1 Flexible industry

To achieve a flexible industry, an understanding regarding areas connected to the production system, Industry 4.0, and development strategies are needed. In Subsections 2.1.1-2.1.3, these three topics are described.

2.1.1 Production system

In the industry, the production system is seen as the basis to provide value for the customer (Qin et al., 2016; Bellgran & Säfsten, 2010). The authors describe, the whole value chain, from design of a product to services are included and integrated. Bellgran and Säfsten (2010) describe the production system as the process of transforming the input of the system to any output, e.g., the creation of goods through combining materials, capital and work.

Capabilities are connected to the organisation's strategy as well as strategies connected to the production system (Slack & Lewis, 2015). Slack and Lewis (2015) define capabilities as the way an organisation is structured. The authors further explain, by using capabilities, it is possible for the organisation's strategy to sustain over time. Brettel et al. (2016) present four different capabilities: *costs, quality, dependability and flexibility.* These capabilities are also called competitive factors (Bellgran & Säfsten, 2010). To create a flexible production it is important to link flexibility with the overall organisation's strategy and include the four capabilities/-competitive factors presented by Brettel et al. (2016); Bellgran and Säfsten (2010). However, Slack and Lewis (2015) also describe these capabilities but mention a fifth capability, *speed.* According to Slack and Lewis (2015), flexibility is defined as the ability to manage frequently changes in demand. Moreover, Brettel et al. (2016) state flexibility of the production system can increase due to upgrades in the technology but also through qualified employees. When the production system is of flexible character, it can manage products with high complexity (Brettel et al., 2016). If customers have specific requirements, thus demanding a customised product, the production system needs to be flexible to meet the customer demand and requirements (Wan et al., 2016). A company should strive to produce more with less resources, to meet customers demand (Mourtzis, 2015). When the production system has high flexibility, it can rapidly respond to changes and new product demand (Qin et al., 2016; Weyer, Schmitt, Ohmer, & Gorecky, 2015).

To enable a manufacturing system that will manage unpredictable changes and improve its dynamic behaviour, a reconfigurable system is suggested (Hees & Reinhart, 2015). The authors claim, to successfully respond to customer needs which are continuously changing, a system which enables a flexible and changeable environment is considered as key aspects. Cost and revenue aspects need to be considered when a company implement variety decisions (Pakkanen, Juuti, & Lehtonen, 2016). For companies to succeed, customised products are needed to be offered (Schuh et al., 2014). Moreover, Schuh et al. (2014) argue, the price is also needed to be competitive compared in relation to other companies. Reduced production costs, as well as optimisation of the utilisation of a production system, can be the result from reconfigurability of a production system (Wan et al., 2016).

A product configuration presents the product variants and their corresponding variant value ordered from a customer or defined by a company (Schuh et al., 2014). The authors also describe a product configuration as how a certain combination of components is assembled to achieve the desired abilities. Moreover, a product configuration is described as one important concept to achieve flexible production (Mourtzis, 2015). Product configurations are needed to determine the parts which are needed to fulfil a variety of customer needs (Pakkanen et al., 2016). Mourtzis (2015) states, a product configuration focuses on maintaining performance of a product, including functions and design, during its lifecycle. For engineers, the analysis becomes even more difficult when the manufacturing system is complex and incorporation between flexibility and reconfigurability must be achieved (Mourtzis, 2015). The author further states, a fast reconfiguration of the production system is required with increased product variety. One challenge is to recognise the benefits and costs for companies during the configuration process of product variation (Schuh et al., 2014).

Modrak, Marton, and Bednar (2014) discuss how assembly variations and product configurations affect the complexity and performance of assembly lines, more specifically, mixed-model and mass customised assembly. Furthermore, knowledge of the connection between the complexity of a system and a certain amount of product configurations is highlighted to identify the optimal design of the system or product (Modrak et al., 2014).

Configuration management is used to communicate and fit order requirements to the available resources in the production system (Hees & Reinhart, 2015; Lindkvist, Stasis, & Whyte, 2013). Its purpose is to address issues related to the impact between different sub-systems in a configuration (Lindkvist et al., 2013). The authors explain, configuration management is the process to manage changes related to engineering systems and data, as well as maintaining different systems in how they should be integrated.

2.1.2 Impact of Industry 4.0 and cloud technologies

The fourth industrial revolution, *Industry 4.0*, is nowadays one common topic within manufacturing and production (Talkhestani, Jazdi, Schloegl, & Weyrich, 2018). The authors explain, it emerged from challenges in the industry and has been introduced due to the needs of a more effective production system. Industry 4.0, requires understanding of flexibility and its role in the production system (Brettel et al., 2016; Qin et al., 2016). The aim with Industry 4.0 is to integrate the production system, humans and intelligent machines, across the whole organisation (Schumacher, Erol, & Sihn, 2016). However, in the fourth industrial revolution, Wan et al. (2016) argue, it is important to meet the demand of customised products in the production. Talkhestani et al. (2018) claim, a reconfigurable production system can be achieved by using the significance of the concept Industry 4.0.

According to Mourtzis (2015), cloud technologies, IoT and Information Communication Technology (ICT) are trends that will convert the function of the enterprises. Cloud technology can be described as one way to store data and to access software from another location than your own (Mourtzis, 2015). The author describes resources are shared between the users. Moreover, Mourtzis (2015) mentions, it is also used to reveal aspects related to manufacturing, e.g., machine availability, collaboration and data integration. According to Mourtzis (2015), an advantage of using cloud technology is that Supply Chain Management (SCM) can be distributed and decentralised through increased mobility and easier access to information. If drawbacks instead are considered, it does not exist standardisation of how to adapt cloud technologies and lost of control over data, on the cloud system (Mourtzis, 2015). Another concept on how to store data, Overton (2012) mentions, is on-premise. The author explains, on-premise can be described as a software located within a physical place, e.g., on a computer. Pakkanen et al. (2016) suggest, having an IT-system which provides the working environment, where product configurations are being managed may improve the lead time, knowledge storing and product quality.

2.1.3 Development strategies

Traditional products are not aimed to meet requirements when customers demand are changing (Wagner, AlGeddawy, ElMaraghy, & Müller, 2014). According to Wagner et al. (2014), this lead to a new phenomenon, Concurrent Engineering (CE), where all lifecycle phases of a product are considered. Moreover, the authors state that CE, is a methodology regarding how to design and develop products. During the implementation phase, the need for CE is increased. CE leads to reduced costs and improved quality (Iosif et al., 2018). Furthermore, CE results in people throughout the enterprise can communicate through a common language (Felic, König-Ries, & Klein, 2014).

Companies must meet requirements from customers in the production system, regardless of the variation (Schuh et al., 2014). Modrak et al. (2014) state, flexible production systems are used to produce mass customised products, where the production system has evolved to meet these demand. To meet variation in the demand, modules or sub-assemblies can be used to create the finished product (Modrak et al., 2014). If companies do not meet customer needs in product variation, the profitability can be effected (Wagner et al., 2014). However, the production system also has to be able to quickly adapt to changes in the market needs, to gain market shares (Hees & Reinhart, 2015). Increased product variation requires a strategy where all steps, from design to finished product are considered (Mourtzis, 2015).

In an industry which is characterised by a high variation, changeable manufacturing systems are essential to implement changes smoothly (Wagner et al., 2014). The authors state, the production system should be profitable meanwhile it should be able to respond quickly to customer requirements which are continuously changing. To face this challenge, Pakkanen et al. (2016) suggest a strategy for the product development including the concepts: *product configuration, product family and modularisation*. The authors continue describing the usefulness of these concepts when working in a mass customised environment. Mass customisation is an idea, where companies provide customers with products which allow high variation (Pakkanen et al., 2016). The aim with mass customisation is the trade-off effect between two parameters: cost and variation (Slack & Lewis, 2015). The authors describe modularisation as to allow improvement concerning managing of the responsiveness to changing demand. Slack and Lewis (2015) state, modularisation is a definition of a specific strategy regarding how complex product and processes should be organised. The authors mention product platforms to enable evaluation of components and is defined as a product structure approach. Through modularisation, the amount of components are enabled to be reduced, thus reducing development cost and the need of different production lines to fulfil customer needs (Slack & Lewis, 2015). Although importance to efficiently manage design and reuse of products and optimisation of product variety's impact on production are mentioned, Pakkanen et al. (2016) explain the lack of including them in design methods.

It is not sufficient to have a modular product family without any defined product configuration, due to the lack of configuration rules and restrictions (Pakkanen et al., 2016). The authors highlight the importance of allowing the same modules in a variety of product variants to increase the value of modularisation and reducing variants with no value-adding features. According to Jokinen, Vainio, and Pulkkinen (2017), a good implemented change management process will enable products to be continuously improved. Pakkanen et al. (2016) suggest a framework to support the design process of product variants and to increase understanding of modularisation. It can be seen that the knowledge regarding a company's products, customer needs, and business of the design team is needed to provide relevant input.

Different products in a product platform can be actualised throughout product variants (Ebrahimi, Åkesson, Johansson, & Lezama, 2016). The authors continue, if product variants are similar, e.g., due to functionality, they are grouped and create a *variant group*. A configuration is chosen from the variant group. A constraint or configuration rule, is a rule for how the product configurations may be formed. Furthermore, this will affect how the product can be ordered by a customer (Ebrahimi et al., 2016).

2.2 Product lifecycle management

The purpose of PLM, the result of a PLM-system and the implication of a product structure are described.

2.2.1 Purpose of product lifecycle management

PLM can both be seen as a methodology and be used in software implementation (Saaksvuori & Immonen, 2002). According to Felic et al. (2014), PLM can be seen as a methodology where product data across the whole product lifecycle is managed. All lifecycle phases from customer requirements, design, engineering until finished product are included in the scope (Zhao et al., 2015; Talkhestani et al., 2018). PLM is described as a business strategy or strategic business solution, where different stakeholders can be integrated in the product's different lifecycle phases (Ameri & Dutta, 2005). Moreover, Ameri and Dutta (2005) state, the ability to have access to the right information at the right time and context can be achieved through a PLM-system. In a PLM-system, functionalities can be used to build the product structure, work with managing different variants and often allows the ability to filter a product structure (Saaksvuori & Immonen, 2002). Saaksvuori and Immonen (2002) describe, allowing a product structure to be filtered enables complex products to be managed more efficiently since the affected parts can be shown or hidden.

The aim with the PLM-system is to reduce costs and time, where problems in manufacturing processes and product development will be understood and improved business performance can be achieved (Zhao et al., 2015). Ameri and Dutta (2005) argue, PLM also results in reuse of knowledge during all lifecycle phases, which results in closing the knowledge loops. Felic et al. (2014) state some advantages by using PLM-systems, e.g., improved collaboration within the company and with stakeholders, reduced product costs, time-to-market, competitiveness and improvement of product's quality. Mourtzis (2015) argues, there are still some challenges within several industrial sectors. The reasons behind the challenges are the complexity of understanding concepts, how to practical use them but also the existing gap between the implementation of the industry and researcher (Mourtzis, 2015).

2.2.2 Product structure

The structure of a product represents the way it is conceptualised, developed and constructed (Petrucciani, Marangi, & Agosta, 2019). The Bill of Material (BOM) is developed from the product structure and is used to perform simulations as well as validation of a product (Petrucciani et al., 2019). Moreover, the BOM involves all different parts and how to assembly the product (Stekolschik, 2017; Jonsson & Mattsson, 2009). Moreover, the authors state, a BOM is complete, when it includes which parts to be comprised, the structural relationship between different levels and the quantity of each. According to Jonsson and Mattsson (2009), all information in the BOM is important, especially in the field of manufacturing. The authors state, using BOMs, are crucial to be able to use different planning methods for material in a company. The BOM is often structured in a hierarchical form (Stekolschik, 2017; Jonsson & Mattsson, 2009). The authors describe, the down level represents material and individual parts to be included and the top level represents how the finished product looks like. When a new product variant is introduced, the BOM might change and differ from the previous appearance which results in different assembly/manufacturing operations (Ebrahimi et al., 2016).

Two different BOMs are common, the EBOM and Manufacturing Bill of material (MBOM), which both are key aspects to enable the creation of modern products (Stekolschik, 2017; Ebrahimi et al., 2016). Ebrahimi et al. (2016) explain, the EBOM and MBOM represent documented structure of the product family. According to Jonsson and Mattsson (2009), both these BOMs must include each item in a product. Stekolschik (2017) explains that the EBOM can be seen as the design structure. The author further states, to create a distinct explanation of the product, other documents, e.g., CAD-items or product specifications are used in combination with the EBOM. In the EBOM, the variant groups are described from a functional viewpoint (Ebrahimi et al., 2016). The authors also state, high variety results in frequently updates of the different BOMs, resulting in time-consuming activities. The MBOM is illustrated by a structured list, where each level of the MBOM is a representation and description of each step in a manufacturing process (Stekolschik, 2017; Jonsson & Mattsson, 2009). The authors explain, it shows how the product should both be manufactured and assembled.

2.3 3DEXPERIENCE

This section aims to provide information about the business platform, 3DEXPERIENCE.

2.3.1 Description of the 3DEXPERIENCE platform

3DEXPERIENCE is defined as a business platform, designed to integrate communities of cooperators and increase collaboration with the aim to create effective products (Petrucciani et al., 2019; Barth, 2013). Dassault Systemès introduced the platform with the aim to place the customer in the centre of the system, where product development and business processes are integrated (Barth, 2013). The 3DEXPERIENCE platform intends to provide value throughout all departments of companies by offering software solutions (Dassault Systèmes, 2020b). It is further explained, the aim is to offer customised product related to different customer demand. Applications in business processes are supported by the platform and include the PLM-system (Petrucciani et al., 2019). Through the platform, engineers and designers can access data from Internet of Things (IoT) and traditional IT-systems, to include knowledge and information management of the product's different lifecycle phases (Petrucciani et al., 2019).

The business platform or the *Compass* as it is also named, illustrated in Figure 2.1, is edited around four different app categories: Social & Collaborative, Information Intelligence, Content & Simulation and 3D Modeling (Barth, 2013). Barth (2013) states, when working digitalised, it is possible to validate tests before implementing it in larger scale. Furthermore, it is also less time consuming due to the ability to create even more iterations of the digital implementation (Barth, 2013). Barth (2013) claims, it is less expensive to use digital models compared to using prototypes.

Figure 2.1: Illustration of the 3DEXPERIENCE platform (Barth, 2013).

In the four app categories, different virtual workplaces can be found. ENOVIA is one of the virtual workplaces, under the Social & Collaborative app category. ENOVIA is a PLM software product, with the focus on project management and engineering processes, which does also integrates 2D and 3D software products (Iosif et al., 2018). Moreover, Iosif et al. (2018) explain, ENOVIA is described to provide a framework which enables collaboration and involves creators and consumers in the whole product lifecycle. The other used virtual workplace, CATIA, can be found under the 3D Modeling app category.

2.3.2 Description of used roles and apps

The roles and apps that have been used on the 3DEXPERIENCE platform and named throughout the report are illustrated in Table 2.1. Each role and corresponding apps are connected to a short description containing its usage.

Table 2.1: Description of used roles and apps on the 3DEXPERIENCE platform.

Role	*App*	*Definition*
3D Product Architect	Product Structure Editor	This app is used to enable navigation of the structure of a product and share different experience between a structure and a 3D model (Dassault Systèmes, 2019).
Mechanical Designer	Assembly Design	An app which is used to design and assembly product parts, where flexible interfaces are used (Dassault Systèmes, 2019).
Product Manager	Model Definition	In a simple manner this app can help companies with managing products with high variability (Dassault Systèmes, 2019).
	Variant Management	An app which is used to help companies with managing the commercial and conceptual conditions regarding a version of a model (Dassault Systèmes, 2019).

2.3.3 The theoretical approach of variant and configuration management

A Unified Product Structure (UPS) is used on the 3DEXPERIENCE platform, which can contain several different structures to enable one adaptable reference with several usages (Dassault Systèmes, 2019). It is further explained, when working with variant and configuration management on the platform, an Engineering Item Structure will be defined and created on the platform. An Engineering Item Structure has the same meaning as a product structure from an engineering perspective. When it has been defined, it will be part of the UPS and can be used in other scenarios and applications on the 3DEXPERIENCE platform (Dassault Systèmes, 2019).

A product, its product variants and variants values can be introduced in the PLM-system ENOVIA, by using the iterative process of Configured Engineering on the 3DEXPERIENCE platform (Dassault Systèmes, 2019). A visual representation of the process Configured Engineering can be seen in Figure 2.2. Moreover, this process defines the working procedure of variant and configuration management and defines an Engineering Item Structure.

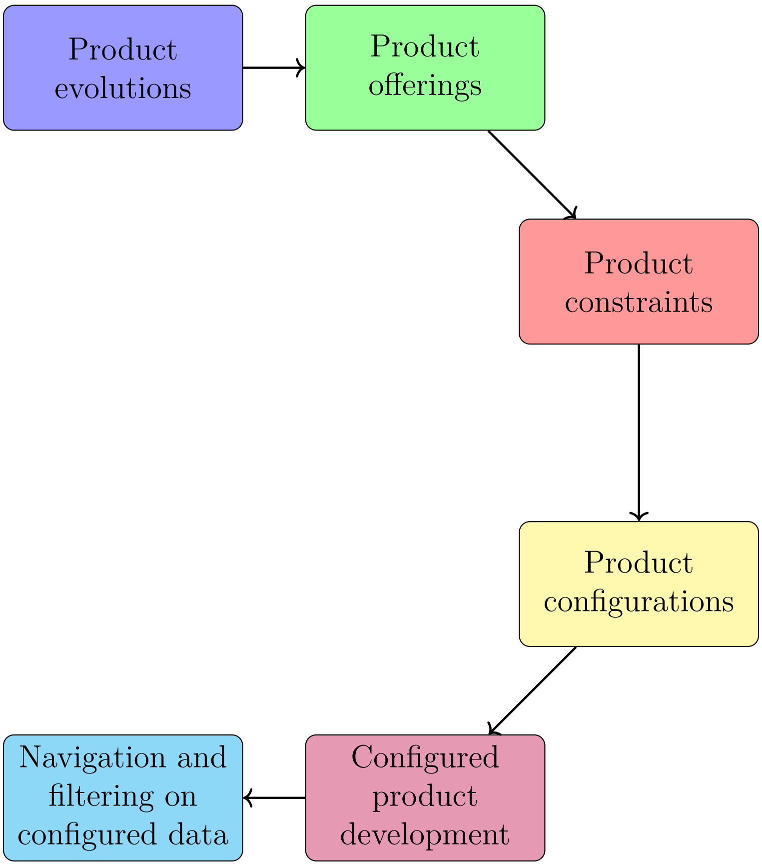


Figure 2.2: Visual representation of the process Configured Engineering used to work with configuration management and defines an Engineering Item Structure on the 3DEXPERIENCE platform.

The first step of the process Configured Engineering is to define the product evolutions (Dassault Systèmes, 2019). The next step is described to define the product variants and variant values. A product variant describes the category that will be presented and variant values the content within a product variant (Dassault Systèmes, 2019). It is further described that the third step defines the product's constraints by providing rules between the variant values to ensure which combinations are valid. The fourth step is to define the product configurations (Dassault Systèmes, 2019). These are defined by using the information from the previous steps to provide valid product configurations. The fifth step is to assign product variants and variant values with the affected components of a product to create a connection between the offerings and the physical components (Dassault Systèmes, 2019). A CAD-BOM imports data from an Engineering Bill of material (EBOM) of a product to ensure which components are needed and the desired quantity of them. Then the needed components' CAD-items are imported and positioned in the correct location to create the CAD-BOM (Dassault Systèmes, 2019). The difference between an EBOM and a CAD-BOM on the 3DEXPERIENCE platform is, a CAD-BOM does also contain the graphical representation of a component and a component's position (Dassault Systèmes, 2019). The sixth step is described to sort the components by defining filters based on desired criteria. A filter will then show the relevant components for the criteria of the filter while hiding the remaining components to obtain the desired definition (Dassault Systèmes, 2019).

3

Methodology

The methodology used throughout the master thesis is presented in following chapter. The chapter consists of a description of the methodology design, followed by a detailed view about each step included in the methodology. The chapter ends with a description of the methodology and research approach.

3.1 Methodology design

The methodology design, consisted of three parallel studies, is illustrated in Figure 3.1. The left side represents the methodology of the interview study, the middle represents the methodology of the literature study, and the right side represents the methodology of the case study. Furthermore, in Figure 3.1, which defined research questions each study will provide answers to, is shown.

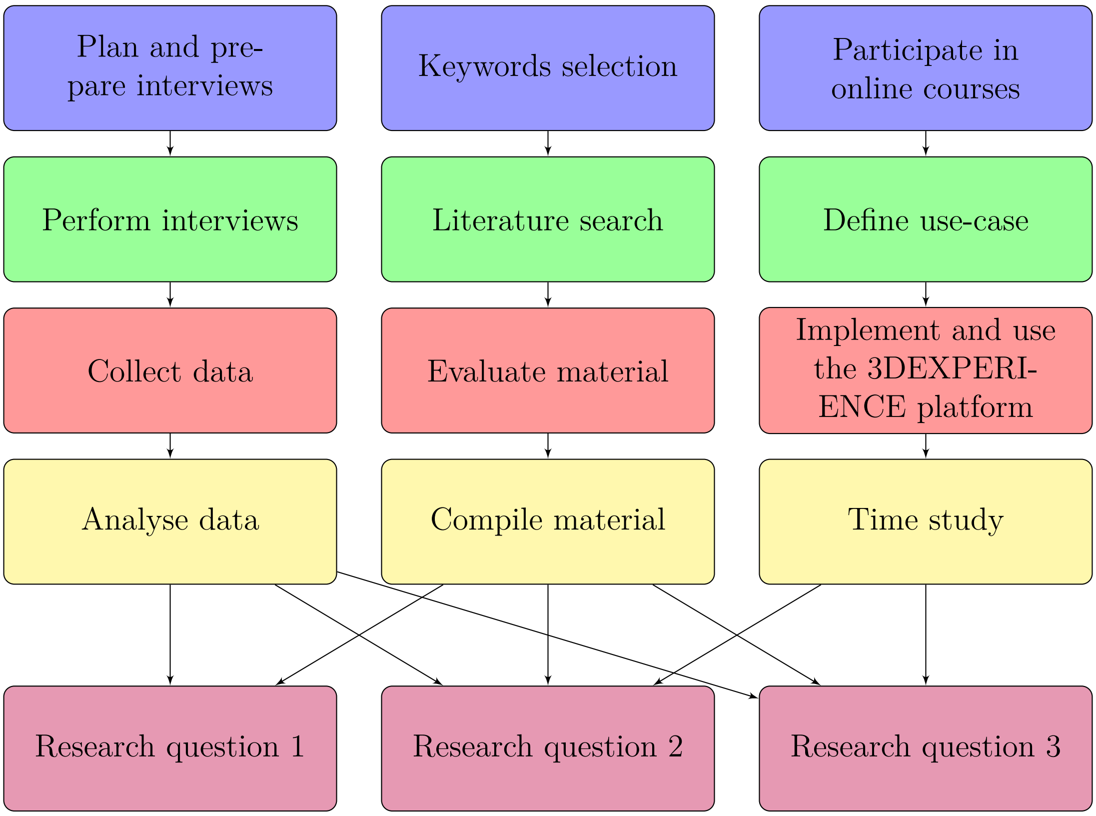


Figure 3.1: Visual representation of the methodology design and which research question they provide answers to.

3.1.1 Interview study

An interview process could be described as a methodology, involving individuals or a smaller number of people (Boyce & Neale, 2006). Boyce and Neale (2006) explained, the aim with conducting an interview was to include individuals' responses and perspectives on a specific idea, issue or situation. Six interviews were conducted with the aim to investigate how companies in the industry are working with: PLM-system, variant management, modularisation and flexible production. One criterion that the interviewees should fulfil, was to have experience within any of the fields PLM, production or product development.

The companies in the interview study are mentioned in the following list as well as the interviewees' working title. Some companies did not want to be named for confidentially reasons such as in what industry they existed in. To respect these wishes, neither names, titles nor companies' name of these interviews are presented in the report. These companies will be mentioned with the letters A-C instead.

(1) Product owner
Volvo Cars

(2) Market specialist manager
Volvo Cars

(3) Change leader
Volvo Cars

(4) Manager Product optimisation R&D
Toyota Material Handling

(5) Company A

(6) Company B

(7) Company C

Company B was the only company of the interviewed companies that was active within the process industry. The other companies were active within the manufacturing industry. When referring to the conducted interviews throughout the master thesis report, the number presented before the company's letter will be used as a reference system. As seen in the list above, there are more interviewees presented than the number of performed interviews. This is due to, (1) and (2) participated during the same interview. Moreover, Volvo Cars is mentioned three times, since three different employees from the same company participated in interviews.

3.1.1.1 Structure of interviews

When performing interviews, different approaches could be used. The two most common according to Bryman and Bell (2011) were qualitative and quantitative interviews. The authors stated it was recommended to use an approach which is flexible and less structured, where the interviewee could add more details and present their perspective, especially when performing qualitative interviews. Hence, the choice to perform qualitative interviews.

3.1.1.2 Process for conducting interviews

Boyce and Neale (2006) presented a step-by-step approach regarding the process for how to conduct an interview. The approach was divided into following five steps:

1. Plan
2. Develop instruments
3. Collect data
4. Analyse data
5. Disseminate findings

The approach presented by Boyce and Neale (2006) inspired the methodology of the interview study in this master thesis, illustrated in Figure 3.2. In this methodology, there are four steps instead of five, since the first two steps presented by Boyce and Neale (2006) were compiled into the step *Plan and prepare interviews*. Moreover, the fifth step presented by Boyce and Neale (2006) was included in the step *Analyse data*.

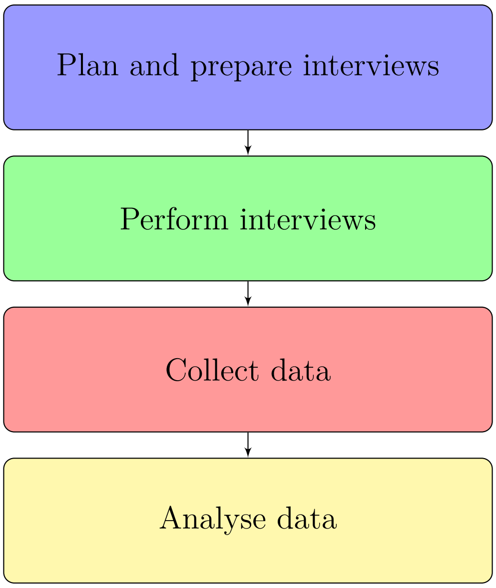


Figure 3.2: Visual representation of the steps included in the interview study.

The first step of the interview study, illustrated in Figure 3.2, was the plan and preparation stage. People which fulfilled the criterion of having experience of any of the fields PLM, production or product development were identified. Planning and preparation of questions to be asked during the interviews were also included in the first stage *Plan and prepare interviews*. The asked questions are presented in Appendix A.

A semi-structured approach was chosen as the structure of the interviews. This enabled the opportunity to have prepared questions to be asked during an interview while allowing other topics to also be discussed and additional information to be provided (Boyce & Neale, 2006; Bryman & Bell, 2011). All performed interviews began with a general question to gain knowledge about the interviewee and their experiences. Thereafter the interviews were divided into four topics: PLM-system, variant management, modularisation and flexible production. The interview process ended by asking if the interviewee wanted to add anything, to not exclude the possibility of additional data. If approved by the interviewees, the interviews were voice recorded to reduce the focus on taking notes during the interviews, which was recommended by Bryman and Bell (2011). The authors stated, after an interview was conducted, data from the voice recording should be analysed by transcribing and summarising the content of the interview. Interviews were both performed face-to-face and by using communication software, where the same procedure presented in Figure 3.2 was used. All interviews were performed in Swedish due to the interviewees had Swedish as native language. Each interview was therefore translated after the transcribing process, which were performed the same day as the interview was performed. Thereafter, the data was analysed to identify relevant themes in each interview and similarities and differences between the interviews.

3.1.2 Literature study

A literature study was performed where useful literature were collected and compiled. A literature review build the design of the research with the aim to create a better understanding of relevant theories and concepts and what was already known in academia (Bryman & Bell, 2011). According to Hart (2018), a literature study could be divided into four steps. The different steps included in the literature search are illustrated in Figure 3.3, which were inspired from what Hart (2018) presented regarding performing a literature study.

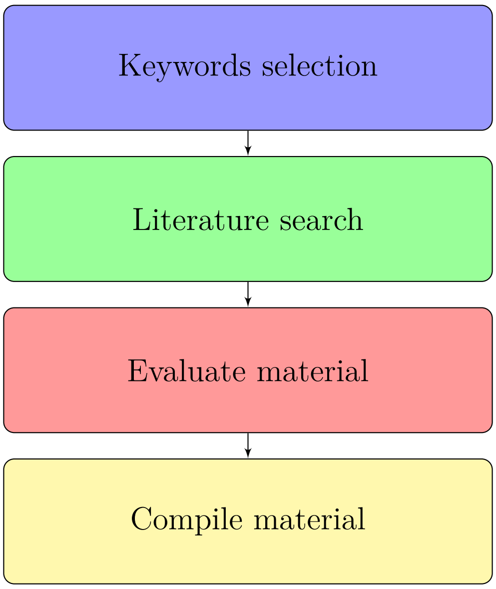


Figure 3.3: Visual representation of the steps included in the literature study.

Rowley and Slack (2004) described four different search strategies when performing a literature review. These four are: successive fraction, building blocks, brief search and citation pearl growing (Rowley & Slack, 2004). In this master thesis, when performing the literature review, building blocks was chosen as the search strategy. This was due to the opportunity to extend keywords by using synonyms and related terms, which was described by Rowley and Slack (2004).

In addition to the performed literature review, material from Dassault Systemès' User Assistance was used to find information about the used roles and apps, when utilising 3DEXPERIENCE. Furthermore, the User Assistance was used to find information concerning the theoretical approach of variant and configuration management. Moreover, course literature from Chalmers University of Technology, which were identified as relevant by the authors of this master thesis, were used. Literature from courses: Manufacturing strategy, Product lifecycle management, Production logistics, Production management and Production systems, were used. The course literature was deemed as useful when deeper understanding about the theoretical building blocks connected to the defined research questions were provided. Moreover, a book about *Cloud Technologies*, found through *ProQuest Ebook Central*, was deemed as relevant. The titles of the used literature from previous courses and the book found through ProQuest Ebook Central are presented in the following bullet list:

- Operations Strategy
- Product Lifecycle Management
- Manufacturing Planning and Control
- Maynard's Industrial Engineering Handbook
- Production Development: Design and Operation of Production Systems
- Microsoft Windows Intune 2.0: Quickstart Administration

3.1.2.1 Keyword selection

Keywords related to the defined research questions and the scope of the master thesis were selected. By considering topics from the master thesis proposal and from discussion with supervisors both at the company and the university, a pre-study was performed. The aim was to identify additional keywords used in this master thesis. The number of identified keywords was 17.

3.1.2.2 Literature search

Before the literature search was performed, different databases were evaluated that could be useful when performing a literature search. Three different databases: Scopus, Google Scholar and Web of Science were evaluated in terms of width of articles, credibility, quality and previous experience of the databases. In Table 3.1, these databases have been evaluated, in terms of what Sjögärde (2014) explained regarding the differences between the databases and the first three mentioned criteria. The last criterion, previous experience, was evaluated based on the master thesis' authors' experience of using the database. Scopus had been used before by the authors in previous work while the authors had a lack of experience in using Google Scholar and Web of Science. The author's explanations were translated to a short evaluation, where a plus sign indicated what Sjögärde (2014) stated as an advantage with the databases, and a minus as a drawback with the databases. The same procedure was implemented for the added criterion, previous experience. Thereafter, the different evaluation criteria for each database were summarised. As seen in Table 3.1, Scopus received the highest total score and hence resulted as the choice of database.

Table 3.1: Evaluation criteria of three different databases.

Criteria / *Database*	Width of articles	Credibility	Quality	Previous experience	Total
Scopus	-	+	+	+	2
Web of Science	-	+	+	-	0
Google Scholar	+	-	-	-	-

By combining the identified keywords with Boolean operators, *AND/OR*, articles which included either both terms or one of the identified keywords in the search string could be found. The Boolean operator *AND* required articles which had both terms while Boolean operator *OR* allowed articles with only one of the two terms presented. To limit the performed search strings, only articles with the criterion *Open access* were analysed. Furthermore, a constraint regarding the written language of the articles was chosen, where only articles written in English were included. When performing a search in Scopus, different subject areas could be included/excluded in the search string to limit the search result. The selected subject areas, that were included and excluded when searching in the database Scopus, are summarised in

Table 3.2. The included subject areas were themes related to the scope and purpose of the master thesis. The subject areas are listed in alphabetical order.

Table 3.2: Subject areas, included and excluded when searching in the database Scopus.

Included	*Excluded*
Business Management and Accounting	Agricultural and Biological Sciences
Computer Sciences	Arts and Humanities
Engineering	Biochemistry, Genetics and Molecular Biology
Material Science	Chemical Engineering
	Chemistry
	Dentistry
	Earth and Planetary
	Economics, Econometrics and Finance
	Energy
	Environmental Science
	Health Professions
	Immunology and Microbiology
	Mathematics
	Medicine
	Multidisciplinary
	Neuroscience
	Nursing
	Pharmcology, Toxicology and Pharmaceutics
	Physics and Astronomy
	Psychology
	Social Science
	Veterinary

The total number of performed search strings in the database Scopus was 10. Each search string in Scopus, where keywords were combined with Boolean operators and with applied restrictions, have been summarised in Table 3.3. The right column in Table 3.3 represents the total number of found articles in each performed search string.

Table 3.3: Keywords, search strings and the generated number of articles.

String	*Keywords and Boolean operators*	*Nr. of articles*
1	TITLE-ABS-KEY (“3dexperience” OR “3ds”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “MATE”) OR LIMIT-TO (SUBJAREA , “BUSI”)) AND (LIMIT-TO (LANGUAGE , “English”))	456
2	TITLE-ABS-KEY (“change management”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	304
3	TITLE-ABS-KEY (“plm” OR “Product lifecycle management” AND “change management”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”)) AND (LIMIT-TO (LANGUAGE , “English”))	6
4	TITLE-ABS-KEY (“flexible production”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	101
5	TITLE-ABS-KEY (“Variant management” OR “Variant handling” OR “Variety management” OR “variety handling”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	177
6	TITLE-ABS-KEY (“enovia” OR “Dassault systemes” OR “Dassault Systèmes”) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “MATE”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”)) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (LANGUAGE , “English”))	433
7	TITLE-ABS-KEY (“ebom” OR “Engineering bill of material”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	11
8	TITLE-ABS-KEY (“plm” OR “product lifecycle management”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”)) AND (LIMIT-TO (EXACTKEYWORD , “Product Life Cycle Management”))	111 (1600)
9	TITLE-ABS-KEY (“Manufacturing bill of material” OR “Manufacturing bill of materials”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	2
10	TITLE-ABS-KEY (“configuration management”) AND (LIMIT-TO (ACCESSTYPE(OA))) AND (LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “BUSI”) OR LIMIT-TO (SUBJAREA , “MATE”)) AND (LIMIT-TO (LANGUAGE , “English”))	100

Each search string was firstly sorted by *Date (newest)* in Scopus. Before any new restrictions were applied, the total amount of articles that the different search strings generated was 3190. Due to the time frame of the master thesis, a few limitations were applied. If a search string generated less than 50 articles, these articles were saved until the next step of the evaluation process. Gentles, Charles, Nicholas, Ploeg, and McKibbon (2016) suggested a criterion, *influence*, to consider after a performed literature search to evaluate the material. The authors explained it as choosing articles that were most cited. To achieve the criterion a new limitation was performed. If a search string generated more than 51 but less than 1000 articles, the articles were sorted according to *Cited by (highest)* in Scopus. The 20 most cited articles in each of the search string were saved until the next evaluation step of the literature study. However, if a search string resulted in more than 1001, which did only occur once in the literature study, a new limitation was introduced. The keyword *Product Life Cycle Management* was selected from Scopus' filter to further limit the search string. Regarding search string eight in Table 3.3, the amount number of articles displayed both the amount before and after using the keyword's filter. The number in the parenthesis displayed the amount of articles before introducing the filter.

3.1.2.3 Evaluate material

Before beginning with the step *Evaluate material*, duplicates were eliminated from the search. Articles found in search string seven were also found in search string nine, thus excluded in string nine. Furthermore, two duplicates in search string one and six were found. These articles were therefore excluded in search string one. Each article was evaluated according to the criterion if they should be able to answer the purpose of the master thesis project. In the first step, both abstract and conclusion were read. If an article was evaluated as relevant and could provide information related to the master thesis' scope, it was kept and promoted to the next step of the literature study, otherwise it was deleted. The number of articles that were identified in the two steps, before and after reading abstract and conclusion, in each search string have been summarised in Table 3.4. After the abstract and conclusion evaluation, the total amount of remaining articles was 23.

Table 3.4: Number of articles before and after reading abstract and conclusion in each search string.

Search string	*Amount of articles, before*	*Amount of articles, after*
1	20	0 (duplicates included in string 6)
2	20	1
3	6	2
4	20	3
5	20	5
6	20	3
7	11	2
8	20	4
9	2	0 (duplicates included in string 7)
10	20	3

3.1.2.4 Compile material

Each article remaining after the evaluation steps was then analysed by reading the whole article. Relevant information were highlighted in the articles and summarised in a common MS-Excel matrix. It was shared between the authors, which was seen as a suitable method called *The grid method*, presented by Timmins and McCabe (2005).

After summarising and evaluation of each articles were made, all relevant information were analysed, in which common categories were identified. The found categories were *Flexible industry, PLM and 3DEXPERIENCE*. With the identified categories, material from each article was compiled and summarised in a new MS-Excel matrix, shared between the authors.

3.1.3 Case study

Dubois and Gadde (2002), defined a case study as a specific research methodology, where a specific phenomenon is investigated. In this master thesis project, a case study was conducted to analyse Smarta Fabriker's new demonstrator and product offerings. It investigated the benefits and challenges of introducing a product, product variants and variant values in a PLM-system. Further, how the implementation in ENOVIA could look like and to analyse the impact an implementation of product variants and product configurations will have on the product and production system. The methodology of the steps included in the case study is illustrated in Figure 3.4.

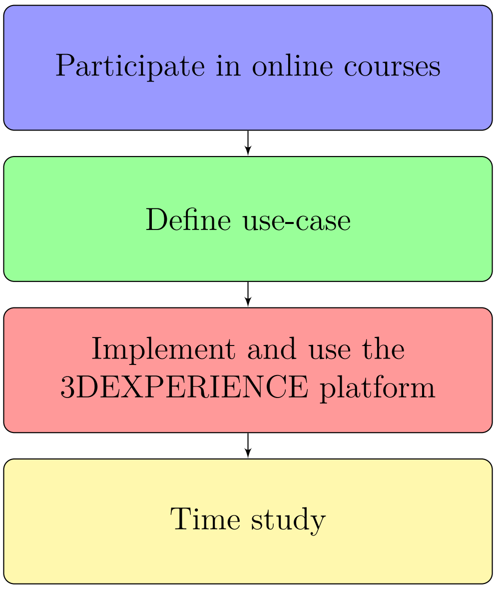


Figure 3.4: Visual representation of the steps included in the case study.

3.1.3.1 Participate in online courses

The first step included participating in online courses on Dassault Systemès Learning Space (Dassault Systèmes, 2020a). The aim was to create knowledge about the 3DEXPERIENCE platform and how to use its support to provide answers to the defined research questions of this master thesis. The roles and apps connected to the courses executed, can be seen in Table 2.1. Furthermore, the courses included smaller projects where different exercises were performed on 3DEXPERIENCE to easier understand how to navigate on the platform.

3.1.3.2 Define use-case

In the second step, *Define use-case*, the approach described in Jacobson, Spence, and Bittner (2011) was used as an inspiration to the methodology presented in this master thesis report. The methodology approach was found through discussion with one of the supervisors at Chalmers University of Technology. Four steps were defined in the presented methodology. In the following list, each step presented in the methodology is explained and where each step is performed in the master thesis report.

Step 1: Define use-case. Define what functionality that is needed from the customer, company or the system itself. The first step is performed in Subsection 4.2.1.
Step 2: User-stories. Description of functionalities in detail. Performed in Subsection 4.2.1.
Step 3: Fit & Gap analysis. Test what the system can solve by utilising the 3DEXPERIENCE platform. The step is performed in Subsection 4.2.2.
Step 4: Deployment. Evaluate the system and use-case, which in this master thesis is translated to discussion. Evaluation of the defined use-case will

be based on what the findings from the use-case are shown. The use-case will not be individually evaluated. The fourth step is performed in Subsections 5.1.2-5.1.3 and will be included in the findings concerning the case study.

According to Jacobson et al. (2011), a use-case could be defined as one way of using the functionality of a system to achieve a specific goal. In this master thesis, a use-case was defined and divided into user-stories to identify the needs Smarta Fabriker had regarding the implementation of their product variants and variant values in the PLM-system ENOVIA. The aim of dividing a use-case into user-stories was performed to identify smaller steps needed to achieve the need of a use-case.

3.1.3.3 Implement and use the 3DEXPERIENCE platform

The master thesis' use-case was evaluated by utilising the 3DEXPERIENCE platform. Several versions of the platform existed, where this project used version *3DEXPERIENCE R2019x*, due to it currently being the latest version released, when this master thesis was written. The platform was accessed by an on-premise client.

Smarta Fabriker had defined four different product variants of the LEGO-made truck: *Body colour, Rim appearance, Battery size and Engine*. The product variants consisted of one or several variant values that the LEGO-made truck could be assembled with. The product variants with their corresponding variant values are summarised in Table 3.5. The product variants with their corresponding variant values were received from Smarta Fabriker who sent CAD-files and an EBOM which were used to assembly the LEGO-made truck. Illustrations of each variant value can be found in Appendix B. The content of the EBOM can be seen in Appendix C.

Table 3.5: The product variants and their corresponding variant values, which were defined for the LEGO-made truck.

Product variants	*Variant values*
Body colour	Grey
	White
Rim appearance	Black
	Grey
Battery size	Small
	Medium
	Large
Engine	Efficiency
	Performance

With the different product variants and their variant values available, relations between different variants values were applied to evaluate how constraints would affect the available product configurations. The first step regarding the performed study on the 3DEXPERIENCE platform, was to use variant and configuration management to define the product and its offers in the PLM-system ENOVIA. It represented the first four steps of the process, Configured Engineering. Then, the CAD-items in combination with the EBOM were used to define the CAD-BOM of the product. The CAD-BOM was defined to provide and illustrate the assembled truck with all its product variants and variant values' components presented. Thereafter, step five and six of the process Configured Engineering were performed. The CAD-BOM was connected with the work from variant and configuration management to define which product variants and variant values were connected to which parts. An Illustration of which parts were included in each defined product configuration was also provided.

3.1.3.4 Time study

One methodology used to evaluate variant values and product configurations and find differences in the time at each work station, was through a time study. To evaluate the time study, the calculated time was considered as a factor to analyse profitability of variant values and product configurations. A time study was defined as an analysis where the time to perform elements are measured (Zandin, 2001). The author explained, the advantages with using a time study was the ability to analyse an operator and the simplicity to analyse the results. Zandin (2001) explained, when performing a time study an instrument was needed to measure the time, someone to observe who was familiar with the tasks at each station and somewhere to note the observed times. To decide the number of required observations, Zandin (2001) stated, the time for each element should be charted. From the beginning, 10 observations were performed. The time samples were afterwards plotted on a normal distribution graph. If the observed times followed a normal distribution curve, the total number of observations for a specific task at a station was sufficient (Zandin, 2001). If not, more observations were performed until the numbers of observations followed a normal distribution curve.

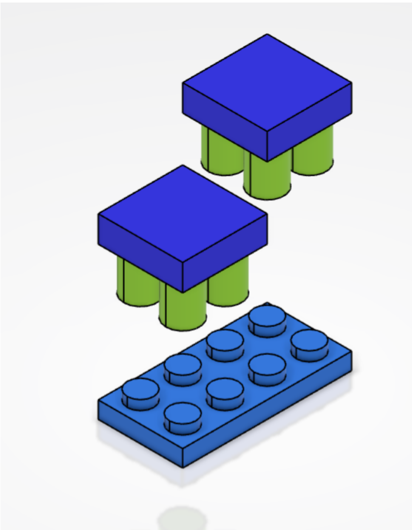
The time needed for the assembly of the LEGO-made truck and its variant values at each station were measured in seconds by using a stop-watch. The measured time considered both manual time, when modules of some variant values were introduced, and when the robot was used at the second and third workstation. One of the group members of the master thesis was identified as operator while the other one measured and observed the needed time. To get familiar with the assembly steps, the operator performed them before starting the time study procedure. Measured data from the time study was extracted into a MS-Excel matrix to enable a presentation of the measured data. Thereafter, the results from the study were analysed and for each station a representative value from the normal distribution curve was found, where the median value was chosen. According to Cortinhas and Black (2012), median and mean values are equal when a curve was normal distributed. The time needed to perform different variant values at different stations was further used to calculate the time needed for each defined product configuration.

Concerning the assembly steps, on the first station, the chassis and wheels of the truck were assembled, where a fixture locked the chassis. The fixtures used in the demonstrator were specifically designed to be adapted for the LEGO-made truck and its product variants. The operator assembled the wheels and added four body holders onto the chassis to make it possible to assemble the body onto the chassis on the third station. Two variant values existed of Rim appearance, Grey and Black. The grey rims had been pre-assembled with tyres, thus ready to be assembled onto the chassis. The black rims, however, had not been pre-assembled. Therefore, the tyres needed to be assembled onto the black rims before being assembled onto the chassis. Time measured at station one concerned all the assembly steps.

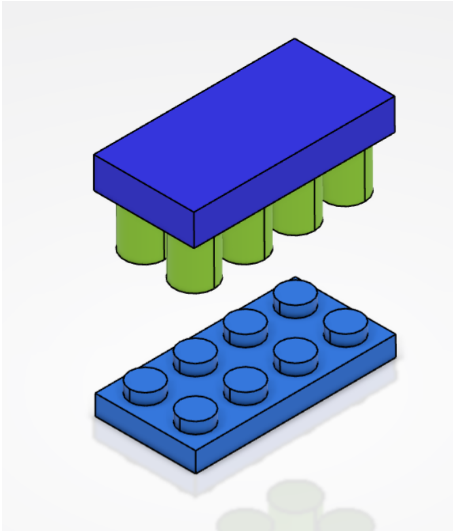
Moving on to the second station, if the robot was used, it scanned a QR-code which enabled the robot to receive information regarding which variant value that should be built. The robot picked battery cell components, which the operator assembled with two battery platform, two battery cells on each platform. Meanwhile the robot worked, the operator assembled the engine by assembling one of the engines with an engine platform. When the robot was finished, the operator connected the two battery packages with the two 1x8 brick battery connector components. The assembled battery and engine were then assembled onto the chassis. If only manual assembly was performed, the operator performed the assembly of the battery packages as well. The measured time at station two was divided into two parts. The first one concerned assembly of the battery package and the second concerned assembly of the engine, and assembly the engine and battery onto the chassis.

On the last station, the body was assembled on the chassis and a quality check performed. If the robot was used, the body was placed up-side-down on a fixture by the operator. The robot then took the body and scanned it for quality inspection. Thereafter, the operator assembled the body and chassis if the quality check was approved and performed a drive test to ensure the truck could roll correctly. If the robot was not used, the operator performed the same steps, where the difference was that the quality check was performed after the chassis and the body were assembled. The difference between Body colour Black and White was component Trailer coupling was pre-assembled for Body colour White but not for Black. Station three was measured in three parts when the robot was used, otherwise one time was measured. The first part concerned adding the component Trailer coupling for the Body colour Black and placing the chassis on the fixture. The second time concerned the time for the robot to perform the quality check and the last part assembly the body on the chassis and perform the driving test. These times were added and presented together.

Modules could only be used during manual assembly and existed for two different product variant values, Battery size Small and Engine Performance. In Figure 3.5a, the appearance of one battery package of Battery size Small without modules can be seen. The two components Battery cell small with the dimensions 2x2 are shown. Figure 3.5b shows appearance of one battery package of Battery size Small when modules are used. Instead of two Battery cell small components with 2x2 dimensions, one Battery cell large with dimension 2x4 can be seen. When performing the assembly of a battery package for Battery size Small in its original state, two Battery cell small needed to be assembled on the Battery platform small component. When using modules, only one Battery cell large needed to be assembled on the Battery platform small for Battery size Small.



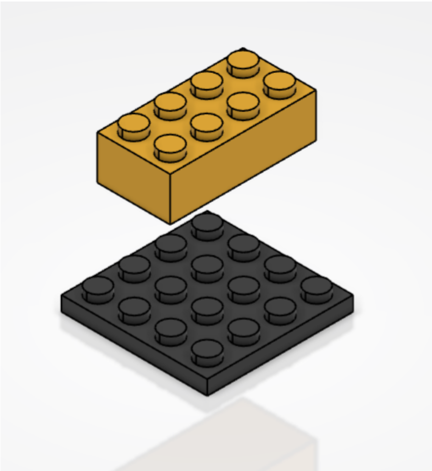
(a) One battery package of Battery size Small original.



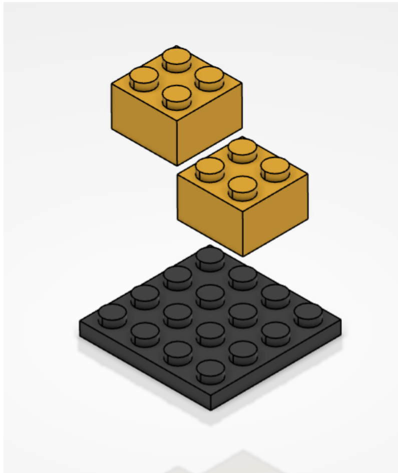
(b) One battery package of Battery size Small module.

Figure 3.5: One battery package of variant value Battery size Small in its original appearance and appearance after module implementation. Using exploded view to highlight components.

In Figure 3.6a, the appearance of the Engine Performance without modules can be seen. The components Engine large with dimension 2x4 and Engine platform are shown. Figure 3.6b shows appearance of Engine Performance when modules are used. Instead of one Engine large component with 2x4 dimension, two Engine small components with dimensions 2x2 can be seen. When performing the assembly of Engine Performance in its original state, only one Engine large needed to be assembled on the Engine platform. However, two Engine small needed to be assembled on the Engine platform when using modules in Engine Performance to fulfil the correct dimensions. Additional figures without exploding views of the variant values with and without modules can be seen in Appendix B.



(a) Engine Performance original.



(b) Engine Performance module.

Figure 3.6: Variant value Engine Performance in its original appearance and appearance after module implementation. Using exploded view to highlight components.

3.1.4 Methodology and research approach

Different methodology approaches could be used when performing a study. Bryman and Bell (2011) presented three common approaches: *inductive, deductive and abductive*. The deductive approach was described as, where logical conclusions are drawn based on different conditions (Bryman & Bell, 2011). The authors explained, on the other hand, inductive reasoning meant conclusions were drawn by associating them with previous experiences. Moreover, Bryman and Bell (2011) stated, the main differences between these two approaches were that the inductive approach is based on previous observations while the deductive was derived from conclusions from the theory. The abductive approach is useful when the aim is to investigate or discover something new (Dubois & Gadde, 2002). An abductive approach could be described as a combination of the inductive and the deductive approaches, where empirical and theoretical data are analysed (Patel & Davidson, 2019). The authors explained, in an abductive approach, the first step was of inductive character, followed by the deductive approach.

Generally, data could be conducted in quantitative or qualitative nature (Patel & Davidson, 2019). Patel and Davidson (2019) mentioned, the differences between different kind of data, *hard* and *soft*. Hard data, connected to a quantitative research was referred to numbers and soft data, qualitative data referred to words. In this master thesis, features of both can be found. Regarding the performed interviews, literature and use-case concerning the 3DEXPERIENCE platform, the data collection were of qualitative character. The time study, can be seen as a quantitative research.

The methodology approach used throughout this master thesis was an abductive research approach. The reason behind the decision was the possibility to create flexibility, when alternating between theory and findings from the studies, where the inductive and deductive approaches were combined. To conduct this master thesis, each part of the methodology design was needed: interview study, literature study and case study. Each of the studies was performed parallel, which was, according to Patel and Davidson (2019), a feature of the abductive approach.

4
Results

The result chapter represents the empirical findings from the performed study. The chapter begins with key findings from the conducted interviews. Then, the case study and its defined use-case, utilisation of the 3DEXPERIENCE platform, and results from the performed time study are presented.

4.1 Key findings from the conducted interviews

The key findings from the performed interviews are presented in following section.

4.1.1 Product lifecycle management

The summarised result from what the interviewees stated on the topic PLM, are presented. Content regarding different needs of PLM-systems, importance of utilising a well functioning PLM-system, as well as advantages and challenges with PLM, can be found.

4.1.1.1 Needs and usage of product lifecycle management-systems

Volvo Cars used different PLM-systems depending on which phase of the product lifecycle it concerned, e.g., in the functional design, logical design, physical design or post-market, (1) explained. Both Volvo Cars and Company A used several PLM-systems due to different systems being specialised in different areas, while Toyota Material Handling and Company C used one PLM-system and Company B none, (1), (4), (5), (6) and (7) mentioned. Company A used software products from PLM-system's supplier or external suppliers, depending on the need, (5) stated. Using products from PLM-system's suppliers had the benefit of better compatibility with the PLM-system (5). On the other hand (5) explained, external suppliers might offer a more suitable product for the need, making it a compromise between what is more important for a certain situation.

According to (5), their primary PLM-system was chosen due to experience in previous system from the same supplier. It also fulfilled the criterion to include all departments' needs within the system (5). (4) explained, by using only one PLM-system, it allowed Toyota Material Handling to keep track of data and articles more easily. (4) claimed, all information was located in one place and people only needed to be familiar with one system. MS-Excel documents in combination with the PLM-system constituted their variant management (4). (4) continued, it would be beneficial to have everything in the same system, but it required adaptation.

(6) explained, an Enterprise Resource Planning (ERP)-system was used, with similar functions as a PLM-system. Their ERP-system was used in combination with MS-Excel documents to make it possible to introduce and manage different production variants (6). Company C used a PLM-system in combination with an ERP-system, (7) mentioned. According to (7), the reason to use a PLM-system was the possibility to manage changes smoother. (7) and (3) stated, there was not an option to not use a PLM-system. In the PLM-system, drawings, constructions and issues of a product were managed while the ERP-system managed production control instead (7). Changes were currently stored in both the ERP-system and in the PLM-system, which for them resulted in duplication, (7) explained. If the changes were needed to be stored in both locations was an aspect they looked into, to reduce unnecessary work (7).

4.1.1.2 Well functioning product lifecycle management system

To be competitive, (1) claimed companies need a well functioning IT-support to manage the complexity of increasing data companies need to manage due to product variety and product configurations. Moreover, (1) described the importance of having the same information model throughout the whole organisation and supply chain. The reason was to minimise uncertainties when implementing variant management in a PLM-system (1). If several PLM-systems were used, it was important that they communicate and share information between each other, (1) explained. According to (3), to find a system that works throughout the whole lifecycle was challenging. Therefore, companies tried to develop their own systems that are adapted to their products (3). (3) continued, it was important to see things from a broader perspective to understand what is currently supported in their system and what kind of deficiencies exist.

4.1.1.3 Advantages and challenges of utilising product lifecycle management

According to (2) and (3), an advantage with using PLM-system was it can create a red thread, from the industry to the end-customer. According to (3), traceability through all lifecycle phases was important, from an idea to implementation until post-market. (3) continued, another reason to use PLM-system was it allowed companies to obtain control. A PLM-system also enabled companies to track what has been delivered to a customer and the possibility to manage complex products, (3) explained. (4) and (5) described, a benefit with utilising a PLM-system was the ability to collaborate between departments within a company. Another advantage with utilising a PLM-system, was it allowed every step of change processes of products and lifecycle stages to be followed digitally (5) and (7). (5) continued, a PLM-system could be connected with other parts of the company, enabling one common platform to store information. (6) mentioned, to succeed when managing customer changing needs, it was important to follow it all the way from customer demand to production. Another reason why Company C used a PLM-system was due to their wide range of products, (7) stated.

A challenge with PLM-systems today was the need to obtain all data and functionalities in their system, which limits the ability to use other systems with other functionalities (1). Another challenge, (1) mentioned, was to integrate a company with several PLM-systems while maintaining the same information model. A challenge, (5) described, was a PLM-system has to be more user-centric, since their PLM-system's interface does not focus on the user experience. Currently, the users could be faced with an overwhelming amount of information, making the decision-making process more complex than needed, (5) claimed. (5) continued, Company A did not have an own production department. The production company producing their products was not connected to the same PLM-system (5). This allowed information and communication to be delayed between the development and production, creating potential mismatches between available data (5).

4.1.2 Modularisation

The core findings from how companies in the industry worked with modularisation and the advantages and challenges it brought, are presented.

4.1.2.1 How modularisation is used in the industry

At Volvo Cars, Toyota Material Handling and Company B, modules were utilised, where standardised articles in products were used instead of only having unique articles in the product structures, (1), (4) and (6) explained. Using different product structures made it easier to work with requirements for each product structure, although the structures needed to be updated respectively, (1) mentioned. Using the same structure or not was a trade-off topic often discussed between different departments, (1) described. (4) stated, the PLM-system could be used to build the product structure as modules. In the PLM-system, fasteners needed to be defined and used to connect modules with each other (4). Toyota Material Handling worked with a platform structure where similar products were placed on the same platform (4).

At Company A, a base product was used to build different product configurations, which (5) explained was how the company worked with modularisation. (7) described several components of Company C's products were designed in a way that can be connected, which only differs in relation to the size of the product. Whereby, it was possible to in some degree work with modularisation (7). Two other criteria determined the changes between products, (7) mentioned. (7) continued, firstly, what was connected to the end of products to fulfil certain needs and secondly, what products would be exposed to, creating requirements needed to withstand.

4.1.2.2 Advantages and challenges with modularisation

(4) explained, modularisation was the ability to have as few articles as possible to be combined into several product configurations. According to (5), the advantage with

modularisation was it allowed the possibility to save time. The result from modularisation was a modern product where flexibility can be created, (5) highlighted. The purpose with modularisation was, according to (3), to enable decoupling between the software and the hardware, making it easier to perform changes. (1) explained, modularisation would benefit the company by reducing the complexity. Using modularisation resulted in a standardised way to work towards, (6) explained. (6) continued, it simplified from the production's point of view and created a possibility to use the same product structures.

From a strict production perspective, (7) highlighted, it would be beneficial to have products which can be used in several ways and satisfy several customer needs. However, it was often the case, a product would become more expensive instead of only storing additional components which satisfy different customer needs, (7) mentioned. Unsuccessful tries had been made to become better at working with modularisation (7). It often resulted in new unique components being made instead, due to difficulties in determining the cost to create and produce a new component (7). (7) mentioned, this was an issue which has to be recognised to eliminate the mindset concerning creating and producing new components as the way to fulfil a need.

4.1.3 Company's view on variant management

How variant management was worked on from a company's perspective are described in the following subsubsections.

4.1.3.1 Determining range of variants and reuse of components

When implementing variant management, from a software perspective, (3) considered the best theoretical scenario would be to test all variants that would be delivered to customers. However, it was often not possible to offer all combinations, due to complexity and storage capacity would be too demanding, (1), (3) and (6) stated. Therefore, (3) explained, optimisation of the customer experience, by offering multiple alternatives to choose from with as few combinations as possible, was the aim when determining the range of variants.

(5) stated, one factor impacting their range of variants, was the environment products would be in, affecting the demands of the product and what the product will be used for. Moreover, (5) described variant management as a possibility to reuse products to achieve different aims, when new variants were created. (5) explained, Company A tried to reuse components of a product as much as possible. If reuse was not an option, e.g., if small variations existed, (5) claimed, a new variant was found where the same tool was used but a new article number was created.

The process at Company B to determine a new variant began with a close communication between customer and the company, (6) stated. (6) continued, the variant's profitability was then investigated by evaluating the volume to produce, its potential competitors and if it would compete with other variants of the company. If approved, the variant was moved forward to the production (6).

4.1.3.2 How to offer sufficient variants

(2) described, customers were today often encountered by many complex choices which was an aspect Volvo Cars tried to reduce. By using predefined packages, customers were provided a selection of variants suitable to be combined (2). Predefined packages could improve the customer experience by reducing information of each variant decision, (2) explained. (2) continued, predefined packages could also reduce the lead time since less amount of potential combinations are considered. (2) continued, same range of product variants would be offered but in a package execution instead. The aim was to better match combinations with both technical and design aspects in mind (2). Some competitors to Volvo Cars offered their customers more choices (2). However, (2) explained, the scope was too extensive as it made customers becoming overloaded and confused by all choices.

The challenge with variant management was, according to (4), to keep down the amount of article numbers, while maintaining the possibility to achieve as many variants as possible. Moreover, (4) stated, if a new variant should be produced, an extensive amount of articles could be needed. It could result in increasing demands of available storage space, where assembly should take place, and potentially adding new fixtures, (4) explained. (1) mentioned how the R&D and production departments were working with reducing the amount of variants. One example by (1), was allowing the market department to offer variants and functions by including solutions beforehand to be activated in a later stage if the demand was there. (1) explained, Volvo Cars was levelling between if producing a part with functions that were activated afterwards was more costly, than producing several parts with different functions to specific customer demand.

(6) explained, it was a long process, if a new variant should be introduced. Hence, Company B, tried reusing their existing production processes (6). Furthermore, adapt their production along what should be produced to minimise the differences, (6) explained. A new variant was created if a customer demand was something that has not been ordered before (6). However, this was often costly, both from the customer's and the company's side (6). Company C had in the recent time worked with variant management in their assembly, (7) claimed. A variant of a product should be tied as late as possible, (7) explained.

4.1.3.3 Working with product structure

(3) and (7) mentioned, it was common to use a top-down approach regarding the product structure. Thus, it was possible to deduce what was included in the product and how it should be built, (3) and (7) claimed. (7) mentioned, Company C's products were often being assembled by using the same kind of components except for one, which resulted in a new variant. (7) explained, this was not an effective way to work, since it resulted in a constant increase in range of products, increased overhead costs and administration costs. At the same time, it had been prosperous for Company C, due to an easier way to keep it in order (7). If the product was being observed and how the product was assembled, if it was small differences be-

tween those, the changeover time was small, (7) stated. If only one component was changed on the product, it did not have a massive negative impact, in terms of the production perspective (7). (7) explained, Company C realised they can manage product variants in another way, where the heavy structure was not needed, with the changes the company performed.

4.1.3.4 What affect the amount of variants?

Law and market requirements needed to be followed and therefore new product variants would be created, which fulfil these requirements (2). (1) and (4) explained, at Volvo Cars and Material Toyota Handling, the market requirements were used as input to R&D to identify variants needed to meet the market demand. Moreover, (1) explained, there were technical variants which determined the functionality to fulfil the requirements and demand, which created additional variants. The factors that affected the amount of variants were: hardware, software and electrical steering (1). (1) explained, software solutions had been used more frequently to offer different variants. (1) continued, it puts higher requirement on keeping track of all generations that were released when software updates would increase.

Concerning the electrical steering perspective, three other factors decided the range of variants a company has (3). Firstly, how the product portfolio looked like, which variants to be sold to the customer (3). The second one was generation revisions, e.g., change of suppliers (3). The last one, (3) explained, was changes in the electrical architecture between model-years or different product-types. At Toyota Material Handling, (4) claimed, constraints and conditions existed which made it impossible to combine some choices. Other markets and competitors needed to be taken into consideration as well, when deciding variant demand, (4) mentioned.

4.1.3.5 Evaluation criteria of product variants

(3) explained, a company needed to determine its focus area, who the customers were, their needs and not operate in several different areas. (6) meant, that Company B wanted to fulfil customer needs, however, it could result in difficulties in the production, e.g., changeovers between different production sequences. To evaluate the profitability of product variants or product configurations, (4) and (5) stated, forecasts were often performed regarding the estimated volume sales before a new project began. At Volvo Cars, (1) claimed, evaluation of the range of products was done from a cost perspective. Aspects such as, how to reduce the amount of customer choices, reduce what was needed to be developed and what to keep track of, were considered (1).

(2) pointed out, volume markets as an aspect to evaluate product variants and their profitability. Smaller markets with the same range of product variants demand as larger markets were more difficult to satisfy and be profitable in (2). (2) explained, smaller volumes made the negotiation of price difficult (2). Volvo Cars solved this by using hubs to reach additional markets and regions, (2) explained. To evaluate if product variants were profitable or not, (6) stated, Company B tried to priorities

their customers in relation to how profitable it was to work with each customer. Occasional customers were more profitable to work with compared to others (6). It resulted in a trade-off between if all customers needs should be fulfilled or if it was more beneficial to choose the most profitable customers (6).

According to (7), the profitability of a product variant or configuration was continuously being evaluated. It was a fairly simple process at Company C, (7) explained. Company C defined product variants or configuration early in the process with a unique article number on top-level (7). Data for each product variant were stored and identified, which enabled easier evaluation of individual product variants and configurations (7). Data such as changeover time and costs related to each variant and its stock value were stored, (7) described. The disadvantage of storing this data, was that this time may not be the same when similar product variants were produced after each other (7). Less steps were then needed to be executed to prepare for the next product variant, (7) highlighted. This was an aspect (7) felt Company C can improve upon. Today, Company C tried to produce similar variants in a sequence to reduce changeover time (7). Although the real changeover time between all product variants was currently not stored in the ERP-system, it would be beneficial to have (7).

4.1.3.6 Entrance of new markets

(3) mentioned, when Volvo Cars entered new markets or customer groups, new product variants had in come cases been created to fulfil the demand without evaluating their profitability first. To ensure the profitability of a product variant, (3) described that Volvo Cars saw the need to have continuous systematic evaluations of the product variant's situation. The continuous systematic evaluation included, product portfolio, the product and its components to choice of suppliers, to estimate needed amount of combinations, (3) further explained. The cost to maintain this process would also need to be considered, as well as the amount of people and space it would require (3). (1) mentioned one challenge with variant management was to have control over products on the post-market as well, to enable functions and introduce variants even in this stage.

4.1.4 Customer's impact on variant management

How customers' impact were considered when working with variant management and fulfilment of customers' needs and issues it brought resulted in customer's impact on variant management.

4.1.4.1 How customers' impact are considered

(1) explained, Volvo Cars' range of product variants varied indirectly or directly by the impact of customer demand. To cope with the complexity of the range of products variants, Volvo Cars used what they call recipes (1). The recipe was created by the result of the customer choices (1). It showed which variants and articles that were needed to fulfil the customer choices and deliver what has been ordered (1).

At Volvo Cars, (3) mentioned customers have the possibility to design their own product. According to (4), Toyota Material Handling does not offer the customer different package solutions, instead the customer chooses particular choices. (4) continued, a base model was chosen by the customer. Thereafter, the product variants adapted to its requirements was chosen (4). Toyota Material Handling's customers put high requirements on their products to be adapted to their needs, where new product variants could be created to fulfil the customer requirements (4). Moreover, (4) claimed, the goal was not to have as few product variants as possible, instead the customers should have the possibility to choose as much as possible.

(7) explained, which market the product would be used in also affected their range, e.g., different requirements depending on, in which country the products would be used. (7) discussed, many of Company C's products were made of a base product and only differ in the component connected to the end. It was fairly easy to produce a new variant to fulfil a certain need (7). According to (7) a new variant could be created in two different ways. The first way was when a customer order a product, where a unique component was needed to fulfil that certain need (7). (7) continued, the company would then evaluate if the product variant could be part of the default range of products or not. (7) explained the other way as, identifying a need on the market in which a new selection of components would be created. Hence, the product variants' selection would be evaluated if this new selection could be suitable for other markets as well (7).

4.1.4.2 Fulfilment of customers' needs and issues it bring

(5) stated, it was important that their customer requirements were fulfilled. (5) continued, but also to predict needs that customers were not currently aware of and include them in future solutions. When customers have the ability to choose between several product variants or configurations, the risks of too complex products and assembly them in the wrong way increase, (3) explained. To resist this to happen, (3) claimed, Volvo Cars tried to follow the variant development carefully. (6) stated, it was their customers that in greatest extent decided Company B's range of product variants and configurations. (6) explained, the company tried to fulfil the customer requirements and produce what the customers wanted.

(7) mentioned, Company C's primary customers were Business-to-Business (B2B) where a deal package could contain several different product variants and configurations. When the profitability of product variants were determined in relation to the customer demand, it could create situations where variants which the customer needed would not be profitable (7). (7) continued, these variants were however needed to be included to make the deal happen, where other variants in the deal package were more profitable to make the overall sales profitable.

4.1.5 Flexible production

Industry representatives gave their thoughts about how companies worked with strategies to achieve a flexible production and how to improve the production's flexibility.

4.1.5.1 Different strategies to achieve a flexible production

Volvo Cars, Toyota Material Handling, Company B and C have their own production while Company A does not, (1), (4), (5), (6) and (7) mentioned. According to (4) and (6), their productions worked according to a predefined sequence list. (4) explained, it was important to work according to the sequence list and not breach it. If it should be breached, it should be if something failed or something extraordinary happened (4). (4) further described, a few operations in the production could take longer time to perform. (4) continued, whereby it was important to balance the production flow to create a flexible production.

(4) explained, Toyota Material Handling's production was divided into different lines after how the products are modularised. (4) continued, same articles were used to a large extent as possible on the same lines. To manage different modules, (4) explained, sub-flows were used along the main production system. At Company C, the production was built to be able to swallow a larger amount of unique variation, (7) stated. According to (7), one of the key aspects for Company C's success, was they were good at producing a main product with different variants. Flexibility was part of Company C's manufacturing strategy, which was a key factor to be successful, (7) claimed. Company C used simplified structures of their products in parallel to the original structures (7). The reason was, if something goes wrong and products are needed to be produced on another line, (7) explained. (7) continued, product specific fixtures were avoided to improve the flexibility in the production.

4.1.5.2 How to improve the production's flexibility

To manage different product variants in the production, Company B had to adjust their production, which could cause a capacity problem, (6) stated. To improve the production's flexibility, Company B worked with competence development of their operators, used automated production systems and focused on technical improvements in their production, (6) explained. (6) continued, Company B tried to enable more time to be used for improving the production's flexibility, by abstricting time from other work tasks to enable more time to be reallocated.

(6) explained, quality and productivity were important factors connected to the production. Hence, Company B tried to minimise wastes in the production (6). Another company that worked with automation to improve the production's flexibility was Company C (7). Automation was used in small or medium size sequences, (7) stated. According to (7), this resulted in that flexibility can be achieved to a lower price. Furthermore, the production's flexibility was improved through analysing the amount of different components to be achieved from a specific material (7). No changeover time between different dimensions were needed and it minimised wastage (7).

4.2 Case study

The results from the performed case study represented the outcome from the defined use-case and its user-stories. The PLM-system ENOVIA was utilised on the 3DEXPERIENCE platform to fulfil the aim of the use-case, and the results from the time study are presented.

4.2.1 Define use-case

The use-case was defined as, introducing Smarta Fabriker's product, product variants and variant values in a PLM-system to have a digital platform where product data could be stored. The use-case was further divided into user-stories which have been defined and are presented in following numerical list:

1. Define the product, its product variants and variant values in the PLM-system. Performed in Subsubsection 4.2.2.1.
2. Define the constraints between product variants. Performed in Subsubsection 4.2.2.1.
3. Create product configurations which are suitable for different customer demand and segments. Performed in Subsubsection 4.2.2.1.
4. Create a BOM that will contain the product components' quantity and position. Performed in Subsubsection 4.2.2.2.
5. Define the relationships between the components affected by the variant values. Performed in Subsubsection 4.2.2.3.
6. Visualise and show the content of each product configurations to illustrate the needed components and appearance of them. Performed in Subsubsection 4.2.2.3.

4.2.2 3DEXPERIENCE

Three steps have been performed on the 3DEXPERIENCE platform to fulfil the aim of the defined use-case and its user-stories. The first step concerned the creation of Smarta Fabriker's product offerings and product configurations in a PLM-system. Variant and configuration management in ENOVIA was utilised. The second step was creating the CAD-BOM of the product. The last step concerned creating a product structure of the LEGO-made truck, from an engineering perspective, by connecting the results between the first and second step.

4.2.2.1 Introducing the product, its product variants and variant values in ENOVIA

The first step of the procedure performed on the 3DEXEPERIENCE platform was to introduce the LEGO-made truck, its product variants and variant values in the PLM-system ENOVIA. It was performed to describe Smarta Fabriker's product offerings and product configurations. This represented the first four steps of the process Configured Engineering and was done by utilising the steps of variant and configuration management in ENOVIA's widget app Model Definition. Following numerical list presents the steps performed on the 3DEXPERIENCE platform to create the model version, its product variants and their variant values. To define the rules constraining the LEGO-made truck's variant values, and to create the product configurations used in this master thesis, are also presented.

1. The process began with defining the LEGO-made truck by using the widget app Model Definition.
2. A model version of the LEGO-made truck was created, where Model Versions in the column Activities was selected. A new model version was added, where the product evolutions were defined and corresponded to the first step of the process Configured Engineering. The product evolutions allowed the role Product Manager to plan each evolution of the LEGO-made truck, what specifications and functionalities the truck would have by defining a model version in ENOVIA.
3. Product variants and variant rules were created by selecting Enterprise Variability in the column Activities. The tab Variant was selected and product variants added.
4. Variant values for each product variant was created by selecting each product variant in the tab Variant. The tab Values appeared, which enabled defining of variant values. Variant values were then added.
5. The related product variants and their variant values were assigned to the model version by selecting the model version to open the tab Variability. The desired product variants and their corresponding variant values were then added. Hereby, the product offerings were defined, related to the second step of the process Configured Engineering.
6. The third step of the process Configured Engineering concerned defining product constraints. In this steps, the rules which determine the relations between the product variants and their variant values were defined. A matrix rule was created by selecting the tab Rules and choose New Matrix Rule as the type of rule to create. The product variant to be related to the other product variants was put on the x-axis of the matrix, named Driving Criteria. The other product variants were put on the y-axis, named Constraint Criteria. Relations between the product variants and their variant values were defined by choosing between the relation alternatives: Selected, Default, Not Available and Available.
7. Product configurations were created by selecting the tab Product Configurations and then add the product configuration and choose the desired variant values. This step corresponded to the fourth step of the process Configured Engineering.

Three relations were defined. The relations chosen were defined as following: Battery size Small and Engine Efficiency as Default, Battery size Large and Engine Efficiency as Not Available and Battery size Large and Engine Performance as Selected. These were chosen to provide constraints to the available product configurations and to illustrate all possible combinations could not be created, due to limitations of the variants values. The constraints were defined from an engineering perspective, to consider which variant values would be suitable to combine or not. Battery size Small and Engine Efficiency were deemed as a suitable combination to provide an environmental choice for shorter distances. This combination was therefore set as a default constraint. Battery size Large and Engine Efficiency were chosen as an unavailable choice as the power of the engine was deemed insufficient to utilise the capacity of the size of the battery. Battery size Large and Engine Performance were deemed suitable as the larger engine was considered to cope with the capacity of the largest battery. This combination could thus offer high performance while enabling a longer distance.

The theoretical amount of product configurations that could be established was the multiplication of each value for each product variants, illustrated in Table 3.5. After the constraints were applied, the total amount of available product configurations available were reduced from 24 to 12. The 12 product configurations could be seen as three main product configurations with different variant values, for both product variants Engine and Battery size. Each main product configuration was created, suited for different customer segments.

Each main product configuration could then be seen as four product configurations. These were combined with different variant values for Body colour and Rim appearance, but having same variant values when considering the variants Engine and Battery size. The reason to include four product configurations within each main product configuration was to enable the ability for a customer to choose between different truck appearances. The main product configuration *City configuration* was defined to offer a truck suitable for short distance travel. *Mixed configuration* was defined to offer a truck that had the possibility to travel further than *City configuration*, while having the same efficient engine. Lastly, *Long distance configuration* was defined to offer a truck for long distance travel. The product configurations within each main were choices each customer segment could choose from to customise its truck further. The three main product configurations and their defined corresponding product variant's values are shown in Table 4.1. All 12 product configurations offered can be seen in Appendix D.

Table 4.1: The three main product configurations with their defined product variants and corresponding variant values.

Main product configuration	*Product variant*	*Variant value*
City configuration	Battery size	Small
	Engine	Efficiency
Mixed configuration	Battery size	Medium
	Engine	Efficiency
Long distance configuration	Battery size	Large
	Engine	Performance

The product configuration process in the widget app Model Definition is illustrated in Figure 4.1. It illustrated the product variant's variant value chosen to create one of the *Long distance configurations*. It showed when variant value Battery size Large was selected, the variant value Engine Performance was automatically selected due to the defined relations. Moreover, it can be seen that Engine Efficiency was greyed out and was not available to choose with the currently chosen variant values.

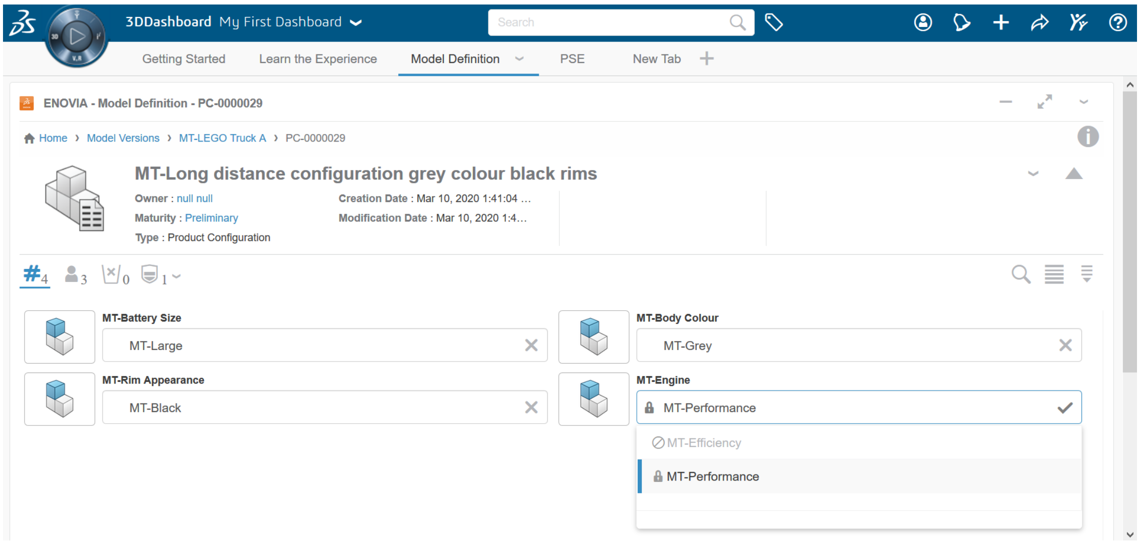


Figure 4.1: The process to define a product configuration in the widget app Model Definition.

4.2.2.2 Creating the computer-aided design-bill of material

The second step of the procedure on the 3DEXPERIENCE platform was to create a CAD-BOM for the LEGO-made truck. The CAD-items and EBOM received from Smarta Fabriker was utilised. Following numerical list represents the steps performed on the 3DEXPERIENCE platform to create the CAD-BOM used in this case study. This step was performed to be able to perform the fifth step of the process Configured Engineering and to achieve the fourth defined user-story.

1. The native app Assembly Design was used to define the CAD-BOM.
2. The needed CAD-items from the EBOM was identified and the CAD-items were imported to the platform by selecting the + sign and Import was selected.
3. CAD-items were inserted into the app Assembly Design by selecting the top-node. Insert was selected and then the object type was, depending on what type the material, was chosen. Thereafter, the search field was used to find the needed material. CAD-items with a desired quantity of more than one in the EBOM needed to be added as well. This was performed by applying the same process as previous step used or by selecting an already inserted CAD-item.
4. CAD-items were named by selecting the file, choosing Properties and changing the title. This allowed for easier searches in the database as well as understanding the functionality of each CAD-item.
5. CAD-items were navigated, positioned and assembled, in the correct location by selecting the item and using the robot.

In Figure 4.2, an illustration of the LEGO-made truck is shown to display some expressions used in the numerical list above, to easier illustrate their location in the app's window. The expressions illustrated are: import navigation in step two, insert navigation in step three, and the position of the robot used to move CAD-items in step five.

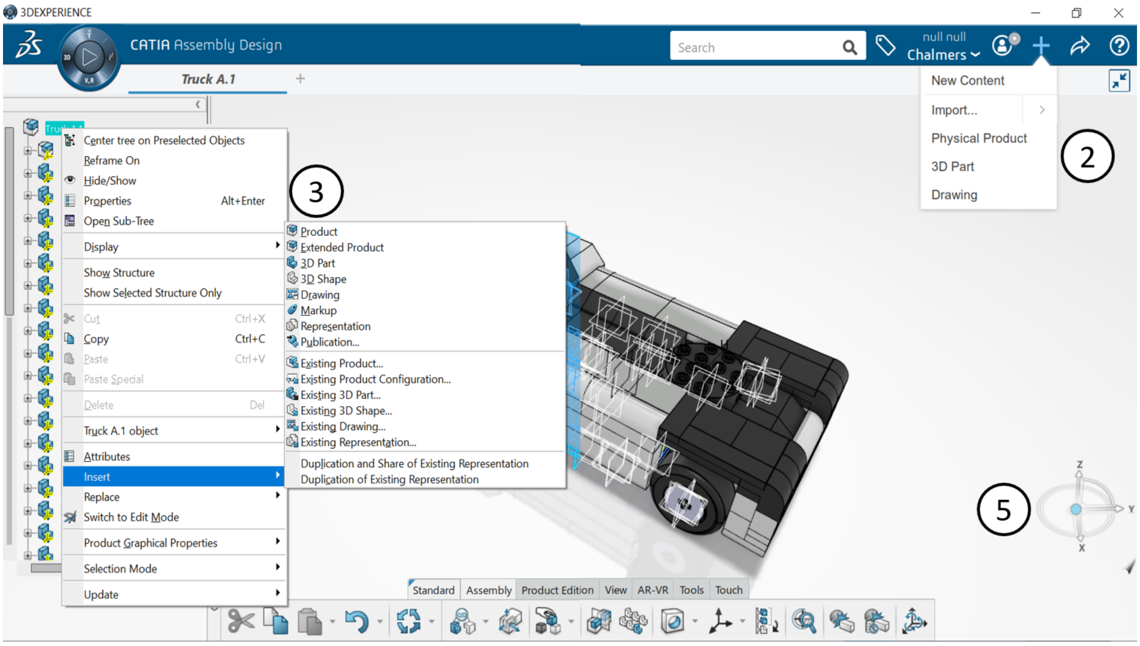


Figure 4.2: Expressions mentioned in the steps two, three and five, from the numerical list, illustrated in the app Assembly Design.

The CAD-items available for all product variants and the corresponding variant values have been inserted into the CAD-BOM and positioned in the right location. This allowed the LEGO-made truck to only use one CAD-BOM to present all articles available of the truck instead of one for each variant value. The complete assemble of the LEGO-made truck is illustrated in Figure 4.3.

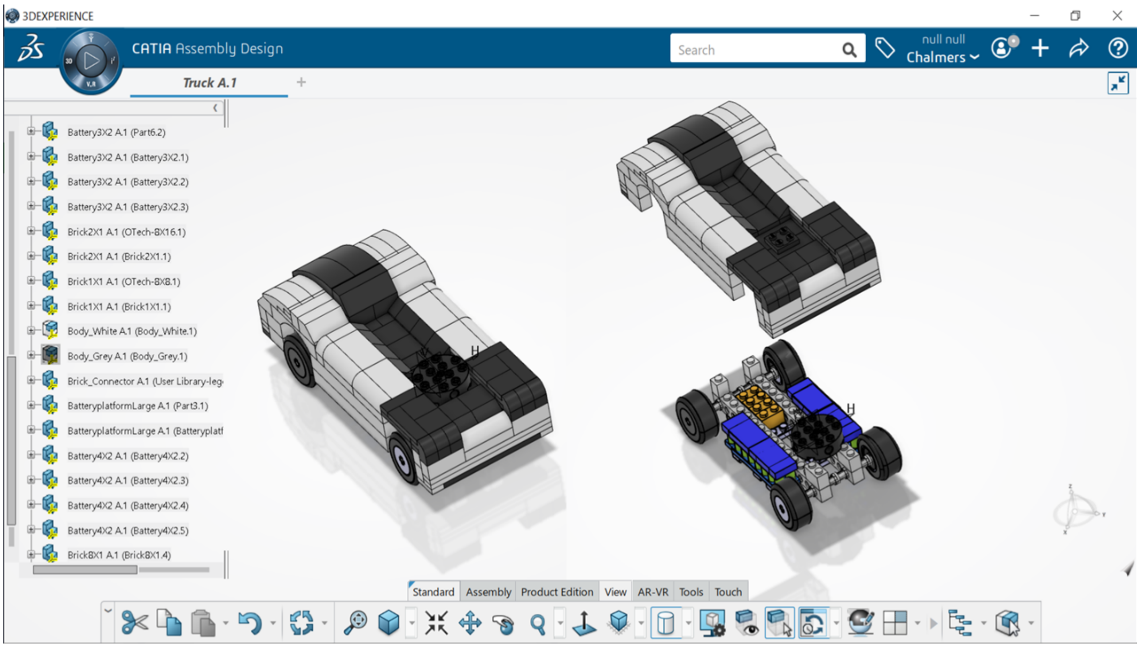


Figure 4.3: The assemble of the LEGO-made truck. The LEGO-made truck to the left presents itself with all CAD-items in its correct location. The LEGO-made truck to the right presents itself with the body positioned above the chassis to illustrate the truck's inside as well.

4.2.2.3 Creating a product structure from an engineering perspective

The third step of the procedure on the 3DEXPERIENCE platform was to connect the content from the variant and configuration management procedure with the created CAD-BOM. The aim was to create a product structure from an engineering perspective. This was done to determine which components in the CAD-BOM were connected to which product variants and variant values, representing the fifth step of the process Configured Engineering. In the sixth and last step of the Configured Engineering process, filters were defined to make it possible to illustrate the affected CAD-items in the CAD-BOM for each product configuration. Following numerical list presents the steps performed on the 3DEXPERIENCE platform to connect configuration management content with the CAD-BOM. Furthermore, to define the filters used to show how the CAD-BOM changes depending on chosen product configuration, are presented.

1. The widget app Product Structure Editor was used to define the connection.
2. The CAD-BOM was inserted by dragging the file and drop it into one of the two windows displayed in the app.
3. The defined model version was connected to the CAD-BOM by selecting the top-node, choosing Edit Configuration Context, and the model version was assigned to the top-node.
4. The variant value was connected to the related CAD-items by selecting the desired CAD-items, choosing Edit Variants and Options, and the relevant product variants to these items was assigned.

5. Filters to illustrate the CAD-BOM was defined and its content when different product configurations with their product variants values were chosen. A filter was defined by choosing Filter, add Configuration and the desired product configuration was chosen.
6. The CAD-BOM was filtered by activate the filter with its corresponding product configuration that was desired to illustrate.

The four product variants and their corresponding variant values had been assigned to the relevant CAD-items in the CAD-BOM. The aim was to define which items of the LEGO-made truck were connected to a certain variant value. Four filters had been defined to choose and illustrate the corresponding CAD-BOM for each product configuration. One filter contained the three main product configurations while the other three filters contained one main product configuration, each containing their four product configurations. The filters and their content are shown in Table 4.2.

Table 4.2: The four filters and their content regarding the product configurations included in each filter.

Filter	*Product configuration*
Main configurations	City configuration
	Mixed configuration
	Long distance configuration
City configuration	City configuration 1
	City configuration 2
	City configuration 3
	City configuration 4
Mixed configuration	Mixed configuration 1
	Mixed configuration 2
	Mixed configuration 3
	Mixed configuration 4
Long distance configuration	Long distance configuration 1
	Long distance configuration 2
	Long distance configuration 3
	Long distance configuration 4

4.2.3 Time study

The results from the time study presented the measured time for each product configuration at each of the three workstations. The total time for assembling each product configuration was the sum of the time for completing the three workstations. First is the result from manual assembly presented, followed by the results from utilising the robot at station two and three. Regarding the presented tables in following subsubsections, PC is an abbreviation of City configuration, PM, Mixed configuration and PL, Long distance configuration.

4.2.3.1 Results from manual assembly

Two cases existed when manual assembly was performed, without modules or when introducing modules. The result from manual assembly without using modules in the demonstrator is shown in Table 4.3. The first column for station two concerned the manual assembly of the product variant Battery size. The second column for station two concerned the manual assembly of the product variant Engine and the assembly of Battery size and Engine onto the chassis. The assembly steps of each column apply manual assembly without introducing modularisation.

Table 4.3: Result from time study for each product configuration without using the robot and modules. Time is measured in seconds.

Product configuration	*Station 1*	*Station 2*	*Station 2*	*Station 3*	*Total time*
PC1	68.74	40.38	16.6	23.95	149.67
PC2	68.74	40.38	16.6	32.19	157.91
PC3	45.58	40.38	16.6	23.95	126.51
PC4	45.58	40.38	16.6	32.19	134.75
PM1	45.58	43.12	16.6	23.95	129.25
PM2	68.74	43.12	16.6	23.95	152.41
PM3	68.74	43.12	16.6	32.19	160.65
PM4	45.58	43.12	16.6	32.19	137.49
PL1	45.58	43.83	17.36	32.19	138.96
PL2	45.58	43.83	17.36	23.95	130.72
PL3	68.74	43.83	17.36	32.19	162.12
PL4	68.74	43.83	17.36	23.95	153.88

When modularisation was introduced, the time needed for the operator to perform each product configuration at each station is summarised in Table 4.4. Modules were introduced for Battery size Small and Engine Performance. The first column for station two concerned the manual assembly of the product variant Battery size. The second column for station two concerned the manual assembly of the product variant Engine and the assembly of Battery size and Engine onto the chassis. The assembly steps of each column apply manual assembly when introducing modularisation.

Table 4.4: Result from time study for each product configuration when using modules without using the robot. Time is measured in seconds.

Product configuration	*Station 1*	*Station 2*	*Station 2*	*Station 3*	*Total time*
PC1	68.74	36.93	16.6	23.95	146.22
PC2	68.74	36.93	16.6	32.19	154.46
PC3	45.58	36.93	16.6	23.95	123.06
PC4	45.58	36.93	16.6	32.19	131.3
PM1	45.58	43.12	16.6	23.95	129.25
PM2	68.74	43.12	16.6	23.95	152.41
PM3	68.74	43.12	16.6	32.19	160.65
PM4	45.58	43.12	16.6	32.19	137.49
PL1	45.58	43.83	19.6	32.19	141.2
PL2	45.58	43.83	19.6	23.95	132.96
PL3	68.74	43.83	19.6	32.19	164.36
PL4	68.74	43.83	19.6	23.95	156.12

Regarding the assembly time of variant value Battery size Small on station two, assemble the variant value without modules took 40.38 seconds and 36.93 seconds with modules. A time difference of 3.45 seconds. Regarding the time to assemble the variant value Engine Performance on station two, assemble the variant value without modules took 17.36 seconds and 19.6 seconds with modules. A time difference of 2.24 seconds.

4.2.3.2 Results when using the robot at station two

The time needed for each product configuration when using the robot at station two is summarised in Table 4.5. The first column for station two concerned time needed for the robot to assemble the battery packages and time needed for the operator to assemble the Engine. The time it took for the operator to assembly Engine Efficiency was 11.06 seconds and Engine Performance 11.57 seconds. The time after the operator has assembled the product variant Engine, was waiting time until the robot was finished with its task. Concerning the second part of station two, the operator connected the two battery packages with the two 1x8 brick battery connector components. The assembled Battery size and Engine were then assembled onto the chassis. Thereafter, the operator continued with the assembly process at station three.

Table 4.5: Result from time study for each product configuration when using the robot at station two. Time is measured in seconds.

Product configuration	*Station 1*	*Station 2*	*Station 2*	*Station 3*	*Total time*
PC1	68.74	94	5.53	23.95	193.22
PC2	68.74	94	5.53	32.19	202.46
PC3	45.58	94	5.53	23.95	172.06
PC4	45.58	94	5.53	32.19	181.3
PM1	45.58	94	5.53	23.95	174.06
PM2	68.74	94	5.53	23.95	198.22
PM3	68.74	94	5.53	32.19	207.46
PM4	45.58	94	5.53	32.19	185.3
PL1	45.58	94	5.79	32.19	186.56
PL2	45.58	94	5.79	23.95	179.32
PL3	68.74	94	5.79	32.19	211.72
PL4	68.74	94	5.79	23.95	204.48

The time allocation in percentage of the performed tasks on station two regarding variant value Engine Efficiency of both operator and robot is shown in Figure 4.4 and Figure 4.5, respectively. For time allocation regarding the variant value Engine Performance, see Appendix E.

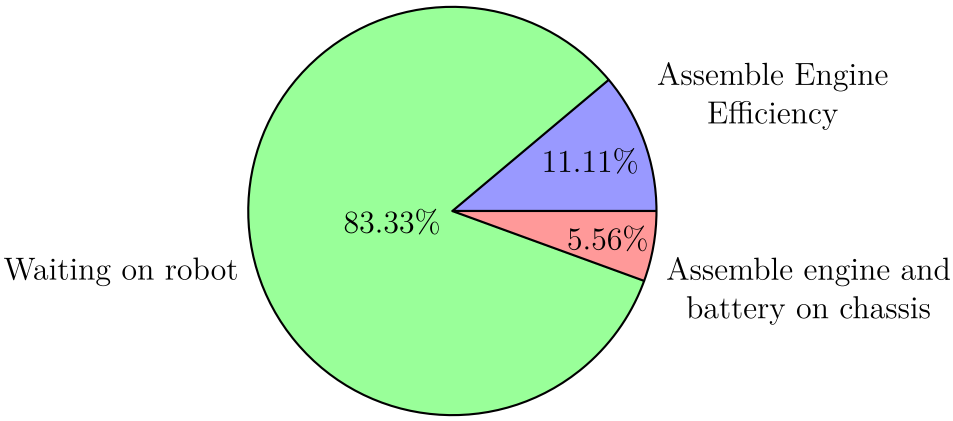


Figure 4.4: The time allocation illustrated in percentage of the operator on workstation two, regarding the variant value Engine Efficiency when working with robot.

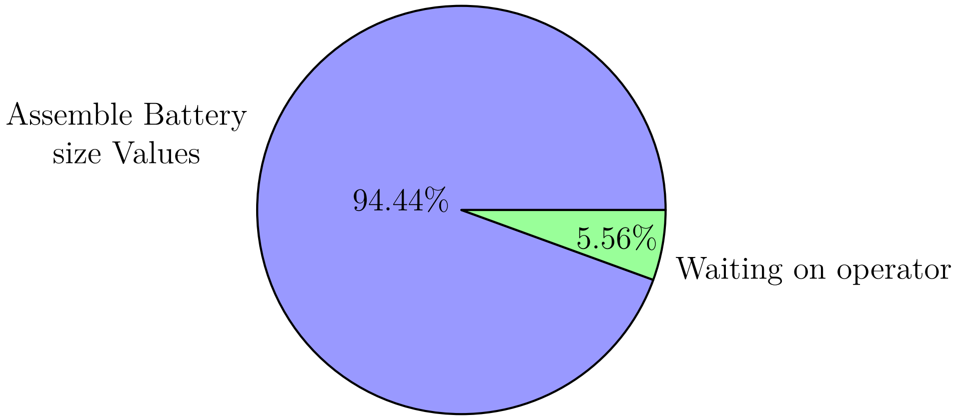


Figure 4.5: The time allocation illustrated in percentage of the robot on workstation two, regarding variant value Engine Efficiency when working with operator.

4.2.3.3 Results when using the robot at station three

The time needed for each product configuration, when using the robot at station three is summarised in Table 4.6. As seen in Table 4.6, the total time of the tasks on station three is only presented in a single time value in the station's column. The time to place the chassis on the fixture was 3.6 seconds regarding Body colour White and 10.54 regarding Body colour Grey. The robot took 36 seconds to perform the quality check. The time between operator placing the chassis on fixture to the robot being finished with quality check and operator could continue with the assembly process became waiting time for operator. Time needed to assembly the body on the chassis and perform the driving test was 8 seconds.

Table 4.6: Result from time study for each product configuration when using the robot at station three. Time is measured in seconds.

Product configuration	*Station 1*	*Station 2*	*Station 2*	*Station 3*	*Total time*
PC1	68.74	36.94	16.6	47.6	169.28
PC2	68.74	36.94	16.6	54.54	176.82
PC3	45.58	36.94	16.6	47.6	146.72
PC4	45.58	36.94	16.6	54.54	153.66
PM1	45.58	43.12	16.6	47.6	152.9
PM2	68.74	43.12	16.6	47.6	176.06
PM3	68.74	43.12	16.6	54.54	183
PM4	45.58	43.12	16.6	54.54	159.84
PL1	45.58	43.83	19.6	54.54	163.55
PL2	45.58	43.83	19.6	47.6	156.61
PL3	68.74	43.83	19.6	54.54	186.71
PL4	68.74	43.83	19.6	47.6	179.77

The time allocation in percentage of the performed tasks on station three regarding the variant value Body colour Grey of both operator and robot is shown in Figure 4.6 and Figure 4.7, respectively. For time allocation regarding the variant value Body colour White, see Appendix F.

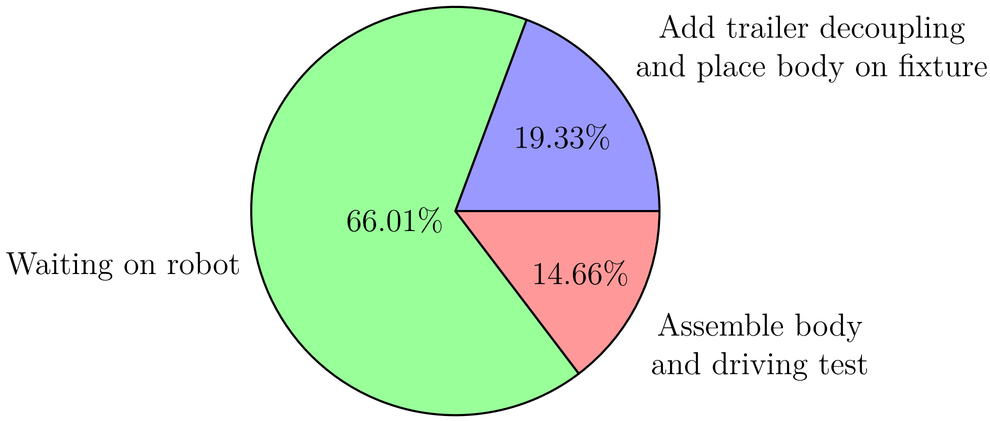


Figure 4.6: The time allocation illustrated in percentage of the operator on workstation three, regarding the variant value Body colour Grey when working with robot.

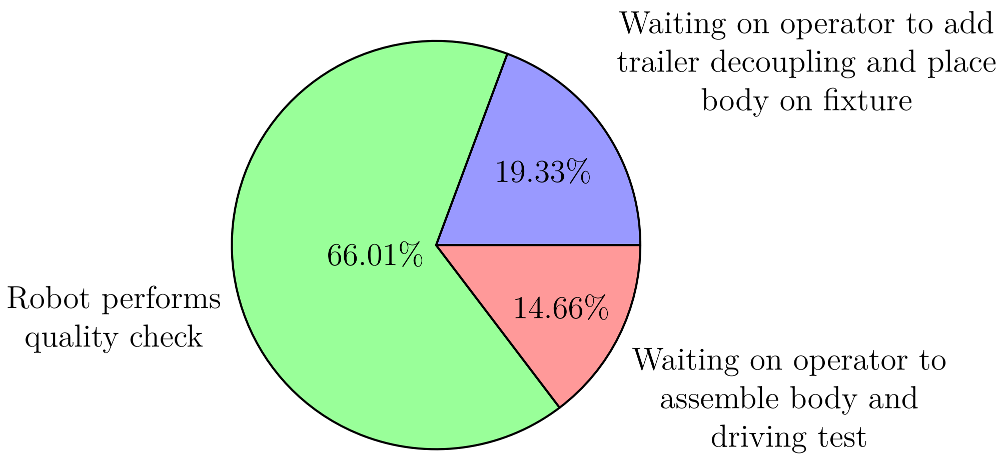


Figure 4.7: The time allocation illustrated in percentage of the robot on workstation three, regarding the variant value Body colour Grey when working with operator.

5 Discussion

This chapter provides a discussion of the major findings. Thereafter, technical aspects of 3DEXEPERIENCE are discussed, followed by a discussion of the methodology used throughout the master thesis project. The chapter ends with discussion of sustainability aspects and recommendation of future research.

5.1 Discussion of major findings

Findings from the three performed studies are discussed, regarding why flexibility is needed in the industry and how to increase flexibility in the industry through variant management. The section ends with identified challenges concerning variant management.

5.1.1 Why is flexibility needed in the industry

The core cause to create flexibility and why mass customised products are of importance, are discussed.

5.1.1.1 The production system's impact

According to the performed literature review, for companies to provide value-added activities to their customers, the production is seen as the system to create value. The literature further stated an increased and varying customer demand meant great strains on the product and production system. These aspects are needed for companies to face, to be competitive in today's market. The role of the production system can thus be seen as highly important to be successful in the industry. The literature study mentioned one reason why Industry 4.0 has emerged, due to the possibility to offer a more flexible production system in the industry. Hence, connected systems which allow data to be collected, stored and communicated, can be used to create and improve flexibility in the industry.

Several authors from the literature review argued that flexibility is one of several capabilities. One industry representative stated flexibility was part of their manufacturing strategy. The literature review showed, by linking capabilities with the organisation's strategy, an organisation can sustain over time. Hence, linking flexibility with the strategy is concluded to be needed to be competitive in today's market. Furthermore it is needed to achieve a flexible production. An interviewee explained one way to succeed was that companies needed to determine who their customers are and the company's focus area. If it is not determined, the organisation will not survive in the long run.

According to the performed literature review, flexibility could also mean faster changes in the production. Technical upgrades in the production system were suggested as a solution to achieve a flexible industry. Flexibility in the production was stated to enable products with high complexity to be managed. Several interviewees suggested using automation in the production as one solution to manage complex products. The literature review concluded, a production system is flexible if it can respond quickly to changes and new product demand, which is needed to be competitive in today's industry. Due to an increasing variety of demand, the changeover time is becoming even more attractive to be reduced, as the amount of setup occasions is growing. Connected to other capabilities the literature review mentioned, an industry representative explained improvement of products' quality by minimising the wastage in the production is in focus. By analysing how many components that can be achieved from a certain amount of material, wastage can be minimised. Furthermore, more time in the production can be used for value-added activities. Hence, it can be concluded, flexibility does therefore play an important role to be successful in today's market.

5.1.1.2 Mass customisation's impact on the production system

Mass customised products are one way to set requirements on the production system, which companies needed to offer to be competitive. The literature review claimed, mass customisation results in a trade-off between the two parameters: cost and variation. From a company's view, production costs need to be reduced and optimisation of the production system needs to be increased. In the meantime, companies have to offer a high variation that fulfil customers demand, to be successful. To minimise the trade-off between cost and variation, the scientific literature stated this can be achieved through a production system which enabled reconfigurability. A reconfigurable system enabled a production system to be flexible and is needed when product variations are increased or unpredictable changes occur. Hence, a company can reduce production costs and increased optimisation of the production system can be achieved.

The literature stated, from a company's view, benefits and costs are important aspects that need to be considered before introducing a new product variant in the production system. A company needs to evaluate the range of markets that products are offered in, to not offer customised products in markets which do not increase revenue. However, from the literature study, it can be concluded that companies need to offer customised products to be competitive in today's market. To evaluate and choose markets which companies' customised products are profitable in is thus identified as important. Solutions to reduce costs when the need is to offer a large variety of products is therefore important to be competitive. The interview study showed, non-specific fixtures are used in a larger extent to manage an increased product variety in the production, thus increasing flexibility.

5.1.2 How to increase flexibility in the industry through variant management

PLM-system, product configurations, modularisation, and working with variant management in production system are identified as key aspects, concerning how to increase flexibility in the industry.

5.1.2.1 The product lifecycle management system

By using a PLM-system, both literature and interviewees stated, product data across all lifecycle phases of a product can be managed. A red thread through all process and lifecycle steps can hence be created. It can be concluded from the literature study, that a PLM-system has similarities with the phenomenon CE, where each lifecycle phase of a product is also considered. The two concepts can thus enable an organisation to align the work of each department towards the same objectives. Hence, it is easier to meet customer demand which is continuously changing and to achieve customised products. From the literature review, it was claimed that a PLM-system resulted in the possibility to close knowledge loops in an organisation since reuse of knowledge is possible. The interviews mentioned, a PLM-system can enable flexibility due to the ability to manage product generations. Moreover, manage complexity which arises when the amount of data increases and allowing data related to each generation to be stored are shown. These are needed to be faced in today's industry.

The literature stated, a PLM-system can be seen as a business strategy. From a company's point of view a PLM-system can facilitate the feedback and changing process, due to the possibility to integrate stakeholders and customers throughout all lifecycle phases as well. The literature confirmed this regarding the PLM-system, ENOVIA. Therefore, it is seen that ENOVIA is a PLM-system which can enable flexibility improvements. Hence, the customer's feedback can be integrated, thus receiving customer feedback after products being released. A closer connection and collaboration environment can thus be enabled to allow faster information and data communication. The work between departments and companies can thus happen instantly. This is also the case with the phenomenon CE. This can increase flexibility in companies' working processes. Furthermore, it can be concluded that this may reduce the impact of changes in demand and unpredictable changes.

From the interviews, it can be concluded, companies used PLM-systems in different ways, depending on their needs. Some companies saw the benefit of utilising one PLM-system to enable easier collaboration. On the other hand, several PLM-systems allowed companies to choose the best PLM-system suited for specific needs. By utilising ENOVIA, the case study showed today and future needs can be managed efficiently. This is due to, current and new variant values, components and relevant information can be added to the products. This will allow continuous updates to the product data and the defined product structure. During the case study, the procedure did not need to consider a transition from one PLM-system to another since Smarta Fabriker did not use a PLM-system. This situation may not be the case in today's market, where many companies already have data collected in other systems. If a transition between PLM-systems were to be shown, other findings might have been found, which was not studied in this master thesis. The procedure for such a transition may differ from the procedure to implement product data in ENOVIA which is shown here.

The interview study showed a PLM-system is used as an information source. A PLM-system will benefit from using only one information source throughout the whole organisation. Furthermore, the interviews showed a challenge if several PLM-systems are used in the organisation, which is to find out how the systems should communicate with each other. If this does not work as it should, it can be difficult to take advantages of each individual system' conveniences. From the literature review, it can be concluded that implementing a PLM-system in an organisation can reduce costs and be less time-consuming. It allowed tests to be analysed and evaluated before implementing product variants and can result in improved business performance and the company's flexibility.

The literature study showed the industry are still challenged by the concepts related to PLM-system and how to utilise them. The case study offered a step-by-step by approach to illustrate how product data can be introduced in the PLM-system ENOVIA. This result can be used to reduce the knowledge gap of how practitioners can utilise a PLM-system.

5.1.2.2 How to work with product configuration and how it can be used to improve flexibility

The literature review claimed managing product configurations resulted in: a flexible production, improved lead time and product quality. The literature further suggested PLM-systems to manage product configurations as they provide a suitable working environment. Therefore, by utilising product configurations it is possible to fulfil a variety of customer needs. The product configurations are suited for specific customer segments and used to store information and component data in products. This has also been the situation with the performed case study, where three main product configurations were defined suited for specific customer segments.

The literature study stated the possibility to perform changes within the product structure. It is possible to hide or show different variants, depending on what a company wants to illustrate. The filters defined in the case study enabled the correct CAD-BOM for each corresponding product configuration to be generated automatically by connecting variant values to each CAD-item. It can reduce the risk of creating an inaccurate BOM than if the process is needed to be manually executed each time. The case study showed, the CAD-BOM connected the EBOM with the CAD-items to identify the quantity of each component, its position and visual. This can make the identification of needed parts for a product configuration easy to conduct. Even though the case study' scope on the platform only considered product development, the result can allow product data to be easier transferred to other parts of an organisation. The manufacturing department, for instance, may use the filters to illustrate the components needed to produce each product configuration.

An interviewee mentioned how a company chooses to present their product variants and configuration as a part of variant management. It was also mentioned, how this can help companies satisfy customer needs, which in turn can help or mar the customer experience. Therefore, it is shown that not only the range of variants are important to fulfil a customer need. The customer experience of how these variants are offered to the customer is also needed to be considered. This can thus improve flexibility as less combinations of variants are needed to be considered, while fulfilling the customer demand. The case study showed that ENOVIA provided the functionality to visualise and overview the product's content, such as their variants, variant values and CAD-items. This can help customers and companies to communicate what the products contain and available choices.

The literature review claimed to communicate available resources in the production system, configuration management can be used. The purpose is to manage changes in the engineering system or data. The LEGO-made truck's product structure was illustrated in a hierarchical approach in the PLM-system, which industry representatives explained was common in the industry. Both literature and interview study stated, by using different constraints and condition in a product variant, it is possible to minimise the customers' preferences. The purpose was to simplify the amount of available product configurations. The case study showed the constraints implemented for the LEGO-made truck reduced the amount of product configurations. The constraints also defined suitable combinations of variant values to be connected, instead of allowing every variant value to be combined although the combination may not be deemed as suitable. This can improve flexibility as several demand can be fulfilled while reducing the range of variants needed to be considered. Another advantage working with product configurations, seen from the case study, is the simplicity of choosing the correct product specification for customer needs without manually updating the EBOM. This can result in a reduction of time-consuming activities.

The time study showed that variant values Rim appearance Black, Battery size Large, Engine Performance and Body colour Grey resulted in the longest assembly time with manual assembly, without modules. Moreover, product configurations PC2, PM3 and PL3 are the most time-consuming configurations in each main configuration to assembly. By understanding the assembly time for each product configuration and variant value and relate it to the customer demand, conclusions can be drawn regarding which variant values shall be offered. Furthermore which combinations are more profitable to assemble than others. For instance, Long distance configurations resulted overall in the longest assembly times out of the three main product configurations. Product configuration PL3 resulted in the longest out of all configurations to be assembled. Smarta Fabriker may therefore be questioning if all variant values for Long distance configuration shall be offered or if further limitations are needed to reduce the time needed to assembly Long distance.

5.1.2.3 The impact of modularisation

To organise complex products and processes, it was claimed in the literature review to use modularisation. The literature also showed, implementing modules across the product offerings will reduce non-value adding product variants. It can therefore be seen if a high selection of product variants needs to be offered, another approach than adding unique articles to fulfil needs has to be considered. It is seen from the interviews that modularisation is used, to some extent, in almost every company to reduce the amount of unique articles. Modularisation can result in an easier way to categorise more products on the same platform. Flexibility can therefore be increased due to less platforms needed to be considered. One way to create a flexible production through variant management, explained by an industry representative, is to reuse components, instead of using new components when a new variant is created.

It is seen, from the performed time study, that only one of the modules resulted in reduced assembly time. The other resulted in an increased assembly time compared to the original design of the variant value Engine Performance. It can thus be concluded, implementing modules do not need to result in reduced assembly time. However, implementing modules in the time study were shown to reduce unique articles. The result was therefore reduced impact a range of product variants will have on storage capacity. It was seen from the time study, that several unique times for assembly of unique articles are needed to be considered. When utilising modules, the amount of times to be considered will then be reduced. It may improve the ability to balance the production flow and reduce the work needed to calculate time to assemble each article, while being able to offer highly customised products.

5.1.2.4 How to work with variant management in the production system

From the interviews it can be seen, to improve flexibility in the production, products which have similar components are being produced on the same production line. This allowed a large range of product variants to be managed by using similar components and using as few production lines as possible. Moreover, to improve flexibility, one company from the interviews planned and built their production with the aim to manage a large amount of unique variation from the beginning. This enabled their production system to be prepared for additional customer demand in the future, by including flexibility as an important criterion when improving the production system. Another company used sub-flows along the main production flow to manage customised products and enable a flexible production. High variation was able to be managed while reducing the impact and disturbance in the main flow. From the case study, it can be seen that the product variants were already assembled on the first station. Additional product variants were also assembled on the two other stations as well. The time study showed, the time needed to assemble different variant values differs quite a lot. By using sub-flows instead to prepare the product variants, this can reduce the variation of time between the stations, allowing an easier balancing of the main-flow of the production system as well as easier to add new product variants to the product.

The literature and interview studies mentioned the importance to work with the distribution of the amount of product variants in relations to which type of production system is being used. Larger volumes and smaller amount of product variants are suitable to utilise special adapted production lines. However, production lines that can manage a wider range of product variants but obtain a slower tact are more suitable to manage variants in low or middle size volumes. If a company does not consider these aspects, a flexible production may not be achieved through working with variant management. Another interviewee highlighted the impact of product variants by describing the work done with variant management in the assembly to make variants be tied to products as late as possible. Whereby, it allowed products to not exclude other variants in the early stages of the production, enabling a more flexible production.

5.1.3 Challenges concerning variant management

Introducing variant management resulted in challenges, that a company needs to take into consideration and phase. Challenges concerned the PLM-system, offering a range of product variants, and the limitations variant management brought. Moreover, how to evaluate variant management, challenges with modularisation, and when Smarta Fabriker utilised the robot in the demonstrator, all describe challenges concerning variant management.

5.1.3.1 Challenges concerning the product lifecycle management system

Concerning obstacles in the PLM-system, an interviewee stated a challenge is that it should obtain all data and functionalities in their system. Therefore, it can be difficult to use other systems with other functionalities. Moreover, keep track of the generations for the software solutions that have been released when offering product variants to customers, is mentioned as a challenge. When the software updates increase, it will affect already released solutions. Hence, it is important for companies to continue with product development, even in the post-market. Another mentioned challenge from the interview study was, companies must have knowledge of how they worked with variant management in the past, current work procedure and future demand. Hence, a company needs to take into account how variant management has been managed during a long time frame. This can be challenging from a company's view, when utilising variant management.

The experience from the case study when working in ENOVIA is that it can be resource-demanding, if knowledge of the platform or variant and configuration management is not sufficient. If the PLM-system will be implemented, time allocated for the employee who will use the platform to learn the PLM-system will be needed.

5.1.3.2 Challenges when offering a range of product variants

Interviewees stated a challenge with variant management was to achieve as many variants as possible while keeping down the amount of unique articles. If this is not considered, the interviewees mentioned the increase of demand in storage capacity.

If the increased storage capacity is needed, it may occupy space that could be used for value-adding activities instead. It may also result in additional fixtures. An interviewee identified a challenge with mass customised products, which is products are becoming too complex which also impact the assembly of products. Whereby, it is easier to perform mistakes in the assembly. This challenge may need to be acknowledged already in the design phase of new variants and products, to highlight this challenge early in the lifecycle phases of a product.

The interview study showed discussion how variants should be included in a product and what is more beneficial or costly. The discussion was to include variants from the beginning to later be activated if needed or managing several variants needed to be produced to fulfil each customer need. It shows an aspect where companies are in some scenarios considering choosing the material cost of product to be more expensive as it may be more profitable in the end. The challenge of determining the cost and profit of products with a high variety of variants can therefore be concluded. This is due to the impact variant management can have when the range of variants is increasing, although it may be directly more expensive from a material cost view to produce. This highlighted the impact variants can have on a company. Further, its impact on the production system and storage, to include and consider each product variant throughout the whole organisation.

An increase of changeovers in production when the amount of product variants increased, was brought up as a challenge from the interview study. It can thus be seen that variant management needs to be consider changeover time as well. The need to work with similar structures and components when working with variant management may be important to reduce changeover time in production. Fewer steps will be needed to be performed, if the products are similar in its design and construction. Similar products can be placed in the same sequence to minimise the impact changeover time has on the production.

5.1.3.3 Limitations of variant management

From the interviews it was seen that some product variants are unavoidable since they fulfil the law and market requirements. If these requirements have a heavy impact on the variant management, it may be beneficial to focus on which markets are most profitable or which countries have the same requirements. The literature review and interview study claimed, variant management resulted in challenges when new product variants will be introduced. Both claimed the EBOM may change, affecting the assembly and manufacturing processes of the products. This may lead to increased difficulties when planning and optimising the processes to efficiently balance the system for all product configurations.

5.1.3.4 Evaluation criteria and challenges with modularisation

The interview study stated challenges when evaluating product variants and their profitability. Product variants' profitability is seen to depend on which markets companies are presented in. The challenge to offer the range of product variants to fulfil a market's customer demand while offering profitable variants in that market is thus identified. Moreover, if companies decide to exclude a selection of variants and products, customer satisfaction may not be fulfilled. Another challenge the interviewees stated, is product variants originated from entering new markets and customer segments have in some cases not been evaluated. Whether a market or a customer segment is profitable to enter can therefore be difficult to answer. Furthermore, this can make it difficult for companies to keep attention to the areas they can and are succeeding in. It may result in an unclear strategy of customer needs and focus areas to improve and align. When determining profitability of product variants, another challenge was seen from the interviews. It can be that a product variant in itself is not profitable to produce, although it may lead to additional sales since it fulfils a customer need. It is therefore difficult to estimate the profitability of product variants. Product variants can have a positive impact on sales, even though the direct profitability is non-existent. A large selection of product variants may therefore be needed to fulfil varying customers demand.

The interview study and the performed case study showed challenges when introducing and working with modularisation. Smaller modifications or introducing a new product variant can result in more time needed to design and construct products. It may also affect how modules are being connected with each other. The interviewees stated modularisation can make it difficult to perform changes of articles. When they are presented in different locations and environment, all these have to be considered. The interview study also showed, using standardised articles instead of unique can make the standardised articles more expensive. This is due to they have to fulfil several needs and requirements. It can therefore be concluded that modularisation can result in time-consuming activities for the product development, as well as for the production.

5.1.3.5 Challenges concerning Smarta Fabriker and utilisation of the robot in the demonstrator

The time study showed the collaboration between robot and operator in its current installation resulted in a major time loss for the operator. The operator needed to wait on the robot to complete its tasks. At the third station, it resulted in large time loss, even for the robot. This created challenges regarding Smarta Fabriker's possibility to utilise the robot at both station two and station three. It is thus concluded when implementing collaborative environments into the production system, not only does the balancing between stations need to be considered. The balancing within stations, between operator and robot to achieve a balanced flow, does also have to be considered. Even though the robot obtained a higher percentage working time than waiting time shown in the time study, see Figures 4.4-4.7, and Appendix E-F, the operator used most of its time to wait on the robot. Therefore, a high percentage of working time for the robot may not result in an improved percentage overall when considering the collaborative environment. It is seen that the balance of work tasks within the station is of high importance to achieve a balanced station.

The time study also showed the robot in its current installation does not reduce the assembly time of the stations nor the product configurations. If the robot has been optimised for each station to perform the tasks faster, the assembly time might have been reduced. If these aspects are considered, the robot may be suitable to use on the stations which are most affected by certain variant values or product configurations to reduce assembly time. However, in its current installation, the relationship between the robot and operator and the assembly time of the tasks performed by the robot, do not achieve an improved assembly time. It should be acknowledged, the data have been extracted from a non-complete production system which was not completed when the data were collected. The demonstrator and its collaborative environment were still in development when this thesis was written and may have improved these aspects. A collaborative environment may therefore have several benefits which were not identified throughout this master thesis.

5.2 Technical aspects of 3DEXPERIENCE

In the beginning of the master thesis, the aim was to use an academic license to access the 3DEXPERIENCE platform, with the required roles and apps. However, throughout the project it was acknowledged that the roles and apps needed to perform the desired procedure on the platform which were not available on the academic license. Dassault Systèmes did help to provide an on-premise license with the relevant roles and apps, to enable the master thesis' authors to proceed with the work on the 3DEXPERIENCE platform. Therefore, it should be acknowledged the procedure performed on the 3DEXPERIENCE platform in this master thesis will currently not be able to be reproduced if an academic license is accessed.

The apps Model Definition and Product Structure Editor used in the project were, at the time this master thesis was written, in their alpha and beta versions. These apps had therefore not been officially released. Some challenge did occur when using these apps in their early state. One of the challenges was technical bugs the authors came across when performing the steps in these apps. The technical bugs resulted in steps needed to be performed several times before being registered. Had these two apps been used in official released versions, the technical bugs would presumably been fixed, creating a smoother and less troublesome user-experience.

Another challenge was the two non-officially released apps, did not at this time have courses to learn from, how to use them. This made the learning process more difficult than for apps which had courses. This resulted in the need to perform courses in apps related to the field and tasks of the two used apps and then translate the procedure to the two apps. The authors of this master thesis did receive guidance from employees at Dassault Systèmes to improve the learning process. If courses have been provided for the alpha and beta versions of the apps Model Definition and Product Structure Editor, the working procedure would been easier to learn. The time for trial and error in the apps would also been reduced. Other key elements to execute the steps performed in a more efficient way would might have been acknowledged as well. The authors believe the new apps, in their alpha and beta state, are more intuitive and user-friendly, compared to previously released apps on the

3DEXPERIENCE platform, which fulfil the same purpose. PLM-systems not being user-centric was also brought up as a challenge from the interview study. Hence, the authors of this master thesis conclude, from their own experience of using the 3DEXPERIENCE, Dassault Systèmes are working towards the correct direction to improve the user-experience.

5.3 Master thesis methodology

The methodology design used throughout this master thesis was explained in Chapter 3. Regarding trustworthiness of the master thesis's methodology, an abductive approach was chosen as research methodology, where three parallel studies constituted the research design. Each of the three studies was divided into smaller steps, as illustrated in Figure 3.1. All three studies were used with the aim to tackle different sources. Thereby, the width of the sources origin increases, where information is extracted from, which increases the credibility.

Interviews were performed with the aim to investigate how companies in the industry are working with PLM-systems, variant management, modularisation and flexible production. The aim was to perform more interviews, from different manufacturing companies backgrounds and if companies used PLM-systems or not. Due to the impact of Covid-19, some planned interviews were cancelled and replacements were not easy to find on a short notice. If more interviews were performed, the result of the interview study could be confirmed by different interviewees. Further, additional viewpoints could be considered, indicating higher credibility. The collected data from the interviews may be affected by the authors' interpretation of what the interviewees stated, where the results can become bias. To mitigate this risk, the interviews were voice recorded. A well defined methodology about the steps that were included in the procedure to increase the credibility of the collected data, was used. To assert the reliability, a semi-structured approach was chosen, where non-leading questions were asked. Hence, the interviewees could express their own thoughts and avoid misinterpretations. Since the asked questions during the interviews contained several terms, such as modularisation and variant management, some interviewees asked what the authors of this report defined it as. It showed, the concepts can have different meanings depending on the environment they are being used. Due to the fuzzy nature of these concepts, the questions containing these might not be unambiguous. The results from the interviews may also be affected by that the interviews was transcribed, translated and summarised. This procedure can distort the original data and making the interpretation bias.

An exhaustive methodology regarding the literature study was chosen to evaluate different findings from the literature search. Literature from previous courses at Chalmers University of Technology was alternated with literature found from searching in the database Scopus, to avoid biased of the results. However, if any of the two other discussed databases, Web of Science or Google Scholar was used instead, the results from the performed literature search may differ. Scopus was evaluated and deemed as the right one for the thesis' purpose. Regarding the performed literature search and reviewing process, a structured methodology was used. The structured methodology included multiple reviewing steps, to strengthen the validity of the literature search. Although limitations were applied to limit the literature search, other articles that could be used to fulfil the aim and purpose, may be screened out. When the first sort by function *Date (newest)* was used, older or more cited articles may be excluded from the search string. These articles could have been used to strengthen the credibility of the collected data from the literature study. When the sort function *Cited by (highest)* was used, older articles with even more citations were found. This procedure was recommended by the studied methodologies.

The reason why a case study was performed, was due to the opportunity to investigate a specific event and use it as a basis to draw conclusions. This was supported by the studied methodologies and literature. The choice to define a use-case for the implementation of Smarta Fabriker's product, product variants and variant values in ENOVIA, was to investigate Smarta Fabriker's needs. Furthermore, how the procedure to fulfil these needs can look like. It made it possible to perform the implementation in the PLM-system with the aim to fulfil these needs. The defined use-case has in itself not been evaluated. It functioned solely as a way to identify the needs wanted to be fulfilled in the performed PLM-system's implementation. The use-case was not defined to be evaluated in terms of how the needs could be fulfilled in different ways.

Since only one case study was performed, it may limit the ability to draw conclusions from the findings, if the same outcome would be achieved in another case study. Furthermore, it may also limit the ability to conclude how adaptable the result from this case study is to the reality of industries. It was difficult to find literature that explained different operations methodologies in a PLM-environment. Hence, online courses that the master thesis authors participated in were used. A procedure how the project itself can be implemented on the 3DEXPERIENCE platform, was found through the online courses and through Dassault Systèmes' User Assistance. Due to only two sources were used, from Dassault Systèmes themselves, it can be seen as bias. However, since the used sources were regarding the 3DEXPERIENCE platform from Dassault Systèmes own Learning Space and User Assistance, the master thesis members considered it as reliable enough.

A time study was performed with the aim to evaluate and find differences in the time to perform different product configurations and variant values, at different stations. The amount of observations was chosen due to what Zandin (2001) explained to fulfil a normal distribution curve, presented in Chapter 3. Therefore, no more observations were executed if the amount of observations achieved a normal distribution curve as it was deemed adequate. To mitigate the risks of unreliable measurements, the same person assembled each product configuration with its corresponding product variants values.

5.4 Sustainability aspects

Regarding the master thesis project in general, it can be seen that economic and environmental conveniences can be achieved, based on the findings. By using a PLM-system, the product and its impact on the production system can be analysed before building the product in reality. It can therefore identify possible opportunities and challenges before releasing and implementing products in the real system. Furthermore, how to utilise the production system more effectively, where economic and environmental advantages can be achieved.

Using modularisation resulted in a possibility to use standardised articles and exclude unique articles for each product configuration. Whereby, less storage capacity was needed and therefore it is possible to, e.g., reduce carrying costs. A company needs to take into consideration if it is more economically profitable to limit the options or not. Some options may be needed to be offered due to the variants' economical profitability, which can gain the organisation.

Concerning the performed case study, it created a possibility for Smarta Fabriker to enable a flexible production in their demonstrator. By creating a digital product structure, it enabled the ability to keep track of changes and document product related information in the PLM-system, ENOVIA. The digital product structure can be used to work with when current and new customer requests can be applied. As the findings showed, a flexible production resulted in economical and environmental advantages. It is easier to adapt the production system concerning demand changes, which Smarta Fabriker can achieve. The robot used in the demonstrator, resulted in the possibility to use automation, where higher quality of produced products can be achieved. With higher quality of produced products, less rework is needed. A reduction in customer complaints related to quality errors can hence be achieved. Furthermore, rework can result in increased costs for Smarta Fabriker. It can be argued that the social sustainability can be gained due to the robot. The robot facilitate for the operator and works in a collaborative environment. Due to the master thesis scope, the social aspects are not analysed, but it can anyway be worth mentioning. A reconfigurable production is seen from the literature study to be economically sustainable. The mobile demonstrator from Smarta Fabriker does thus enhance economic sustainability.

As the performed master thesis showed, a flexible production can result in a possibility to not utilise special designed production lines to handle particular product variants. Whereby, different customer demand can be met and economic sustainability be achieved. The benefits of different production line types can be seen. It can result in both economic and environmental trade-off from a company's point of view, if a company chooses to use several specialised production lines or not. Several specialised production lines, which manage higher productivity, speed and single volumes or a production line with the ability to manage a range of variants, have to be considered. Is it more environmentally friendly to build production lines with increased variation capacity, or specialised lines adapted to produce high volume but only manage low variation needs to be evaluated. Companies need to decide if their range of product variants is needed to fulfil customer demand. Moreover, the volume of each variant to adapt and align the production system to their customer needs.

5.5 Future research

The implementation of variant management in a PLM-system of the LEGO-made truck was done in Dassault Systèmes' PLM-system, ENOVIA. It is therefore difficult to answer if the procedure performed on the 3DEXPERIENCE platform will behave in the same way if other PLM-systems had been used for the implementation instead. Even though ENOVIA has been used throughout this master thesis, the authors do acknowledge that there are other PLM-systems available on the market. Since other PLM-systems exist on the market, it would be of interest to perform a solid investigation regarding the usage of different PLM-systems. One approach could be to investigate the implementation of variant management between different PLM-systems by utilising the same case study as in this master thesis. Whereby, it would be possible to illustrate potential differences in the procedure, if all steps are able to be performed on the investigated PLM-systems.

From the performed interviews, it was concluded that five out of six companies used PLM-systems. Company D, the only company active within the process industry did not use any. Hence, if this correlation is also a causation could be investigated. Further, to map out potential gaps in industries to identify where PLM-systems are not used or. Moreover, if there are misinterpretations of what a PLM-system is between industries. From the interviews, three factors which affect the amount of variants were stated: hardware, software and electrical steering. The interview study showed an increase of software solutions to offer variants. In the case study, only the factor hardware was analysed when working with the product variants and configurations of the LEGO-made truck. Future research can therefore include software and electrical steering in an analysis to see similarities and differences between them and hardware.

The scope of the case study in the PLM-system ENOVIA may affect how the results have been interpreted. The conclusions drawn from the program may not provide a fair picture of how an organisation work, since the scope only concerned the process of product development within a PLM-system. Future research can therefore include a wider range of an organisation to analyse how variant management can be implemented in several departments. Moreover, how the impact from several departments affect the decision-making process of how product variants and variant values can be offered can be interesting aspects.

From the interviews, sub-flows were seen as a functionality in production to improve variant management and flexibility. Smarta Fabriker does currently not have sub-flows implemented in their demonstrator. Future research can thus be implementation of sub-flows in the demonstrator to analyse potential improvements but also challenges with the implementation. Furthermore, changeovers in production are seen to have an impact on variant management. The performed case study did not include changeovers as the time study only considered assembly time for each station and product configuration, while not investigating changes between the product variants. Future research can therefore be analysing Smarta Fabriker's changeovers impact and how to reduce changeovers by implementing it in their demonstrator. How changeovers are being considered in a PLM-system would also be of interest to analyse in future research.

From the result, estimate and determine profitability of a product variant is seen as a difficult and extensive task. There are several factors to consider which is not directly linked to the cost of producing a variant. For future research, it may be of interest to create a framework which contains profitability factors. Furthermore, how they affect each other and how they are weighted in relation to their impact on profitability. This can provide a tool for the industry to increase the knowledge of variants and their profitability. Hence, allowing them to choose the correct decisions of variants to be included and excluded.

6 Conclusion

The purpose with the master thesis was to investigate why flexibility is needed to be competitive in today's market and how variant management can improve flexibility, but also its challenges. The purpose was further to investigate the benefits and challenges of utilising a PLM-system and product variety's impact on a production system by conducting a case study. Three research questions were defined with the aim to fulfil the scope of the master thesis and are presented below.

1. Why is flexibility needed in the industry to be competitive in today's market?
2. How can customised products be managed to increase flexibility?
3. What are the main challenges when utilising variant management?

6.1 Research question 1

Flexibility is shown to be even more important in today's industry for companies to succeed. Flexibility needs to be aligned and included in an organisation's strategy. However, it can be concluded that a company needs to consider its focus area and who the customers are to be competitive in today's market. A flexible production improved the ability to manage a wide range of product variants, both concerning needs from current customers and better adapt how customer needs are changing over time.

With today's product variation, the production is required to be adapted to the increased amount of product variants. Furthermore, the complexity in products where a flexible production is needed to assist with it. It is seen that customised products are more important than ever before, as customers desire unique products that fulfil their own needs. It can be concluded from the literature and interview studies, by improving flexibility, industries can manage customised products. Whereby, it can be concluded that flexibility is needed in today's industry for a company to be competitive.

6.2 Research question 2

Through this master thesis, several aspects to manage customised products with the aim to increase flexibility were shown. PLM-systems are shown to empower collaboration and communication, allowing organisations to align work towards the same goal to easily adapt and fulfil the customer needs, which are continuously changing.

PLM-systems manage product generations and product complexity in each lifecycle phase of a product, enabling flexibility. The case study shows how products variants can be implemented in the PLM-system ENOVIA. A product structure from an engineering perspective and filters have been used to visualise the product for different needs. Constraints can be applied, where non-profitable product variants are not combined in the same extent to limit these options. The case study shows, Smarta Fabriker can offer customers product configurations suitable for different customer segments to better manage customised products. The presentation of customised products is shown to impact customer needs and can improve flexibility. As all three studies show, modularisation can be used to reduce the amount of unique articles. Modularisation allows less funds to be tied and less storage capacity to be needed.

To manage customised products, sub-flows along the main-flow in the production and utilising fixtures which can manage several products are shown. Smarta Fabriker can consider these aspects in the future to improve flexibility. To manage customised products efficiently, products with similar components are planned in the same sequence. Hence, minimised tensions from changeovers and unbalanced production flows are achieved. The importance to relate production volume of product variants with the type of production is also identified.

6.3 Research question 3

The three performed studies conclude challenges when working with variant management. One identified challenge is compatibility restrictions between PLM-systems which limits the ability to add specialised systems. Another challenge is the products' lifecycle scope which industries need to control within variant management. Software solutions are shown to increase in the future and the challenges to manage generations of software have been identified. The study shows the industry is still challenged by how to utilise PLM-systems. The step-by-step procedure to utilise variant management in the PLM-system ENOVIA may reduce this knowledge gap.

Challenges to evaluate profitability of product variants have been identified. One is how entering markets affects the profitability of product variants. Evaluating product variants for each market to offer sufficient product variation while being profitable, is concluded difficult. Challenge to determine if potential increase in market shares weigh more than profitability of variants when entering markets is shown. The study shows the direct profitability of variants may not identify the actual need, as other aspects which indirectly make variants profitable are shown.

The study shows the challenge to offer customised products without using unique articles, as it creates difficulties in production and warehousing. Challenges with modularisation are shown. Modularisation can result in time-consuming activities for product development and in expensive components to fulfil several needs. The case study shows modularisation can increase assembly time. With high product variety, the challenge to balance a production flow, both between and within stations, is shown. Changeovers' impact with increasing product variety is also identified.

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A
Interview guide

The interview guide represents the questions that were asked during the performed interviews. The interviews were performed with a semi-structured approach. Other questions could be added during the interviews, if other relevant topics were brought up. In the following numerical list, the main asked questions divided into different topics are presented.

General questions:

1. Explain your role in the company and give a short description about your working tasks.

PLM-system:

2. What PLM-system(s) do you use?
    - If yes, why do you use PLM-system(s)?
    - If not, why do you not use PLM-system(s)?
3. What do you identify as the advantages and disadvantages with using PLM-system(s)?
4. How does your company work with variant management in PLM-system(s)?

Variant management:

5. What determine your range of product variants/configuration?
6. How does your company evaluate if a product variant and/or a product configuration is more profitable/not? What criteria are used in your company for the evaluation process?
7. How does your company evaluate a product variant's and/or configuration's profitability compared to the customer needs/requirements? Can the evaluation process result in a trade-off?
8. What do you think is the most important to consider when implementing product variants in PLM-system(s)?
9. What challenges do you identify when working with variant and configuration management?
10. How does variant and configuration management help you to manage changes in customer demand?

Modularisation:

11. Do you work with modularisation?
    - If yes, how do you work with modularisation?
    - If not, why do you not work with modularisation?

12. What are the advantages and challenges with modularisation?

Flexible production:

13. How does the production's flexibility affect your way to work with variant management and an increase of variants in your products?
14. How does your company work with improving the production's flexibility?

End question:

15. Anything more you want to add or explain?

B

Variant value illustrations

In the following figures, illustrations of the variant values in this thesis can be seen. The figures are illustrated to provide an understanding of the variant values' appearances.

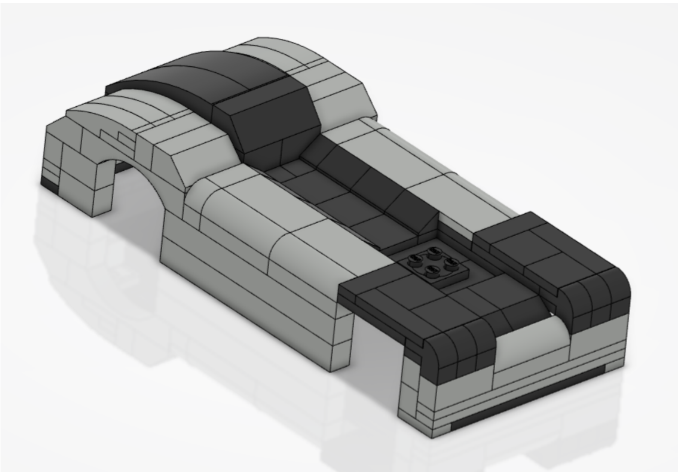


Figure B.1: Illustration of variant value Body colour Grey.

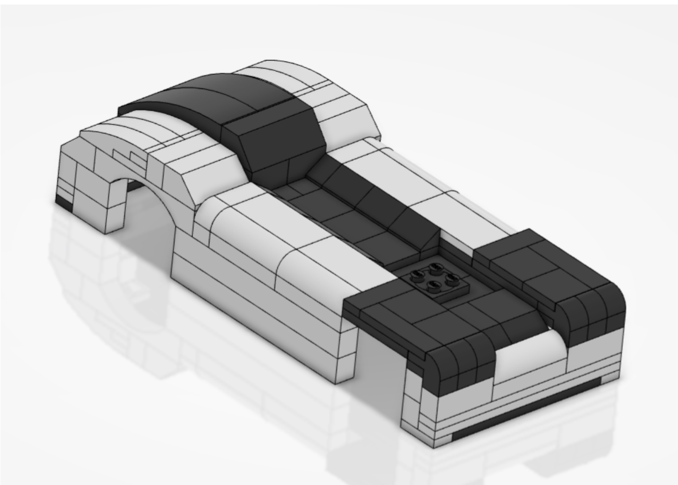


Figure B.2: Illustration of variant value Body colour White.

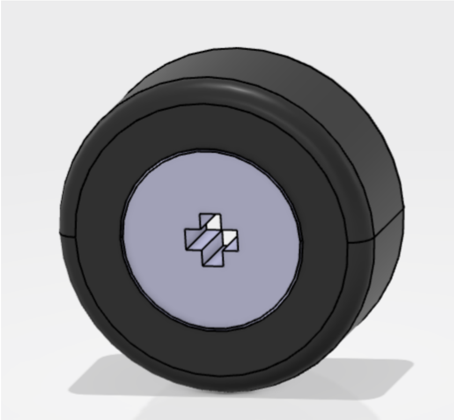


Figure B.3: Illustration of variant value Rim appearance Grey.

Figure B.4: Illustration of variant value Rim appearance Black.

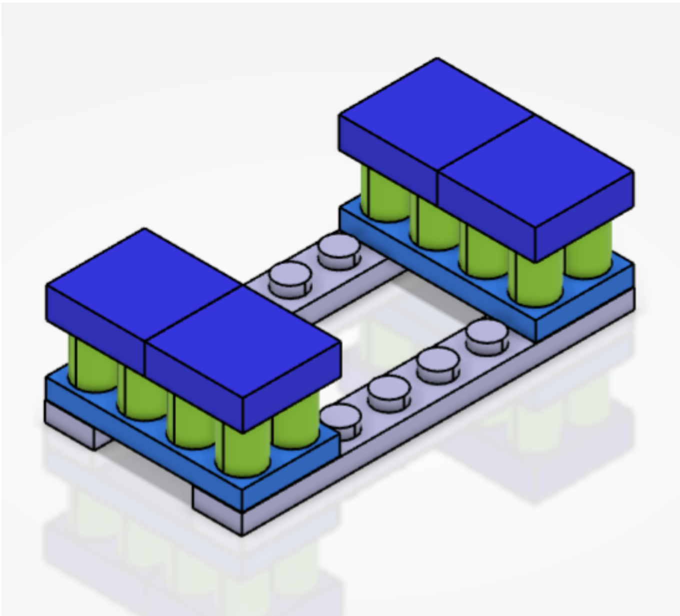


Figure B.5: Illustration of variant value Battery size Small.

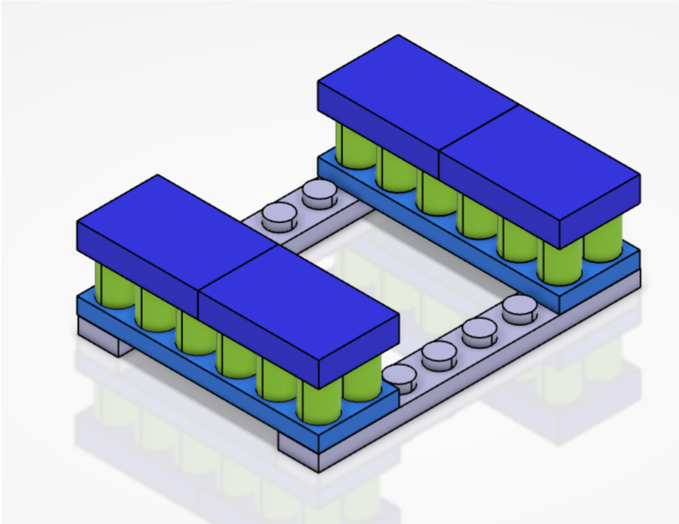


Figure B.6: Illustration of variant value Battery size Medium.

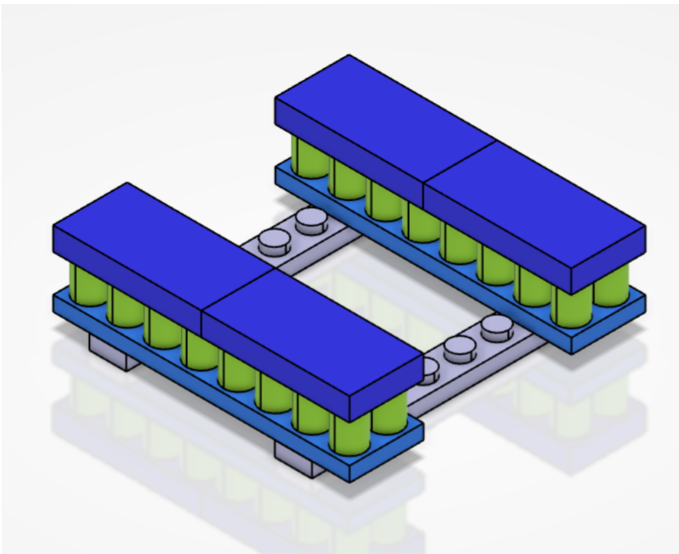


Figure B.7: Illustration of variant value Battery size Large.

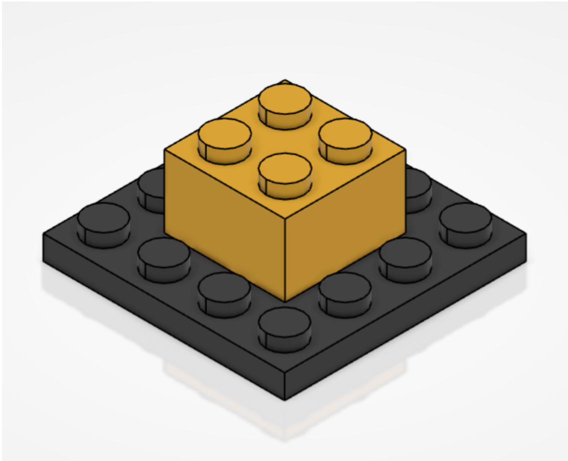


Figure B.8: Illustration of variant value Engine Efficiency.

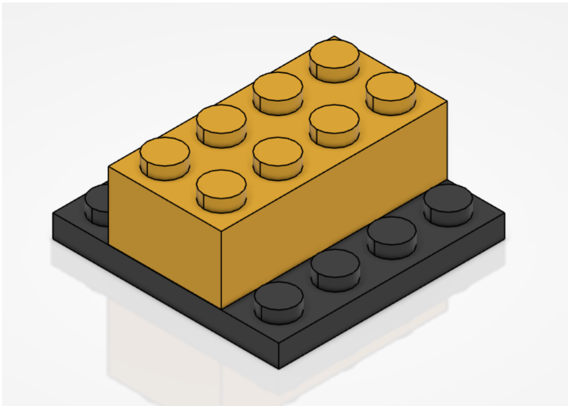
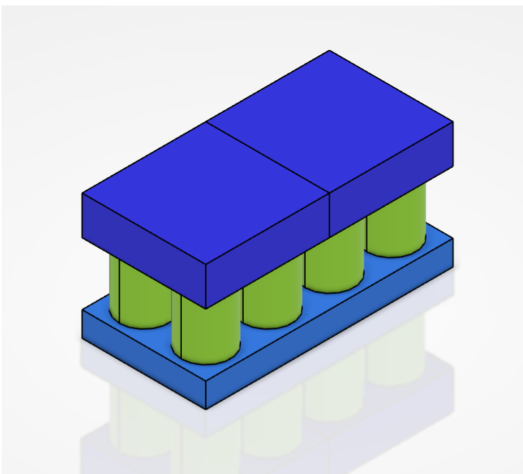
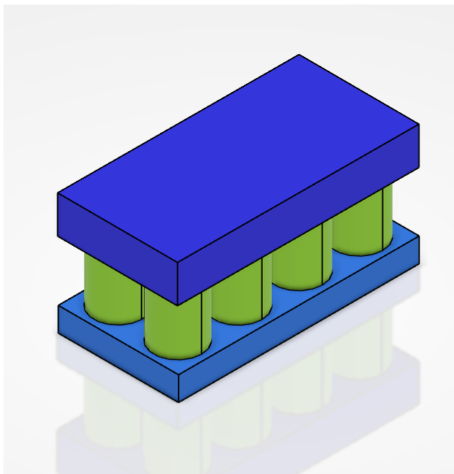


Figure B.9: Illustration of variant value Engine Performance.



(a) Battery Small original.



(b) Battery Small module.

Figure B.10: The battery cells of variant value Battery size Small in its original appearance and appearance after module implementation.

(a) Engine Performance original.

(b) Engine Performance module.

Figure B.11: Variant value Engine Performance in its original appearance and appearance after module implementation.

C

Content of the engineering bill of material

Below, a table is shown to illustrate the content of the EBOM, received from Smarta Fabriker. In Table C.1, the category *Modules* can also be seen. This category illustrates the components if modules are used instead of the original components of the variant values Battery size Small and Engine Performance.

Table C.1: The engineering bill of material containing the components received from Smarta Fabriker and the quantity of each component.

Category	*Components*	*Quantity*
Body	Body grey	1 piece
	Body white	1 piece
Rim	Rim grey	4 pieces
	Rim black	4 pieces
Battery	1x8 brick battery connector	6 pieces
	Battery platform small	2 pieces
	Battery cell small	4 pieces
	Battery platform medium	2 pieces
	Battery cell medium	4 pieces
	Battery platform large	2 pieces
	Battery cell large	4 pieces
Engine	Engine platform	2 pieces
	Engine small	1 piece
	Engine large	1 piece
Body holders	1x1 brick chassis front	2 pieces
	1x2 brick chassis back	2 pieces
Trailer attachment	Trailer coupling	1 piece
Modules	1x8 brick battery connector	2 pieces
	Battery platform small	2 pieces
	Battery cell large	2 pieces
	Engine platform	1 piece
	Engine small	2 pieces

D

Product configuration

Below are the 12 defined product configurations illustrated with their product variant and corresponding values. The product configurations are divided into three categorises: *City, Mixed and Long distance.*

Table D.1: Product configurations with their variant and corresponding values.

Product configuration	*Product variant*	*Values*
City configuration 1	Body colour	White
	Rim appearance	Black
	Battery size	Small
	Engine	Efficiency
City configuration 2	Body colour	Grey
	Rim appearance	Black
	Battery size	Small
	Engine	Efficiency
City configuration 3	Body colour	White
	Rim appearance	Grey
	Battery size	Small
	Engine	Efficiency
City configuration 4	Body colour	Grey
	Rim appearance	Grey
	Battery size	Small
	Engine	Efficiency
Mixed configuration 1	Body colour	White
	Rim appearance	Grey
	Battery size	Medium
	Engine	Efficiency
Mixed configuration 2	Body colour	White
	Rim appearance	Black
	Battery size	Medium
	Engine	Efficiency
Mixed configuration 3	Body colour	Grey
	Rim appearance	Black
	Battery size	Medium
	Engine	Efficiency
Mixed configuration 4	Body colour	Grey

	Rim appearance	Grey
	Battery size	Medium
	Engine	Efficiency
Long distance configuration 1	Body colour	Grey
	Rim appearance	Grey
	Battery size	Large
	Engine	Performance
Long distance configuration 2	Body colour	White
	Rim appearance	Grey
	Battery size	Large
	Engine	Performance
Long distance configuration 3	Body colour	Grey
	Rim appearance	Black
	Battery size	Large
	Engine	Performance
Long distance configuration 4	Body colour	White
	Rim appearance	Black
	Battery size	Large
	Engine	Performance

E

Time allocation illustrations of station two between operator and robot

In following figures, the time allocation in percentage for different tasks of both operator and robot on station two for variant value Engine Performance is shown.

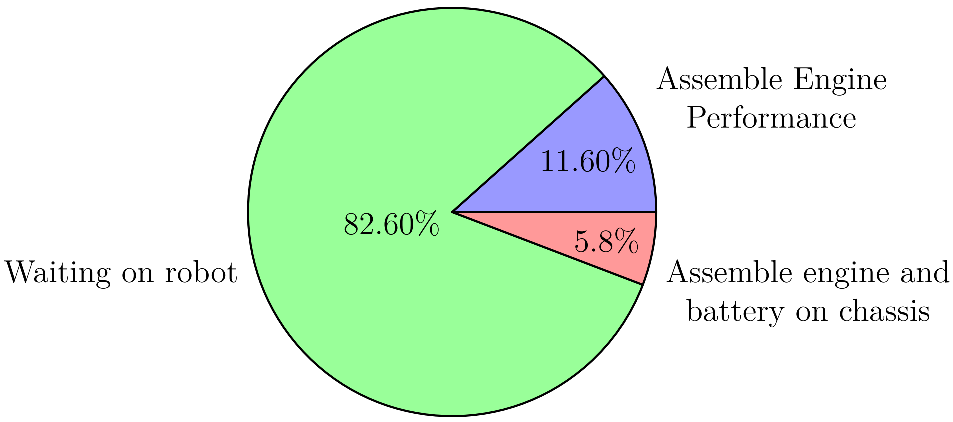


Figure E.1: The time allocation illustrated in percentage of the operator on workstation two when working with robot for variant value Engine Performance.

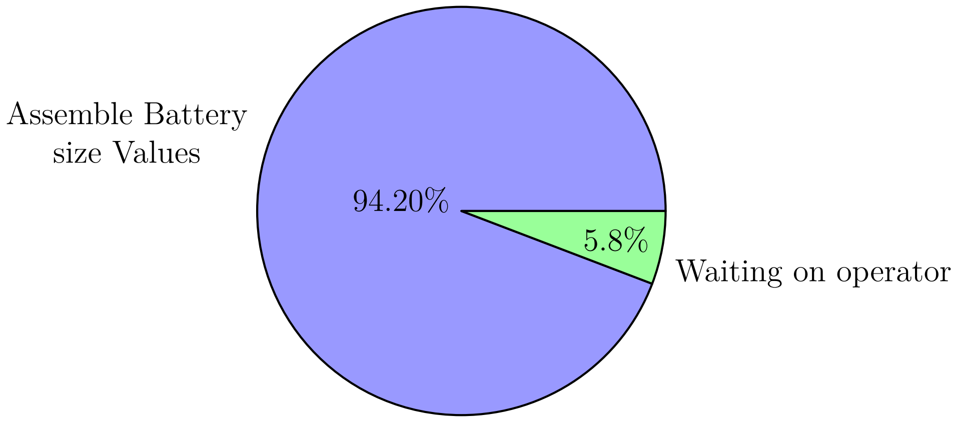


Figure E.2: The time allocation illustrated in percentage of the robot on workstation two when working with operator for variant value Engine Performance.

F

Time allocation illustrations of station three between operator and robot

In the following figures, the time allocation in percentage for different tasks of both operator and robot on station three for variant value Body colour White is shown.

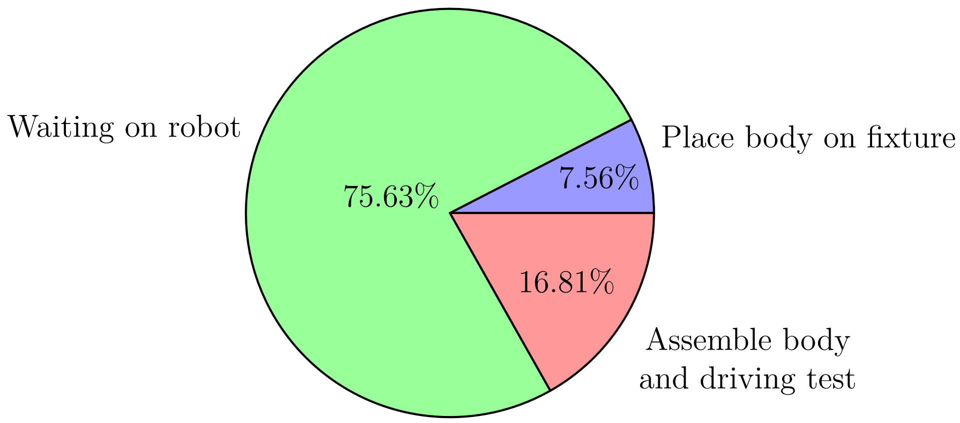


Figure F.1: The time allocation illustrated in percentage of the operator on workstation three when working with robot for variant value Body colour White.

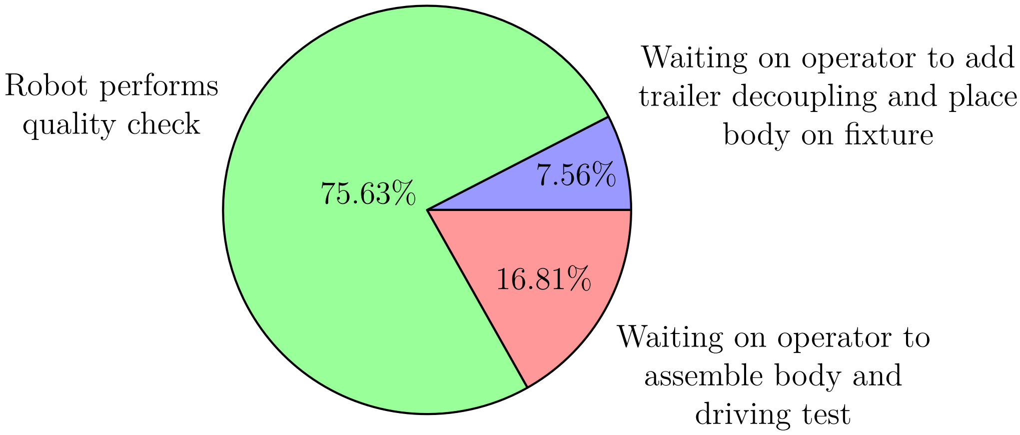


Figure F.2: The time allocation illustrated in percentage of the robot on workstation three when working with operator for variant value Body colour White.