Digitalization of the product development process at Scania engine assembly

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Abstract

The technology is constantly developing and companies are striving to work towards a more digital approach. Scania CV AB is a world leading company manufacturing buses and trucks for heavy transport applications. To maintain their competitive position at the market the company has the ambition for the product development process to become more digitalized. A goal is to implement a more simulation based and drawing free working method.

This project has been carried out at the engine assembly department. The purpose with the thesis was to identify how parts of the product development process could be more digitalized. This included identifying the gap that will occur between the current working process and a more digital approach. Furthermore, it involved finding solutions for the gap and to present possible impacts of a digital working approach.

The initial phase of the thesis was to find a suitable methodology for this type of study. The project proceeded with conducting a literature study to gain deeper insight of the subjects covered. A good foundation was obtained and the empirical study could commence. The data collection in the empirical study was gathered mainly within Scania through interviews, observations and archive analyses. Based on this information an analysis and result was carried out and presented. A gap was identified describing deficient areas in the current digital environment. The working method Model Based Definition (MBD) and a software called Industrial Path Solutions (IPS) are presented as solutions for the gap. Suggestions of how the working process should be modified have been set as prerequisites. Impacts including cost savings, quality improvements, shorter lead times and ergonomic benefits have been submitted.

Keywords: MBD, assembly, working process, test assembly, product development

Sammanfattning

Tekniken utvecklas ständigt och företag strävar därför att arbeta mot ett mer digitalt arbetssätt. Scania CV AB är ett världsledande företag som tillverkar bussar och lastbilar för tunga transporter. För att behålla sin konkurrenskraftiga position på marknaden har företaget ambitionen att göra produktutvecklingsprocessen mer digitaliserad. Ett mål är att utveckla en mer simuleringsbaserad och ritningslös arbetsmetod.

Detta projekt har genomförts på produktionsavdelningen där montering av motorer sker. Syftet med uppsatsen var att identifiera hur delar av den nuvarande produktutvecklingsprocessen skulle kunna bli mer digitaliserad. Detta innebar att identifiera det gap som kommer att uppstå mellan den nuvarande arbetsprocessen och ett mer digitaliserat tillvägagångssätt. Lösningar på gapet och effekterna av ett mer digitalt arbete skulle också presenteras.

Den inledande delen av arbetet innefattade att hitta en lämplig metod för denna typ av studie. Projektet fortskred med en litteraturstudie för att få djupare inblick i de ämnen som projektet kommer att grundas i. Med en bra grundförståelse kunde en empirisk studie påbörjas. Datainsamlingen till den empiriska studien samlades huvudsakligen in på Scania genom intervjuer, observationer och arkivanalyser. Baserat på denna information genomfördes och presenterades en analys och ett resultat. Ett gap som beskriver de bristfälliga områden i den nuvarande digitala miljön identifierades. Arbetsmetoden Model Based Definition (MBD) och mjukvaran Industrial Path Solutions (IPS) presenterades som lösningar på gapet. Även förslag på hur arbetsprocessen kan ändras för att möjliggöra för ett mer digitalt tillvägagångssätt har redogjorts. Följderna av detta som inkluderar kostnadsbesparingar, kvalitetsförbättringar, kortare ledtider och ergonomifördelar har också sammanställts.

Nyckelord: MBD, montering, arbetsprocess, provmontering, produktutveckling

Acknowledgments

First we would like to express our gratitude to our supervisor Martin Jidegren at Scania. Martin has been a great support throughout the project and always provided the help we needed. The project would not be the same without his guidelines and the time he has spent discussing and leading us forward. We would also like to thank Sara Holmer, head of DEPB, who has given us the right conditions and opportunities in order to carry through the thesis. The group of DEPB has also been very helpful and has always made us feel like a part of the group. Big thanks are also addressed to employees at Scania who were interviewed and gave us great input.

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List of acronyms and abbreviations

AA	Augmented Assembly
AE	Augmented Environment
AR	Augmented Reality
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
DTA	Digital Test Assembly
DFA	Design For Assembly
DFM	Design For Manufacturing
DFX	Design For X
DMU	Digital Mock-Up
DOL	Design On Line
FEA	Finite Element Method
FFU	Fit For Use
GD&T	Geometric Data and Tolerances
IMMA	Intelligently Moving Manikin
IPS	Industrial Path Solutions
MBD	Model Based Definition
MBE	Model Based Enterprise
PD	Product Development
PDM	Product Data Management
PMI	Product Manufacturing Information
R&D	Research and Development
SES	Scania Ergonomic Standard
SOP	Start of Production
SOCOP	Start of Customer Order Production

VB	Virtual Build
VE	Virtual Environment
VMASS	Virtual Manufacturing Assembly Simulation System
VR	Virtual Reality
2D	Two Dimensional
3D	Three Dimensional

1 Introduction

This chapter presents a brief introduction of the thesis. It includes information about the company where the project will take place and background information about why this thesis is conducted. Purpose and objectives are defined and at last some delimitations are presented.

1.1 Scania CV AB

Scania CV AB is a company founded in Sweden 1891. Ever since, they have developed and delivered buses and trucks meant for different transport solutions. By innovation and customer focus, they have grown and garnered attention from all over the world.

Today, Scania is one of the leading manufacturers of buses and trucks for heavy transport applications. In 2014 they became wholly owned by the Volkswagen Group but are still in charge of their own development. It is a worldwide company represented in about one hundred countries, with production sites in Europe, South America and Asia. The company has 45 000 employees worldwide, and the head office is still located in Sweden, more specifically, Södertälje. Scania's aim is to develop high-quality products that are adapted for each customers demand, and with a short lead time (Scania Global, 2017).

"Our core values define our company's culture. They're closely linked, guiding our actions and creating value for our stakeholders. We share a way of thinking and working, and everyone at Scania contributes by strengthening and continually improving how we operate."

1.2 Background to the project

For over 200 years, the primary source of describing and storing information regarding a product has been in two dimensional (2D) drawings. As a result of the technology advances, the work has become more digitalized and today the products are mainly described in a three dimensional (3D) environment. However, Scania continues to document, set requirement and review 2D drawings during the development process. The increased work in digitalized environment has been proven to be more efficient and generating higher quality. Therefore, many companies are moving towards more digitalized working methods. The department of Research and Development (R&D) at Scania has the intention to discontinue creating article and assembly drawings by the end of 2020. The goal is to implement the method called Model Based Definition (MBD), which is the practice of using drawing free product development. Several companies within the manufacturing industry are already using this method of working with successful result.

The expectation for Scania working with MBD is to improve the productivity efficiency and to minimize the costs of poor quality. Furthermore, this will lead to cost effective products through more and earlier iterations. The knowledge and decisions will also be made from simulations, which reduces the costs of physically testing the products.

From the production point of view MBD enables more complete digital work in earlier stages of the development process. Assembly analyses will become more digitalized and physical prototypes for testing will not be needed in the same scale as today. The current development process for when a product is to be introduced in the production assembly is divided into three generations. In each generation a test assembly is performed in order to see if all parts can be assembled on the engine. If problems are identified, they can be improved to the next generation. The outcome is a lot of material use and long lead times.

The project will be carried out at the engine assembly in a group called Global Product Engineers (DEPB). They operate as a link between the design engineers in the development teams and the assembly production of the engine. Since an engine contains hundreds of parts and due to the complexity, it requires good coordination in order to assemble the parts in the most optimal way. The work performed by the Global Product Engineering group is to simplify the assembly of the article and make it feasible.

1.3 Purpose

The purpose with this thesis is primarily to identify in what extent the development process at the engine assembly could be more digitalized. The current working process at DEPB involves digital work, but mostly physical work with physical prototypes. The gap that will occur between the present method and the future more digital product development will be investigated. In order to implement MBD and achieving a more digital approach, the gap need to be non-existent. Furthermore, solutions of how to eliminate the gap should be suggested. The impacts of working more digitally will also be investigated.

1.4 Research questions

With the purpose in mind, the following research questions were formed:

1. *What gap will occur?*
2. *How can the gap be solved?*
3. *What impacts will a more digitalized working method result in?*
4. *What role will MBD have in an increased digitalized environment?*

1.5 Focus and delimitations

The main focus of this project will be at the engine assembly within DEPB. The development process will be studied to identify the possibilities of implementing a more digital working approach specifically at this department. Limitations has been set to mainly study the test assembly activity. Other responsibilities included in the work of DEPB will therefore not be deeper investigated. The thesis will therefore not take into account how other production assemblies are being managed at Scania. It might be possible to identify similar gaps at other production units, but this will not be further studied in this thesis. Another limitation with the thesis is the provided time of 20 weeks.

2 Methodology

This chapter will give an introduction to various methods that can be used for this type of thesis. Furthermore, it will give deeper insight into the methods that will be used during the project and how they are to be carried out. Methods for conducting both literature study and empirical study will be presented.

2.1 Introduction to methodology

The methodology describes the basic workflow of the project. It can be a necessary tool for the execution of the thesis but not a description in detail of how the project should be performed. The method sets up a framework of how to proceed with the project in order to achieve the best result. There are different types of methods to use when conducting a project depending on the objective and purpose. Before starting a project a suitable method should be selected.

2.2 Research methods

This master thesis has a problem solving purpose since it will be carried out within applied science. According to Höst, Regnell and Runeson (2006) there are four relevant methods to choose between within applied science and a short description of each will follow.

- *Surveys* are used if the purpose of the thesis is to describe the current state for the studied object or phenomenon. The research question is often wide.

- *Case study* is a comprehensive study of one or several cases. Often used to gain insight of a company's working methods without affecting the studied object.

- *Experiment* is a more controlled analyse. It is conducted when comparing different alternatives and to find connections and explanations to a phenomenon.

- *Action research* is a carefully observed and documented study. The objective is to observe a problem in order to improve it, find a solution and implement it. This is often related to work involving quality improvements

2.3 Chosen method

The method that will be used throughout this thesis is the *case study*. The research questions of this thesis requires a flexible approach and needs to be investigated deeply in order to obtain the best possible result. Surveys and experiments are less flexible and more quantitative methods, which is not desired in this case. Action research is a similar method to the case study, but is more time consuming and the objective is to implement the suggested solutions. Therefore, a *case study* is assumed to be the most ideal method for this project.

2.3.1 **Case study**

Case studies are usually used when describing a phenomenon or an object more comprehensive. To gain insight of the working processes of an organization, this method can be used to gather information. It describes a specific case that has a specific purpose and the conclusions drawn are not applicable on other cases. The case study is a flexible way of working and enables changes in alignments during the study. Qualitative data is preferred in this type of study (Höst et al., 2006).

In a case study there are several different techniques used when gathering data. The most common ones will be used for this project. They are the following:

- Interviews
- Observations
- Archive analysis

Theoretical explanations of these executions are presented below. It also provides information of how this data will be collected.

2.3.1.1 Interviews

Interviews are an oral type of communication, often used when there is an interest of finding out more about ideas, opinions, knowledge and thoughts. Collecting data with this technique is not dependent on the subject and can be done in all kind of cases. Interviews are lingering, both in terms of planning and processing it. Therefore, the choice of persons to interview is important (Ejvegård, 2009).

There are various types of interviews used at different occasions, depending on the aim with the interview. The interview can have one of the following degrees of structure; structured, semi-structured or unstructured. These different types can also be combined within a study (Höst et al., 2006).

2.3.1.1.1 Who to interview

For relevant data to be gathered through this project, interviews are of big importance. Therefore, the selection of people to interview will be carefully studied. It is a great benefit if the person being interviewed has a lot of knowledge about the topic and can give a lot of input. Interviews will be held both within and outside of Scania. Moreover they will have different structures and the questions will be modified with each interview.

2.3.1.2 Observations

To study a phenomenon or a course of event, observations are a good method to use. It means studying an event by participating and collecting data from different occasions. The observations can be managed in several ways. According to Höst et al., (2006) there are four kinds of observers dependent on the degree of interaction with the studied phenomenon.

- An *observing participant* tries to integrate into the observing group, and the group is aware of the observer being there.
- The *fully participating observer* is integrated in the group. Nevertheless, this observer tries not to show being an observer.
- The *participating observer* is included in the context, but not really a part of it. The data collection can be collected with open methods, for example interviews or by asking the observant to think out loud.
- The *fully observer* does not take part of the study and is preferably totally invisible. The data collection is managed by for instance a camera.

2.3.1.2.1 Observations to be executed

This project will build on many different observations. They will vary in degree of participation and have different purposes. Observations that will take place will have the purpose to give deeper insight and more information about the study.

2.3.1.3 Archive analysis

Archive analysis is a technique used when gathering data from documents that has been produced for other purposes. Previously collected data can be formulated into the following four types (Höst et al., 2006).

- *Processed materials* are data collected from scientific studies.

- *Available statistics* is collected data where no conclusions have been drawn.
- *Registry data* is collected in order to fulfil a purpose and is available unwrought.
- *Archive data* is data not systematized as data.

2.3.1.3.1 Archive analysis investigated

Archives that will be analysed through this thesis are primarily archives obtained from the internal network at Scania. This network contains information about all ongoing projects, working processes at the company and other relevant information for the thesis. The data that is collected in the internal network is presented in all four different types as mentioned above. Secondly, processed materials published online will be utilized for the analysis.

2.4 Literature study

A literature study of the topics covered in the project is an important part of the overall thesis. It gives a deeper understanding and a good foundation in order to build on already existing knowledge (Höst et al., 2006).

Several approaches of proceeding with the literature study have been investigated. The comparison between the guidelines established by Okoli, C., Schabram, K. (2010) and Hart (1998) shows approaches that are quite similar. The second one has been selected for this thesis due to its defined structure. Hart (1998) have conducted a detailed process for a literature study including, among other, planning and performing phases. To obtain a systematically research these steps will be followed through the literature study. The phases and steps involved are described below.

2.4.1 **Planning literature study**

The initial phase of the literature study begins with a detailed planning. The aim with this is to ensure that the literature study is performed with the right intentions. Guidelines for the planning phase are listed below.

- *Define the topic.* Make some general reading about the topic and get familiar. Do research on encyclopedias and start preparing a list of terms for further research.

- *Think about the scope of the project.* What time frame, what languages will be searched and what subject areas will be relevant. Prepare a vocabulary list of terms and phrases that will be used for searching.

- *Think about outcomes.* What is the aim of the search and why should it be performed. What can be the possible outcome from it.

- *Think about the housekeeping.* It is important to keep record of what have been searched and how. This is in order to be able to go back to the same source and undertake further researches.

- *Plan the sources to be searched.* Investigate likely relevant sources of information that might be needed. Involve a subject librarian for guidance at this stage.

- *Search the sources listed.* Go through the list of sources that have been created. Start with the general and further the more abstract indexes. Take notes about leads and ideas that need to be further investigated.

2.4.2 **Conducting literature study**

With the planning as input, the next stage in the literature study can commence. To get a good structure there are four stages of conducting the literature review. The stages are explained in table 2.1. The table also contains the accompanying sources and outcome for each stage.

Table 2.1 Steps for conducting the literature study (Hart, 1998).

Stage	*Source*	*Outcome*
• Background information and ideas search • Begin mapping topic	Encyclopedias, dictionaries, text books	Initial mapping of the topic
• Focus topic and analyse information needs	Subject librarians guides to the literature	Identification of sources of information and guides to the literature
• Detailed search of sources • Construct initial bibliographies	Abstracts, indexes, electronic sources, bibliographies	Identification of articles, reports, work in progress
• Secondary evaluations of the literature	Review journals indexes to reviews citation indexes	Identification of reviews of items. Citation map of the topic

Consequently, the literature study is performed by collecting data and information from all kind of different sources. The primary search for information is very wide, including almost every kind of source without further reflection. This is done in order to avoid the possibility to miss any relevant information. Many different key words are going to be used during the research and data will be collected from the internet, books and articles.

The information that will be considered relevant and have trust worthy sources will be further investigated. Pertinent data is going to be documented and the information will be compiled. This process will be made iteratively as the sources are further analysed.

2.5 Outline for the thesis

For the thesis to be conducted in a defined and structured manner, a general outline for the thesis has been set. The map below visualises the outline. The thesis is starting with an introduction to the project and establishing working methods. The thesis will then follow with a literature study that will cover a theoretical foundation of the pertinent areas that will be studied through the thesis. A deeper and wider understanding of the areas will be obtained and the project will proceed with an empirical study. The empirical study will be based on the outcome from the case study. The case study will involve interviews, observations and archive analyses both within Scania and other companies. When the literature study and the case study have been put through, there will be relevant theoretical and empirical data to start analysing. The collected data will be analysed and the outcome will be the result of the thesis and the established research questions. Finally, a discussion regarding the project will be presented and some recommendations for the company.

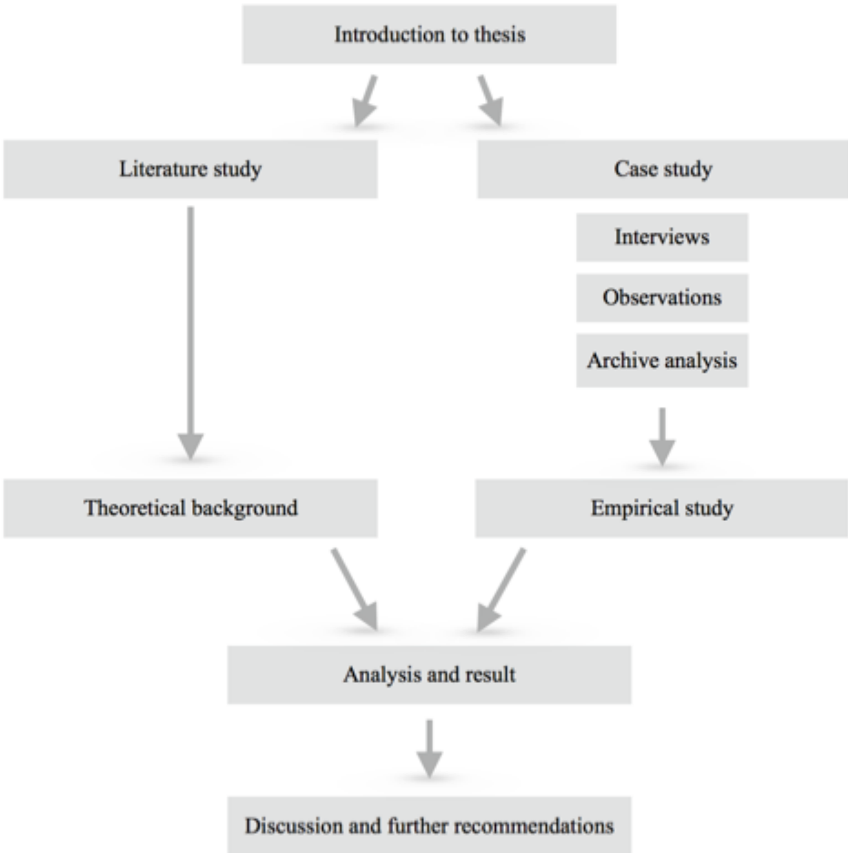


Figure 2.1 Outline for the thesis.

3 Literature study

This part of the thesis covers the literature study. The purpose with this is to gain a broad foundation and understanding of the subjects covering this project. Initially Model Based Definition is investigated and interpreted. It provides general information about MBD and possible possibilities and difficulties. Secondly, the literature study covers the assembly part of the product development process. Various aspects and approaches are presented.

3.1 Introduction to literature study

This literature study has been performed as explained in the chapter *methodology*. The steps summarized in planning and conducting the study have been guidelines through the process. In order to map which topics that were of relevance to study, a wide background search was performed. This resulted in topics based on the purpose, research questions and the objective of this thesis. The outcome was two central focuses, Model Based Definition and assembly. The main search tool that has been used throughout the study is databases provided by Lund University and Royal Institute of Technology, which includes articles, journals, doctoral theses and books.

3.2 Model Based Definition

3.2.1 **History**

The production of engineering drawings increased in the 1980s as a result of the emergence of solid modelling and specialized drafting software packages. The drawings have been used for communication by engineers and technical personnel involved with the product in question, particularly in industry. The drawing is mainly used to graphically convey both the idea and the information required for the design. The product is depicted as a two dimensional view from various angles such as front, bottom, top, side, oblique and auxiliary. Depending on the complexity of the object, the numbers of views shown are different. The engineering drawings also include information as symbols, different kinds of lines, dimensions and lettered notes. Thus, the information given on the drawings should be totally complete in order to be understood and able to manufacture (TheFreeDictionary.com, 2017). Engineering drawings have been considered to be the clearest way of informing someone what to make and how it should be made (Bourguignon, Cani and Drettakis, 2001). It is also considered to be a graphic universal language that can be understood worldwide.

With the increased production of drawings, Chen, Feng and Ding (2002) came up with an approach for 3D computer assemblies of mechanical products automatically generating into assembly drawings. Since the implementation of Computer Aided Design (CAD) systems in product development, drawings are no longer regarded as the primary source of product definition. They still maintain some information that is not included in the 3D model, such as geometry data and tolerances (GD&T). However, the information given on the drawings is considered being possible to add to 3D models. The engineering drawings could therefore be phased out and replaced by the method called Model Based Definition (Quintana et al., 2010).

3.2.2 **Introduction to MBD**

Model Based Definition is a practice of managing the product development process using only 3D models built up in CAD as the main source of information. The 3D model will contain information about the overall product life cycle with a complete product definition such as design, tolerances, technical documents, production, distribution and services. Instead of having the product information scattered in both 3D models and in 2D drawings most of the data regarding the product will be stored in the 3D model (Huang et al., 2014). The three dimensional model will therefore become the completely used reference document throughout the engineering and manufacturing phases, instead of relying on engineering drawings (Alemanni, Destefanis and Vezzetti, 2010). An MBD dataset is formed by including GD&T into the CAD. Figure 3.1 below demonstrates how the MBD dataset contains information from the engineering drawing and 3D model combined. The 3D annotations are placed in a planar view called annotation planes.

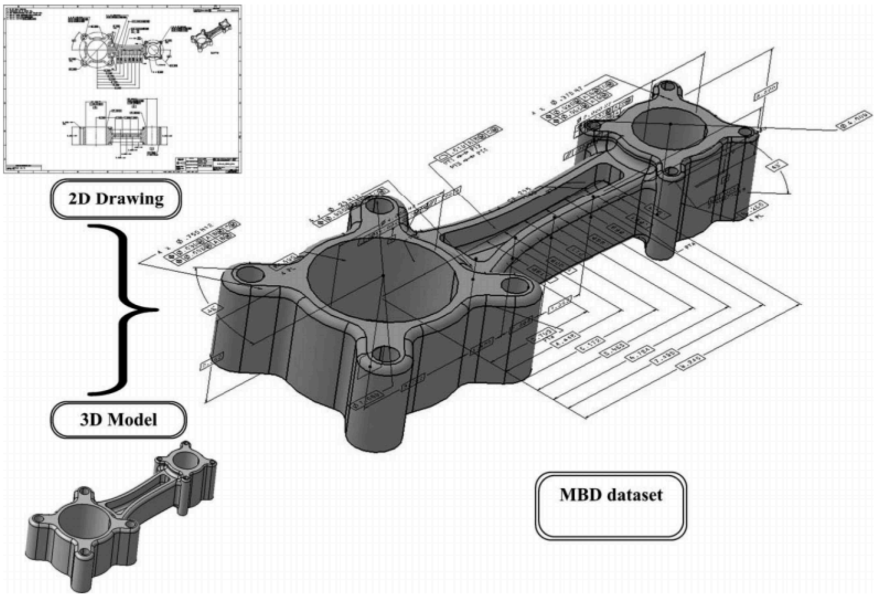


Figure 3.1 Example of MBD-dataset (Quintana et al., 2010).

3.2.2.1 MBD in enterprise

Model Based Definition is a foundation to the concept called Model Based Enterprise (MBE). MBE is defined as a fully integrated and cohesive environment based on 3D product definition. The definition is assigned through the entire enterprise with the aim to enable a fleet, seamless and priceworthy proliferation of products from concept to disposal (Camba et al., 2014). By the annotated 3D model and its corresponding data elements that fully describe the product definition in MBD, MBE is possible to apply. Moreover, the models in MBE can be applicable to multiple domains such as mechanics, software, manufacturing and electronics among others. The main tenet with MBE is to make the model available through the whole life cycle, and for the data to be created once and reused by all downstream users (Lubell et al., 2012).

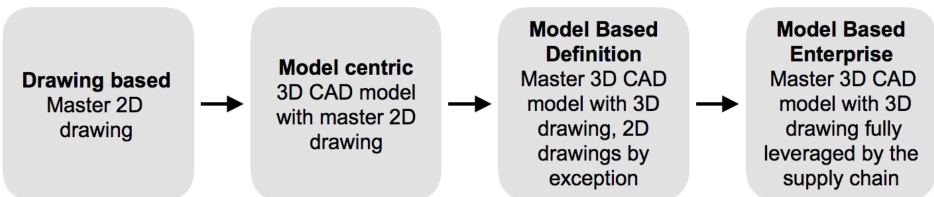


Figure 3.2 Showing the journey of drawings (Lubell et al., 2012).

3.2.3 **Impacts of implementing MBD**

3.2.3.1 Possibilities

3.2.3.1.1 Simplified working progress

An MBD dataset prevents conflict and ambiguity between 2D drawings and 3D models since it will be the single source of information. This will eliminate errors that can occur when referring to the incorrect source and decreases the risk of misinterpretation (Olson, 2015). MBD enhances the communication and the ease of collaboration. Different departments can collaborate better since everything is included in the 3D model. Design teams can work with teams on the manufacturing floor (Spatial.com, 2017).

Another benefit with MBD is the opportunity to discover design intents very early in the product development process. Usually the GD&T information is captured after developing the solid model. With MBD this information can be seen earlier when the geometry is defined and evolved (Quintana et al., 2010).

3.2.3.1.2 Time savings

There are lots of benefits using MBD and it can be viewed as the next step in the 2D and 3D transition. With an MBD dataset there would no longer be a need for engineering drawings since the MBD dataset would be the only product definition carrier. This would lead to storing only one file with information about a product and no need for spending time on creating a 2D drawing and managing two files (Rudeck, 2017). A single source of information also reduces the risk of redundant design definition and work (Quintana et al., 2010).

3.2.3.1.3 Human factors

Humans live, think and create things in 3D with our minds, therefore 3D models create a realistic view of designs. The 2D drawings are complicated and might require training to understand complex parts in the drawing. A 3D model will be easier to understand and no technical expertise will be needed (Quintana et al., 2010). When creating a 2D drawing it is reconstructed from a 3D model with different 2D views of the object. This transition from a 3D model to a 2D drawing can result in errors related to human interpretation (Spatial.com, 2017). Furthermore, human errors can occur when notes are being transferred into the drawing. The traditional 2D drawing contains information about the GD&T, bill of materials, manufacturing and other engineering information, which is interpreted by humans. MBD relies on all the data being defined and generated solely based on the 3D model. This will reduce the risk of human interpretations and a reduction in the processing time (Qualitymag.com, 2017).

An MBD working structure creates opportunities to analyse and process the model directly by engineering software applications. For example simulation programs such as finite element analysis (FEA), but also manufacturing programs like computer aided manufacturing (CAM). In a 2D drawing humans must interpret information from the engineering drawings into these programs. This information is needed for production and as support and is known as Product Manufacturing Information (PMI). This could be GD&T, inspection requirements, material- and process specifications. Each program then creates its own internal model with this data. With MBD this is included in the 3D CAD and can therefore be analysed without human interpretation and the same model will be used for all programs. This results in fewer errors and in reduced lead time (Lubell et al., 2012).

3.2.3.1.4 Overall benefits

By the use of an MBD model the product development process will be facilitated. As mentioned above MBD saves time, quality and costs. Moreover, it creates opportunities for easier digital simulations, digital prototype construction and digital production preparation on the same 3D master.

3.2.3.2 Difficulties

3.2.3.2.1 Standardization

Moving to an environment fully carried out by MBD will also come with some issues and difficulties to cope with. The CAD program are currently in a mature stage of their development, providing many different features and solutions. With this basis, companies are starting to realize the opportunities of MBD and therefore trying to procure their own method of using it. This will lead to a lack of global strategy and suitable plans to support the development. Furthermore, MBD is a way of managing product data and not only a tool; every company will have to customize the MDB within its product lifecycle management. This means that standards and joint practices should be defined to ensure that it becomes a common language for managing the data (Alemanni el al., 2010).

In order for the MBD process to be feasible, all engineering drawings should be eliminated. This means all annotations attached to the 2D drawing would have to be moved to the 3D model. In order for the companies to do this, they will need to have a transposition process that enables dimensions, tolerances and general notes to be transferred into the 3D model (Quintana et al., 2010).

3.2.3.2.2 User accessibility

The 2D drawings can currently be visualised by downstream users who do not have access to the CAD systems, which would not be possible if MBD is implemented. The drawings are in electronic format and can be exploited both printed or electronically. Thus, when implementing MBD all users should have the same accessibility to the systems used, or the model needs to be converted to a non-CAD file format. Access to CAD applications is often expensive. Therefore, generally a minority of the participants have access and the second option is the most feasible (Quintana et al., 2012).

3.3 Assembly

3.3.1 **Introduction to assembly**

The definition of an assembly is the act of combining components together. The component comprises of several parts or subassemblies put together to fulfil a specific function. The assembly should be capable of being disassembled without destruction. Thereby, it could also be disassembled into various parts or subassemblies.

Assembly operations are of great importance in companies today. In some occasions, they are even considered to be the key components of modern manufacturing systems. The assembly process account for a big part of both cost and time of product development. By managing the assembly operation in a specific manner, the product could be manufactured in the most efficient way. This includes planning and training the operation as early as possible in the product design (Al-Ahmari et al., 2016).

The assembly process is not systemized and can be designed in different ways. The level of automation can vary, and the planning of the assembly sequence differs from companies and products. Depending on the manufacturing process there are numbers of different levels of automation, however, this chapter will only give an introduction to the concepts of manual and automated systems. Later on planning, methods and different types of managing an assembly will be presented.

3.3.1.1 Manual assembly

A manual assembly is defined as a manual process since there are human workers working with the assembly. This means that the worker is managing the components included in the assembly and mounting them together. Human workers means more flexibility; therefore the demands for designing the product for manual assembly are often lower compared to the automated (Eskilander, 2001).

3.3.1.2 Automated assembly

The automated process does not involve humans, only mechanical assembly equipment. The automated equipment is programmed in order to fully complete the assembly. This process does not have the same versatility as a human or the same sensing capabilities when working. However, automated processes have the availability of working constantly while manual processes are limited by the workers working hours (Eskilander, 2001).

3.3.2 **Assembly planning**

Assembly planning is an important part of the product development process. In this process it is determined how different parts should be put together in a specific order to create the final product. This order is known as the assembly sequence of the product (Dalvi, 2016). As mentioned above the assembly process is costly and time consuming, the assembly sequence planning is therefore an important aspect. A well-defined assembly plan involves consideration for minimum assembly time, ergonomics, operator safety and quality. This can improve production efficiency and reduce the product's time to market, which would result in cost savings and competitive advantages (Seth, Vance and Oliver, 2010).

The assembly sequence planning has traditionally been carried out by manually inspecting 2D drawings or physical prototypes of the product in order to decide the optimal sequence (Ng et al., 2013). Nowadays, since the products become more and more complex and because of the technological advances, the three dimensional CAD models are examined and assembled. However, physical prototypes are still built as a final verification (Seth, et.al, 2010).

3.3.3 **Methods of managing assembly**

The concept of making products easier to manufacture and assemble has been evaluated ever since the industrialisation began. They are still being examined since it is preferable to have the most efficient way of making products. There are several different techniques and methods to help developers improve their work. The methods presented below appear to be the most established and common used in industry and are proven to be efficient, hence they are the only ones taken in consideration.

3.3.3.1 Design for X

Design for X, also known as DFX, is an acronym to simplify other acronyms starting with "Design for...". DFX can be seen as an activity, or a method of working, which is goal focused and has the purpose to fit the product to the life phase system (Eskilander, 2001). There are several ways of interpreting the X, where WDK (1993) has two:

1) A product lifecycle phase of the lifecycle or one of the sub processes (for example: manufacturing as phase and gripping as sub process)

2) A specific property (for example: quality or cost)

3.3.3.2 Design for assembly

DFA is one interpretation of DFX, where A stands for assembly. Products designed for manufacturing have great potential of reducing costs by simplifying the product and the related manufacturing. The assembly is a part of the manufacturing system, which, as mentioned earlier, is a highly cost-intensive process. Therefore, design for assembly is a technique that has a big opportunity to improve the product design using the concept of Design for Manufacturing, DFM. An explanation to this is that DFA and DFM have been frequently used and due to the other DFX methods being quite young (Eskilander, 2001).

The idea with DFA is to eliminate the source of problems that are likely to appear in the assembly before the product is finished. Thus, this is a method often used to avoid well-known problems (Eskilander, 2001). The technique is based on several methods of measuring the assembly efficiency and has outlined in 13 design-for-assembly guidelines. Consequently, it is the best way of measuring the ease with which a product can be assembled. DFA is measuring a product in terms of the overall assembly efficiency and the facility of which components can be retrieved, handled and mated.

The guidelines for DFA are listed below:

1. Overall component count should be minimized.
2. Make minimum use of separate fasteners.
3. Design the product with a base component for locating other components.
4. Do not require the base to be repositioned during assembly.
5. Make the assembly sequence efficient.
6. Avoid component characteristics that complicate retrieval.
7. Design components for a specific type of retrieval, handling and mating.
8. Design all components for end-to-end symmetry.
9. Design all components for symmetry about their axes of insertion.
10. Design components that are not symmetric about their axes of insertion to be clearly asymmetric.
11. Design components to mate through straight-line assembly, all from the same direction.
12. Make use of chamfers, leads, and compliance to facilitate insertion and alignment.
13. Maximize component accessibility.

These guidelines are compiled by Ullman (2010) and are overall steps to follow. Some of the guidelines have further steps and guidelines established.

3.3.4 **Physical assembly**

Physical testing and verifying products have been prevalent in industry during a long time. By physically performing tests, product performance, quality and competitiveness, the global markets have been influenced. The physical testing as well as the physical assembly is linked to product certification. Some manufacturers have to test their products physically in order to pass certification criteria or to see if the prototypes are following safety standards and combustion. By evaluating products or processes physically, valuable knowledge is generated and useful data can be gathered to improve the design of future products and variants (Maropoulos and Ceglarek, 2010).

In order for physical assemblies to be accomplished, physical prototypes must be produced. Therefore, this process is both costly and lengthy to perform. If modifications are made in the product design, which contributes to the tools being modified as well, the process will take even more time and cost more (Dalvi, 2016).

3.3.5 **Digital assembly**

Digital prototyping is a way of exploring the concept of a product before it has been built such as virtual simulation of products, which uses 3D CAD software. This can be used in order to simulate the product lifecycle phases, for example the assembly part of the development process. Digital simulations are a core component of the assembly planning since it can identify assembly constraints, assembly sequence and equipment selection. It can be performed before the product is physically realised and therefore more cost effective and less time consuming. Early engineering changes can be discovered with a digital simulation, resulting in the cost of producing a physical prototype will disappear. Many industries are moving towards more virtual testing and less physical prototyping (Maropoulos and Ceglarek, 2010). Figure 3.3 demonstrates how the development process has evolved over time.

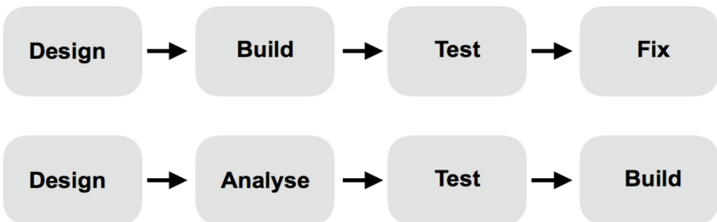


Figure 3.3 Upper showing the traditional way and lower the digital.

3.3.5.1 Virtual prototyping

Virtual prototype, or digital mock-up (DMU) as it also is referred to, is a digital simulation of a physical prototype. The testing and construction of a virtual prototype is called virtual prototyping and is a method in the product development process. The DMU represents the assembly of the structure and all the spatial positions of the different parts. The digital mock-up can be used to carry out experiments of how the product should be assembled, dissembled and checking clash detection (Ma and Grafe, 2011). The ideal virtual prototype shows all aspects of the product. The shape is created by 3D CAD and the product structure represents oth the parts and the assembly. In the product structure it is essential to set up a Product Data Management (PDM), which manages all the data and information about the product.

3.3.5.1.1 Virtual reality in assembly

The virtual reality (VR) technique is according to Seth, Vance and Oliver (Seth, et alt. 2010) the ideal tool for simulating assembly planning. VR is a technology which combines human interaction with computer technologies. It can be described as a three dimensional, computer generated environment that can be explored by a person. VR provides several sensations such as visual and auditory, which gives a feeling of being in the virtual world created through the computer.

Virtual reality in assembly allows engineers to analyse assemblies and disassembles early in the design stages through importing concepts in the virtual environment. This could help optimizing the design process towards DFA as mentioned above (Seth, et alt. 2010). Even though VR is viewed as a valuable technique throughout the assembly process, most of the research in this area has been focused on the designing of products and plan for the assembly. Little research has been carried out in the developing of VR environments contributing to training operators on assembly. VR is not yet fully applicable in the commercial industries and Abdulrahman M Al-Ahmari, Mustufa H Abidi1, Ali Ahmad and Saber Darmoul (2016) have through their study "*Development of a virtual manufacturing assembly simulation system*" addressed the four main issues with the development of virtual environment in manufacturing assembly simulation, which are the following.

1. The translation of data generated by CAD systems
2. Modelling the physical behaviour and constraints of objects
3. Collison detection
4. Integration of various hardware and software systems

Abdulrahman M Al-Ahmari et al. have through their research focused on developing a virtual manufacturing assembly simulation system (VMASS) that solves some of the problems mentioned above. Their proposed suggestion is a system that optimally can translate CAD data to VR software and also enables visual and force feedback for example when collision occur in order to train assembly operators in the best manner (Al-Ahmari et al., 2016). VMASS is a system with great potential, however it needs user-based evaluation to decide the effectiveness of the system.

3.3.5.1.2 Augmented reality

As mentioned above and according to Ong S.K. (2011) the virtual environment (VE) brings limitations to the assembly planning due to a lack of adequate sensory feedback and real spatial feeling. Nevertheless there is another technique apart from VR that is considered good, especially for assembly planning. This is called augmented reality (AR).

Augmented reality combines artificial information with the real environment to improve the perception of the surrounding environment to the user. The artificial information is visualised as virtual objects that are placed at the right place at the right time regarding the user's view (Ma and Grafe, 2011). AR is a technique that has a good potential in many engineering fields, amongst the assembly. It enables the users to check for possible errors and planning the sequence by seeking to complete the assembly with real and virtual components in the augmented reality environment. Therefore it could also entail better analyses of ergonomics in the design process (Wang et al., 2013). The application of AR in the assembly is called augmented assembly (AA) and the environment where AR is used is augmented environment (AE). In AE, the real environment is combined with virtual objects to further improve the design and planning of the assembly. Product assemblies in AE are combining physical parts, virtual contents and real feedback to analyse the assembly. Thus, in many reported AA systems information about the assembly has to be extracted from CAD data. This requires high preparation time for each application, bringing limitations concerning the time aspect (Ong, 2011).

According to Ma and Grafe (2011) the main challenge with AR is the coherence between the mixture of computer generated and real world elements in the user's field of view. An exact tracking of the user in the real world is needed. This information determines where the virtual objects are being placed in the user's view, and what size the object should have.

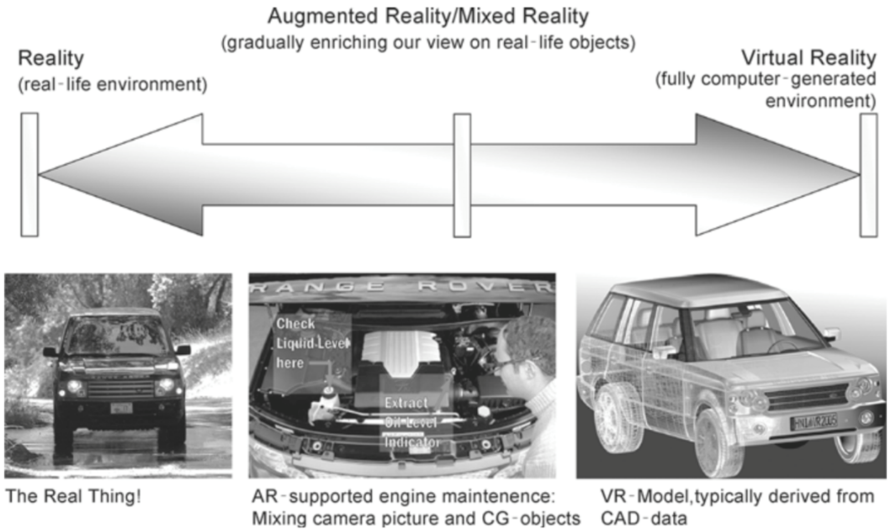


Figure 3.4 The relationship between augmented and virtual reality (Ma and Grafe, 2011).

3.3.6 **Making assembly ergonomic**

Industries are moving towards increasing automated assembly operations, however manual assembly operations are still conducted in many manufacturing companies. The ergonomic aspects are therefore of vital importance both for productivity and safety. Ergonomic aspects in the assembly include comfortable environments for the operators. Poor assembly sequences, poorly designed station layouts or bad product designs can result in uncomfortable positions and motions, which increases the risk of injuries (Björkenstam et al., 2016). Furthermore, poor ergonomic environment can result in health problems, quality and productivity loss, which leads to increased cost of the final product. The figure (Falck, Örtengren and Högberg, 2009) below demonstrates how poor product design and poor process design affect the total cost. Poor product design can be high assembly force due to bad seizure and an example of poor process design is wrong assembly line heights.

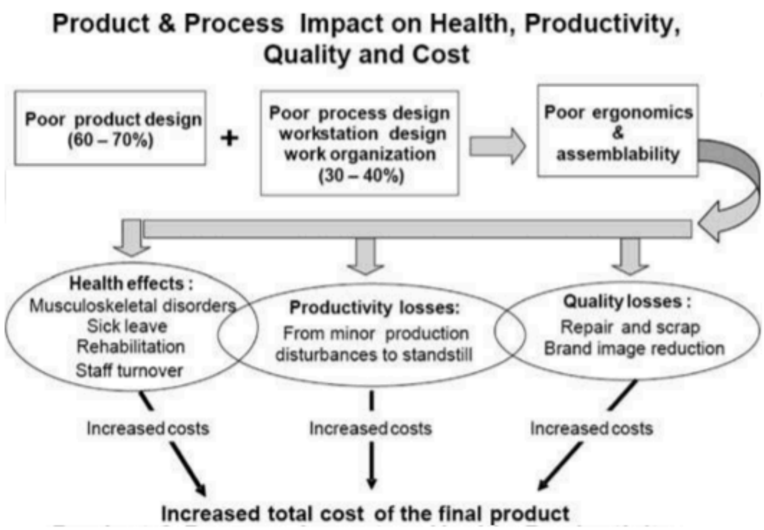


Figure 3.5 Increased total cost due to poor ergonomics (Falck, Örtengren and Högberg, 2009).

Some common applied ergonomic requirements in an assembly process at an industry can be weight requirements, assembly force, sharp edges, working height, static work etc. If these ergonomic issues can be detected and prevented early in the product development process it could both save costs and increase the quality of the product. Engineering changes of the product are, as mentioned earlier, less costly and easier to make earlier in the process. For these reasons ergonomic studies in virtual environments are needed before creating physical prototypes. Simulations with digital manikins in computer environments are an approach that is conducted in many companies (Falck, Örtengren and Högberg, 2009). During a long time it has been used for efficient assembly in the design process, such as in the automotive industry, the aircraft, health care etc. Digital manikins are created in many digital human modelling tools such as Jack, DELMIA, SAFEWORK etc. (Duffy, 2009). According to Björkenstam et al. (2016), in the research *"Enhancing digital human motion planning of assembly tasks through dynamics and optimal control"* they emphasise that ergonomic studies has not yet reached its full potential. It is limited to software support when creating realistic pose prediction, motion generation and collision avoidance. The result of this is that ergonomic studies are mostly done for static poses and not for full assembly dynamic motions.

4 Empirical Study

This chapter presents the outcome from all empiric data that has been collected. Empirical studies that have been performed are identifying the current working process at DEPB and also looking into how different departments at Scania and other companies are working with digital environments. The study has been carried out through a case study with interviews, observations and archive analyses as explained in the methodology chapter.

4.1 . Conducting of the empirical study

As explained in the methodology chapter the different techniques used when gathering data for the empirical study have been interviews, observations and archive analyses. A workshop with DEPB was also conducted to further strengthen the empirical study. Table 4.1 below demonstrates which type of technique that is used within each chapter presented in the empirical study. Structure of the interviews and names of the interviewees can be seen in appendix B. The subjects discussed during the workshop can be seen in appendix C. The archive analysis consists of information mainly obtained from Scania's internal network that is only available for employees at the company.

The initial approach for the empirical study is going to be a wide research of the product development process at Scania in general. It will continue by investigating the structure of the engine manufacturing department and how the assembly process is performed. The study is starting in a wide scale in order to get an overall view and to understand the position and purpose of DEPB in it. The study will then proceed with an investigation of the work managed at DEPB. The main focus will be to examine their physical and digital working methods related to test assemblies since the purpose is to identify the gap between these different working approaches. Furthermore, benchmarking about relevant areas at Scania and an another company was also conducted.

Table 4.1 Sources of information used throughout the study.

Source of information	*In which chapter the information is presented*
Interviews with employees at DEPB	The results from the interviews can be seen in chapter 4.4 Global product department DEPB
Interview with employee at Tetra Pak	The result can be seen in chapter 4.6.1 Tetra Pak Lund
Interview with digital test leader at Chassis department	The result from this interview can be seen in chapter 4.5.1 Digital test assemblies at chassis department
Interview with senior technical advisor at Research and development department	The result from this interview can be seen in chapter 4.5.2 MBD at Research and development
Observations	The result of the observations carried out can be seen in chapter 4.4.2 – 4.4.4, 4.5.3 and 4.3.2
Archive analysis	The result from the archive analysis can be seen in chapter 4.2 - 4.3.1 and 4.4.1
Workshop with employees at DEPB	Results from the workshop have contributed to chapter 4.4 and parts of chapter 5.1

4.2 Product development process at Scania

The product development (PD) process at Scania is cross-functional and designed to achieve high function and quality products in order to meet customer needs. It is developed to create products within the right time, short time to market and with an approved cost frame. Nevertheless, the customer needs are the main focus throughout the whole process. In order to meet the needs and maintain high delivery performance, different demands are made to enable parallel and cross-functional work. Scania aims to maintain a global product portfolio, which means that the PD-process must be designed from a global point of view. A method that is applied within the organisation is to learn from earlier projects and assignments to constantly improve processes, products and services.

The PD-process is divided into three different sub processes comprising pre-development, continuous introduction and maintenance of current products. The sub processes are called the yellow arrow, green arrow and red arrow and are illustrated in different colours seen in figure 4.1 (Scania CV AB, 2013).

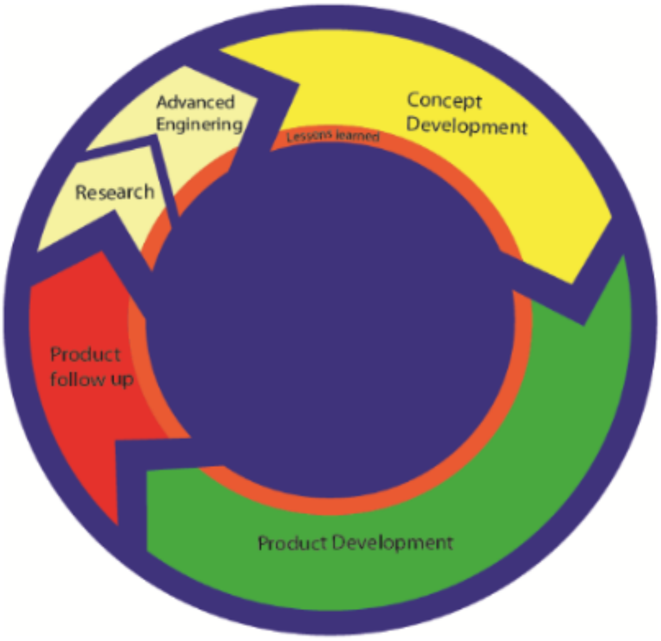


Figure 4.1 The product development process at Scania (Scania CV AB, 2013).

4.2.1 Yellow arrow

The initial phase is the yellow arrow, which deals with predevelopment. Investigation is carried out in order to see business possibilities, technical solutions and risks before the product is developed. The yellow arrow comprises of three areas, research, advanced engineering and concept development (Scania CV AB, 2013).

- *Research* – The objective with research is to build knowledge about new technology and future scenarios, and how they can be applied in strategic fields. Research is not only carried out within Scania, but also at different strategic partners and at Universities.

- *Advanced Engineering* – The aim with advanced engineering is to see the possibility of the researched technology to be applied at Scania's products and services and in what extent it can be used.

- *Concept development* – In order to develop a competitive product there must always be a customer need behind the project. This area aims to convert these customer needs into solutions appropriate for Scania. The customer needs can be identified in different forms: directly from the customer, from researched and advanced engineering, from legal demands etc. When the concept development is complete, a technical concept has been developed and the main technical risks are eliminated for the upcoming green arrow. It can now be decided whether the project will be transferred into green arrow.

4.2.2 **Green arrow**

Industrialisation and development of both services and products are included in the green arrow. The projects are designed in order for them to be plannable and that deliveries included in them are offering high delivery precision. The green arrow is divided into four different types of processes and working procedures (Scania CV AB, 2013).

- *Design OnLine (DOL)* - The DOL embraces smaller projects, which have their own processes. For a case to be noted as a DOL-project the resources needed shall not exceed 1000 hours. They are dealing with customer requirements associated with trucks, buses, and marine and industrial engines. The assignments in DOL are followed up throughout the whole process.

- *Special order projects (S-orders)* - Products that cannot be reached through Scania's regular marketed product programme (A-orders) are being ordered as S-orders instead. The S-order organisation is using particular development processes depending on the specific need for the order.

- *Fit for Use (FFU)* - Fit for use is supporting the business of high-quality customizations. It is acting as an addition to the regular product programme with arrangements and completion of vehicles. The aim with FFU is also to reduce the cost of adaptations and lead times from order to delivery.

- *Product development project (PD project)* - The aim with PD projects is to change the regular product programme (A-orders) at Scania. The market introduction is already promised and this is the part where the project becomes truly cross-functional and many different employees are involved. The initial phase in a PD project is the configuration, which is based on the information contained from the concept development process in the yellow arrow. All departments involved will develop a project plan and the outcome from the configuration is summed up in a project and object definition (PDf and OBf). Furthermore, introduction of time, cost, investments, etc. are established in the PDf. When the PDf is approved the project moves into the development phase. This is when the product development takes place and continues until major deviations with the PDf are eliminated. This is carried out through three generations called development, performance and verification. When the project is in the process verification and market prepare phase, the main focus is completing production preparation and make sure all departments are ready to release the product. The new product will then be produced and delivered to customer. During the ramp and close phase the project result is summarized in a report and if there are any open deviations they are handed over to red arrow, which is the product follow-up process.

Figure 4.2 Green Arrow – PD-process.

4.2.3 Red arrow

Within the red arrow the current product range is maintained and followed up. The primary reason for this is to improve the quality observed by the customer. Quality problems often result in big costs and therefore affect the company's business. Thus, the highest priority for Scania is to eliminate deviations that are affecting the customers as fast as possible. Product quality issues can be launched differently in various sub processes. Some of these are further explained below (Scania CV AB, 2013).

- *Field Quality* – Deviations in field quality are most often perceived by the end customer or detected by one of Scania's production units. This could both be a supplier or a marketing organisation. Missions that occur in field quality are referred to different solution processes (quick, medium, heavy) depending on the complexity of the case.

- *Delivery Stop* – This is used when a unit has been detected with major or critical deviations and has already been delivered to an internal or external customer, or is about to be.

- *Production* – The production unit can discover deviations, which are of big importance to be corrected. These cases are set within the production unit by an improvement group.

4.3 Engine manufacturing department

4.3.1 **Structure of the engine manufacturing department**

The engine manufacturing department, also called DE, is one of several production units within Scania CV AB located in Södertälje. This unit is producing engines operating on ethanol, diesel and gas for their trucks and buses together with marine and industry engines. Processes carried out are assembly, testing and painting new and updated engines.

The map below is showing the managing system of the engine assembly. The map gives a general overview of how the work is managed at the department in order to deliver products and services that are fulfilling agreements with customers, laws and regulatory requirements. Each sub department will be briefly explained further below the map (Scania CV AB, 2014).

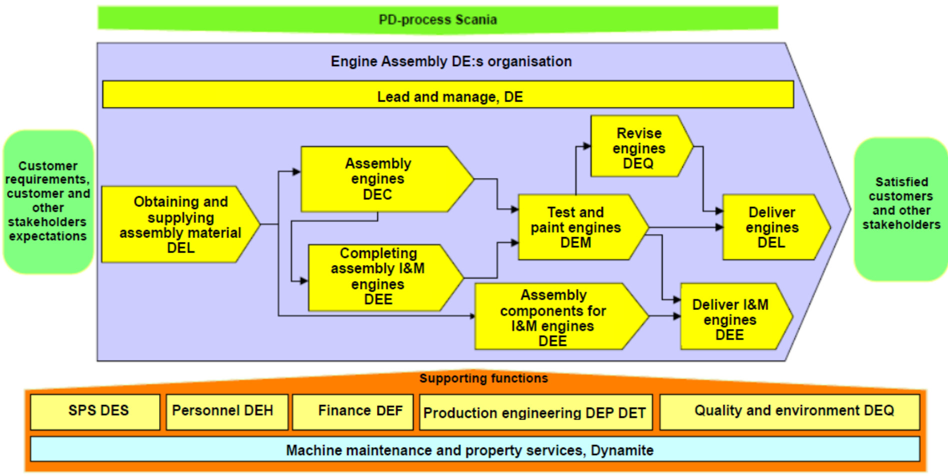


Figure 4.3 Overall map of DE (Scania CV AB, 2014).

DEC (Assembly) - The mission of DEC is to assembly engines to marine and industry customers as well as buses and trucks to internal customers within Scania. This should be managed at the right time in accordance to specified requirements.

DEE (Marine and industry engines) - DEE is complementing engines for industrial and marine installations according to Scania's technical specifications, painting and enveloping the engines according to delivery plan.

DEF (Financing) - DEF is responsible for maintaining and developing the financing systems of DE. Responsibility for adaptations of Scania's central accounting guidelines is also included in the assignment of DEF.

DEH (Personnel) - Employees of DEH are involved in recruitment processes by supporting managers when there is a need for recruitment within DE. They also establish agreements and are responsible for wage formation.

DEL (Logistics) - DEL is preparing the logistic process and bringing standards, routines and instructions for material handling.

DEM (Testing, verification and painting) - DEM is testing and painting engines as well as repairing if needed.

DEP (Global production engineering) - DEP is preparing and validating the introduction of new products and renewal of existing products. They are also responsible for providing assembly- and control instructions and assembling engines on behalf of PD projects.

DET (Local production engineering) - In contradistinction to DEP, DET is preparing and validating the introduction of new products on the production line. Their responsibility is also to plan the installation and start-up of production equipment and to improve the current assembly process.

DES (Scania production system) - DES is responsible for developing, documenting and maintaining the current posture within DE with accordance to Scania's production system.

DEQ (Quality and environment) - DEQ is developing and operating the processes of DE for quality assurance.

4.3.2 **Assembly process**

Scania utilizes a modular system for their engines and therefore provides several different variants and customer selectable components. All variants are fundamentally based on three different models of the engine block, two straight and one V-shaped. The engine assembly process is divided into two assembly lines, the straight engine and the V-engine. Human beings are mainly operating the assembly process manually, only a few activities are performed by robots. In order for the assembly workers to know how articles are intended to be mounted, they are provided with training and element sheets. The element sheet contains information, both written and visualised, of how a specific product should be mounted and in what order. It also provides information about specific assembly requirements, such as torque. This enables a standardized working approach where all assembly workers operate in the same way and order.

The straight assembly line, D12 line, accounts for the largest volume of engines produced. This is where the straight five- and six cylinder engines for buses, trucks and marine applications are produced. This line is divided into ten areas with two main groups, the base engine and the final assembly. The base engine line consists of the three first areas where the main components of the engine are assembled.

The final assembly line consists of the remaining seven areas and this is where the final assembly of the engine is performed. The assembly workers rotate within their area among different stations. The engines move along the line and the pace time for each station is one minute and 58 seconds. The tasks at each station are all balanced to fill 90% of the cycle time.

The D16 line is where the V-engines are produced. This line is more compact than the D12 line, formed like a circle and located in the middle of the building. This line has a longer pace time of seven minutes at each station, resulting in more tasks at each station. The line is divided into three areas.

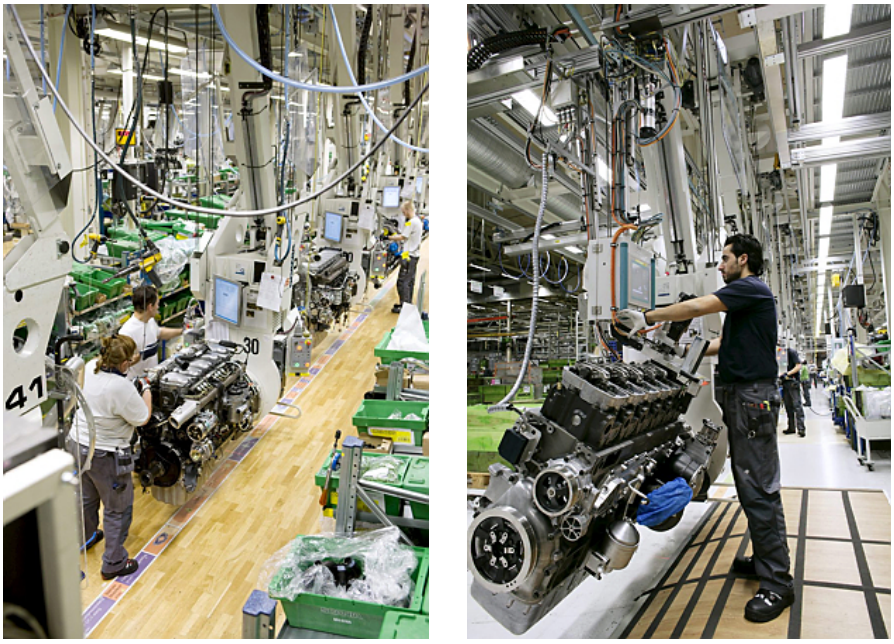


Figure 4.4 Picture showing the D12 line (Media.scania.com, 2017).

After the bus and truck engines have been assembled on the D16 and D12 line they are transported to the in-lane. This is where they are prepared for the testing cell. The engines are filled with oil, adapters installed, engine control units programmed etc. After the in-lane they are tested in the testing cell where power is measured versus fuel consumption. The engines are thereafter cooled and transported to the out-lane where everything installed on the in-lane is removed. The engines are then painted in the paint shop and ready to be transported to chassis. The production flow for the marine and industry engines differ some after the assembly lines. They have a marine completion and an area called after- and before painting. This is due to their complexity and different application areas.

Other than the production flow mentioned above, there is a development line located in the engine factory. The development line is an area where physical test assemblies are performed in order to physically visualise and test the mountability of new solutions. The tests are performed on engine prototypes called mock-ups and the articles tested are prototypes made in both the actual material and in 3D-printed plastic. This line is also where engines under development are produced to execute performance tests. Furthermore, the development line is where the assembly workers practice assembling new engines and where the element sheets are created. A map of the engine factory can be seen in the appendix C.

4.4 Global product department DEPB

4.4.1 **Working process and responsibilities**

The global product department DEPB is a sub department to the global production engineering DEP within the engine manufacturing. The department is represented by eleven employees all mainly working with introducing PD projects in the production flow without deviations. In order for this to be possible they are responsible for conducting several assignments. These assignments include working closely with R&D in order to adapt the product to the production environment and achieve manufacturability. DEPB should also find deviations that could lead to quality and ergonomic issues or cause disturbance.

There are always several PD projects in progress simultaneously and at least one representative from DEPB is involved in each project. Since there are several ongoing projects, the employees at DEPB may be involved in various projects at the same time. The projects are proceeding by the project team following a project map, which includes milestones for each department to fulfil.

4.4.1.1 Milestones

Before a project has started, deadlines for each milestone are set up. This provides all members of the project team with guidance and guidelines through the project. Milestones contain activities that need to be accomplished in order to fulfil the milestone. Depending on the complexity and the number of new articles, the deadlines for the milestones are varying. Different projects can therefore differ a lot in terms of time consumption.

The map below shows a general view of the phases that are performed by the DEPB department within each project. The phases comprise of milestones and are further explained below. Since this project is focused on digital work, the phase most related to this will be deeper investigated. This is primarily concerning the development phase.

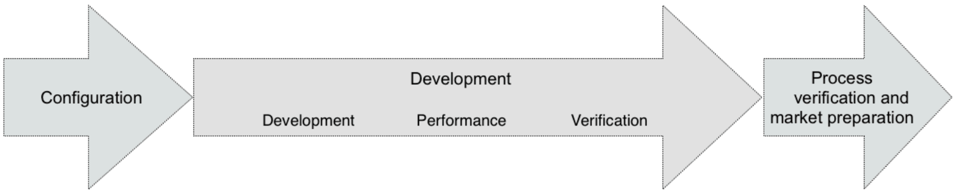


Figure 4.5 Map visualizing the working process.

4.4.1.1.1 Configuration phase

Configuration is the initial phase in the green arrow process. This phase consists of three milestones for DEPB. The first milestone is called concept review, which involves getting acquainted with all new parts and concepts and going through them with an assembly perspective. Questions such as how the new parts will affect the assembly time, the need for assembly drawings and new pre-assemblies, are asked. This is conducted by mainly using the 3D models created by the design engineers. The milestone also includes examining the new design solution from a painting, repair and testing perspective.

The second milestone carried out by DEPB is a risk analysis. This includes identifying early risks possibly affecting the assembly process in the project. The last milestone in the configuration phase is called test demand. This involves evaluating the need for a mock-up in the project. Furthermore it includes identifying the aim and the complexity of the test assembly (Scania CV AB, 2016).

4.4.1.1.2 Development phase

The development phase is divided into three generations, development, performance and verification. The three generations are consisting of similar milestones with only a few adjustments. They are conducted in the same manner with the aim to reduce the number of deviations. In the verification generation the deviations are therefore supposed to be eliminated. The milestones included in the development generation are listed and described below. Since the milestones in the three generations are very similar, only this generation is described (Scania CV AB, 2016).

- *Assembly sequence ready for development test* - This milestone includes preparing and conducting an activity called virtual build (VB). VB is a process where the entire assembly sequence for a new engine is analysed digitally in a 3D environment. Critical areas from a production point of view are identified and observations of what needs to be further investigated. People from different departments at DE are invited in order to give input from their perspective. DEPB is the group preparing the VB. They create the assembly sequence with 3D parts and make it, if possible, in accordance with the current sequence at line.

- *Development test assembly performed* – After identifying critical assembly activities involving new concepts and parts in the VB, they are test assembled with physical prototypes. The test assembly is performed at the development line with a mock-up. An analysis of how the additional parts differ from today's parts with regard to ergonomics, time, sequence and access for tools is carried out. DEPB is the group responsible for the test assembly activity but other groups affected are also participating.

- *Risk analysis development test* – DEPB is performing a risk analysis concerning the product tested. It shows what kind of risks the tested product can cause and the consequences it can entail. This can for example be whether there is a risk for assembling the wrong article. This risk analysis is then communicated with a project leader at a risk analysis meeting.

- *Product demand from development test assembly* – DEPB's requirements and preferences on product changes are communicated and agreed with respective design engineer. An investment judgement is carried out and communicated with a project leader. Furthermore DEPB are responsible for identifying the need for changes in the test cell, where the engine is tested, and whether the new product will affect the painting area or other departments concerning the engine besides from the line area.

- *LTA on all FRAS from development test assembly* – This milestone includes doing a follow-up if deviations from earlier milestones have been handled and that a time for introduction exists. A long-term action plan is developed and agreed.

4.4.1.1.3 Process Verification and Market Prepare

This phase consists of 12 milestones. At this point all preparatory work has been made in order to get a final result of the engine. The work at DEPB is now mainly consisting of preparing the handover of the engine to the local organisation DET and to get it ready for Start of Production (SOP). This process starts with a handover of the assembly sequence of the engine and continues by controlling previously identified risks. If deviations are found after this point, they are also being handed over to the local organisation. This phase ends with Start of Customer Order Production (SOCOP). This means that the first engine intended for the customer is produced on the D12 or D16 line (Scania CV AB, 2016).

4.4.2 **Digital work**

Digital work refers to work that is done digitally by computer-based programs and digital tools. At DEPB it mainly concerns working in programs called CATIA V5 and DELMIA V5, these will be further explained later on. DEPB is most often starting working digitally as early as in the yellow arrow of the project. In order for them to do this the model has to be designed and available in the 3D environment. The models are sent to them by the design engineers at R&D when the design is completed. DEPB are then reviewing the engine and the new articles briefly in the CAD. However, this is an early stage of the product development, which means articles and concepts are still changing and being re-designed. Since it is not certain that a yellow project will go further and into a green project, the review is superficial at this stage.

When it has been determined that a project is going into the green arrow the thorough work begins. At this point DEPB should have access to the CAD-model including all parts of the engine. Through interviews with the employees of DEPB it appeared that this is not always the case. In some projects the 3D models are not finished at this point which leads to DEPB not having a chance getting to know the new articles and giving their input to the design engineers in time for the next generation. It also appeared that the employees at DEPB are working a little differently with the digital basis that they have access to. Since the employees have different backgrounds they possess various knowledge and therefore work differently in some aspects. With different habits and earlier experiences, some prefer digital work and some physical. But altogether, when examining the engine and articles in the 3D CAD they are looking into:

- The overall engine environment
- Different views of articles to visualise them
- How articles are placed
- 2D drawings to get e.g. measures and tolerances
- Interfaces
- Access with hands, tools etc.

When they are acquainted with the new parts of the engine, DEPB are responsible for putting together the new assembly sequence for the engine. The sequence with the new parts is based on an existing engine that is most similar to the new one, called a reference engine. Independently of how many new parts there are in relation to the reference engine, a new sequence needs to be built up. The sequence is then a foundation for the VB meeting.

4.4.2.1 Virtual Build

The purpose with virtual build at Scania is to save time and cost and to enable for deviations to be solved in time. It should also enable for production equipment to be ready for the scheduled SOP. The virtual build takes place as a meeting where different departments at DE, and in some cases the design engineers from R&D, are participating. The meeting is carried out by the representative from DEPB showing the engine and all new articles in DELMIA V5. It is taking place once in every generation of the project, meaning it should occur three times in one project. All personnel involved are giving their input from their point of view. This could be thoughts, possible risks or how the assembly is managed in the best way. The meeting is composed in such a way that all concerned stations, testing area, in- and out lane and painting area are examined in order. When showing the new parts and the assembly sequence, only the new articles of the engine are demonstrated and not tools, manikins or the surrounding of the engine at line. The virtual build is prepared by DEPB far in advance before the VB-meeting. The primary task and the most time consuming one is to build up an assembly sequence in the most optimal way with all new parts involved. They are also investigating the tool accessibility, ergonomic issues, need for a lifting device, weight of the article, interfaces etc. The most optimal and desirable scenario is that all parts of the engine are created and complete in the 3D environment by the design engineers before the VB. This is not the reality in many cases, some parts are still under development and therefore not available in the 3D for the first VB.

Points that are raised during the meeting are noted in order for them to be further investigated later on. Some of them may be checked digitally by the DEPB group, but most common is to investigate them further when physical prototypes have arrived so they can be test assembled. For the next VB meeting all new parts should have been test assembled physically, and if needed, re-constructed in 3D to fulfil all criteria they need to comply with. When the next meeting is taking place, the engine should be updated with new designs that have been created. The project group is then again going through all new articles and giving input on the new solutions. Figure 4.6 demonstrates an engine in DELMIA V5 and the sequence line on the left with all the different areas.

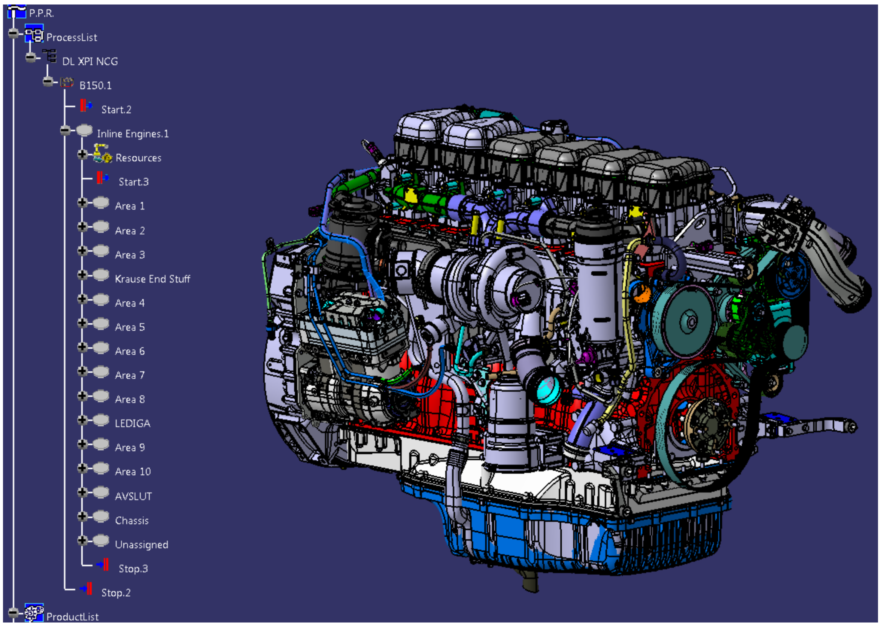


Figure 4.6 Example of an engine being examined in DELMIA.

The process of making VB is quite new and still under development. The process is therefore not totally standardized and not all employees at DEPB are doing it. A common perception within the group is also that the activity of performing an assembly sequence and a VB meeting happens very rarely. Sometimes as infrequently as once a year. This results in a lot of time spent on just getting acquainted with the program and the process of building up the sequence. DELMIA V5 is perceived not to be that user friendly, and instead of making the job facilitated it compels the employees to do some double work. When building up a new sequence, they are not able to take the reference engine and replace old parts by the new and getting a new sequence. They need to build up the sequence from scratch, even though many parts of the engines are the same.

4.4.2.2 CATIA V5

CATIA is a leading engineering and designing software for 3D computer aided design provided by dassault systems. It enables to design, simulate, analyse and manufacture products from several industries. It also provides the possibility to design articles with respect to its function (3ds.com, 2017). This CAD software is used through the whole organisation of Scania. DEPB is using CATIA after the design engineers have designed the articles. They are then able to get acquainted with the articles and giving the designers input from the production and assembly perspective. DEPB themselves are not designing anything in CATIA but they are using it to verify and examine articles.

4.4.2.3 DELMIA V5

DELMIA is a platform which enables companies of a new way of thinking about construction, operation and planning to achieve great manufacturing and is also provided by dassault systems. DELMIA offers work in different types of areas such as digital manufacturing, operations management and planning the delivery chain. It also allows the user to do the design and the testing of a product in a simulated environment (3ds.com, 2017). DEPB is using DELMIA when the 3D model has been imported from the CAD file. Usually the entire engine is imported after the articles have been examined in CATIA. The main are of use and working task for DEPB in DELMIA is to create assembly sequences for the entire engines. The VB meeting held by DEPB is also conducted in DELMIA.

4.4.3 **Physical work**

Physical work at DEPB refers to the work when prototypes of engine articles are being tested on a physical mock-up. Prototypes can be constructed in the actual intended material or in 3D-printed plastic material. The physical work at DEPB starts during the development phase in the first generation. This is when the first physical test assembly is performed, which is a milestone in the development generation. In order to obtain a detailed picture of the test assembly activity, both observations of the test assembly and interviews with the employees at DEPB were held. A protocol created for the observations can be seen in appendix D and the interview questions can be seen, as mentioned earlier, in appendix B. A comprehensive explanation of the test assembly activity is described in the following chapter.

4.4.3.1 Test assemblies

The test assembly process is performed by DEPB according to a document describing the preparation, the conducting and the follow-up of the test assembly. They are responsible for inviting concerned employees within different departments to the test assembly activity. The preparation included for DEPB is also making sure the article to be mounted have been ordered and in place at the development line for the test assembly. The average lead time for a physical prototype to be delivered is 8-20 weeks depending on the type of article and the manufacturing method. If assembly drawings or product drawings exist, DEPB are responsible for bringing them to the test assembly.

The conducting of the test assembly takes place at the development line and all the affected departments invited are participating. The workers at the development line are responsible for preparing the mock-up and also transacting the test assembly. The test assembly is carried out according to a global test assembly checklist. It includes several tasks that need to be investigated in order for the test assembly to be accomplished. The tasks are executed in order and everyone attending the test assembly is engaged. The different tasks included in the checklist are listed in the figure below. They are rated with either a yes, no or not applicable. The checklist for the test assembly is based on Scania's own established DFA criteria.

Check List for Test Assembly				
		Yes	No	N/A
1.	Is it possible to assemble according to master sequence?			
2.	Is the assembly time for the new part reduced or at least the same as the reference part?			
3.	Is the new part designed so that the number of variants are not increased?			
4.	Is the accessibility with green tools according to the tool rating document verified?			
5.	Is the assembly green according to SES design?			
6.	Can the assembly be performed with the surrounding parts positioned in their outer positions?			
7.	Is the assembly designed so that:			
	a. no individual adjustment is needed?			
	b. it can't be assembled incorrectly? (Poka-Yoke)			
	c. the part is held in place when it is positioned?			
	d. none of the assembly is done hidden from view?			
	e. chafing between parts is avoided?			
8.	If there is a demand for masking of the part, has a test of the masking been performed?			
9.	Has the interfaces between engine and adapters for preparation lines, engine test, paint shop, repair shop and audit been checked and adapters test assembled?			
10.	Is the clearance between the new part and the assembly line, preparation lines, engine test, paint shop, repair shop, audit and/or logistic areas checked and verified?			
11.	Test assembly approved?			

Figure 4.7 Checklist used in physical test assemblies.

Everything from the test assembly is documented by DEPB. If the test is not approved due to the number of issues discovered in the test assembly it is documented and communicated to the affected departments in order for them to solve the problem. A follow-up test assembly shall be held with the aim to verify that the deviations found are resolved.

4.4.4 **Ergonomics**

It is important for Scania to have healthy and satisfied employees. Products are therefore tested and re-designed in order for the employees working at the assembly lines to have the best possible ergonomic situation while working. Due to this, Scania has developed own standards for ergonomics that should always be followed. There are several standards aimed for different departments at Scania and for different purposes. The one that will be further explained is the Scania ergonomic standard for design.

A part of the work assignments at the group of DEPB is to investigate how an article of the engine is assembled with respect to the ergonomic factor. This aspect is being taken into consideration in both digital and physical test assemblies. But according to the employees at DEPB it can currently be hard to see all factors digitally. It is possible to get measures and an estimated weight of an article, but this does just give a direction of the real situation. It is important to feel the article in order to get a trustworthy visualisation of the article. A common perception is also that it is hard to see accessibility with hands and arms digitally since there are no human operators with real body parts in the programs. Therefore, the ergonomic evaluation is most often made physically at the engine assembly department.

4.4.4.1 Scania Ergonomic Standard Design

The Scania Ergonomic Standard for Design (SES-Design) has the purpose to produce products that are ergonomic and easy to assemble. This is done early in the product development (yellow arrow) so that different solutions can be compared. The standard is divided into two parts, where R&D is doing the first part and the global product engineers the other. The work of DEPB involves evaluating the conditions of the operators assembling parts. The evaluations can be done at test assemblies and experiences from existing assemblies can also contribute to the evaluation.

When the evaluation is made at R&D, different ergonomic factors are being assessed at DEPB. These includes working position, angle of the neck and the back, position of arms and hands, working height, accessibility etc. The template for the tasks included in the SES evaluation can be seen in appendix E. The physical SES evaluation is made at the development line where an operator is assembling the article. The observer from DEPB is following a SES checklist and making notes regarding each ergonomic factor. Ergonomic experts are included in the evaluations when needed to support and give extra input. According to different parameters the evaluation of each ergonomic situation is noted as green, yellow or red. The picture below shows an example of one position that is evaluated. All evaluations combined are then resulting in a final score that indicates how ergonomic the assembly is. If the final score for the assembly is red, a re-design of the article or the tool is needed.

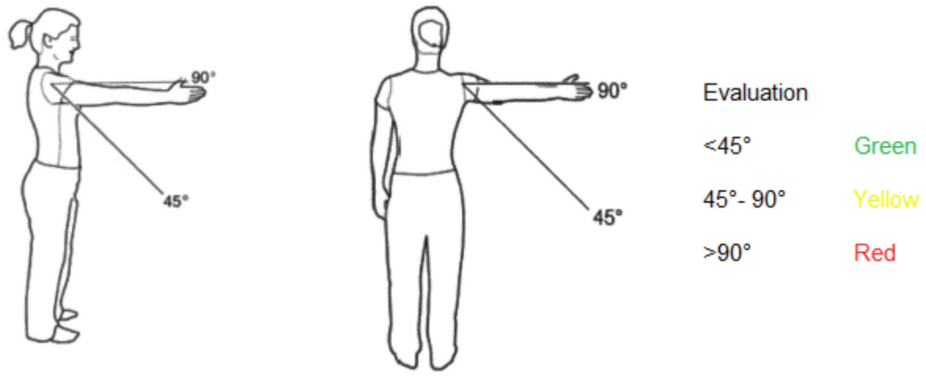


Figure 4.8 Example of evaluation of ergonomics.

4.5 Digital work at other departments

4.5.1 **Digital test assembly at chassis**

The chassis production at Scania has come a bit further with digital test assemblies, why a visit was planned and carried out. The chassis production is the end assembly of the entire truck. This is where the engine, gearbox, cab, shaft etc. are sent and assembled into the final truck produced to customer.

A meeting with a digital test leader at chassis was conducted. The test leader is working in a group called Global Preparation and Development of Final Assembly, MPP, and has great knowledge within the area of digital environment and assembly. Through the meeting it was clear that the working process considering test assemblies at the chassis is fairly similar to the one at the engine assembly. The same computer programs are used, but chassis are using them in a wider extent.

The working process at chassis is beginning with a virtual build, which is carried out in a similar way as in the engine assembly. The assembly sequence has been established, and the intention with the meeting is to find need for digital test assemblies (DTA). When these have been identified it is the test leader's responsibility to manage the DTA's of involved parts. The DTA is carried out in DELMIA V5, where two types of simulations are made: assembly simulations and ergonomics simulations. The assembly simulation is managed by testing the mountability of articles according to the line sequence. Analyses involving lifting tools access, hand tool access, assembly sequence and cable and pipes simulations are also conducted. The cable and pipe simulations are difficult to evaluate digitally, therefore there is still a need for testing this type of articles physically. The DTA is performed according to the DFA checklist at Scania. The ergonomic simulation is analysing the ergonomics of an assembly worker. This includes reachability, posture analyses, visibility and grip study. In DELMIA V5 digital manikins are applied in relation to the article being assembled to visualise body positions. The manikins are only showing a static motion and can therefore not show dynamic motions or the impact on the body. The evaluation is made by reviewing the picture and draw conclusions by own estimation with accordance to SES. The picture below demonstrates an example of how manikins are used to visualise the reachability and posture.

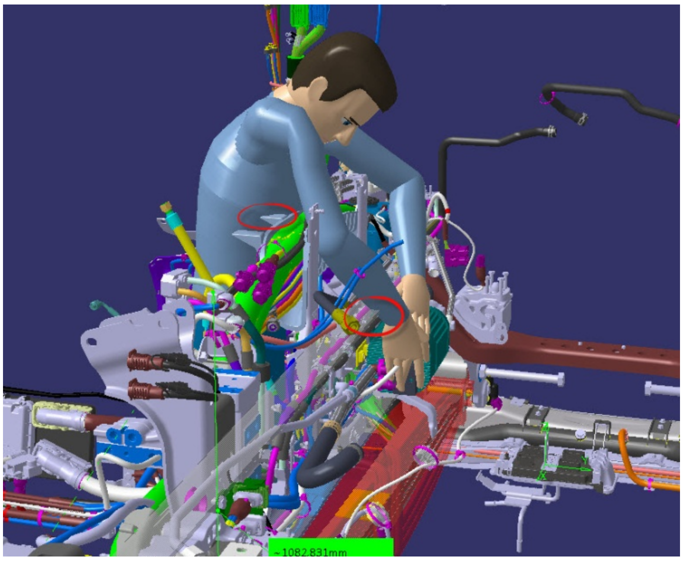


Figure 4.9 Example of manikin mounting statically.

The process is proceeding with a new virtual build where the deviations from the first virtual build are verified. After this, new DTA's are made if needed. The process is looped until no further deviations are identified. The process is then continued by testing and verifying the assembly physically. The physical test assembly is only made once as a final verification for both assembly and SES evaluation.

4.5.2 **MBD at Research and Development**

To get relevant information about the work with MBD at Scania a person currently working with it was interviewed. The interviewee is working at the R&D department as a senior technical advisor in a group that is working with organisational development. A lot of the work at the moment involves geometric and technical simulations.

According to Scania, MBD is a model of the reality which includes all information about an article or a model that is needed in their processes. It should only be one model carrying all information through the whole organisation. The description should be visualised as the reality and not only nominally as the CAD models are today. The model should also include all information that is shown on 2D drawings, such as requirement setting, tolerances and torque. All information is stored in a database and is machine-readable. MBD is a foundation to a more automated approach and a better way of utilizing the technique.

The work with MBD at Scania has been under development for a few years. Preparatory work has been made and is still in process. Suppliers of the system solution for MBD are evaluated in order to achieve the best possible to fit the company's purposes. There is still no strict plan for how or when it will be introduced, but widely speaking, it should be implemented sometime around year 2020 – 2025. An idea is to start a pilot of the concept within a process at Scania that is fully internal and is not including external suppliers. Even though the whole MBD concept will not be implemented in a couple of years, it will still be possible to use the 3D models containing all information which could automatically produce a 2D drawing.

4.5.3 IPS at Scania

There is a group at Scania constantly working with developing the digital environment in a production point of view at the company, called the DTA-forum. The group is represented by a couple of employees from engine, chassis, service, gearbox, shaft and cab all giving their input to the development and keeping their departments informed about the work. The group is currently working with a newly introduced software called Industrial Path Solutions (IPS). The software itself is relatively new to the market but also new to Scania since it has been under development for about one year. IPS is a software for analysing and simulating articles and assemblies. It is supposed to be a complement to the two programs currently used, DELMIA and CATIA, since they do not have the same ability for analyses. This is also the reason for why the software has started to be introduced at Scania. There is a need for analysing soft material and ergonomics which cannot be managed in the current software, but IPS provides these possibilities. A big advantage for Scania working with IPS at this early stage is that they have the possibility to give their input to the developers of the program. This means they can affect the functions and possibilities for it to be designed in specific manners.

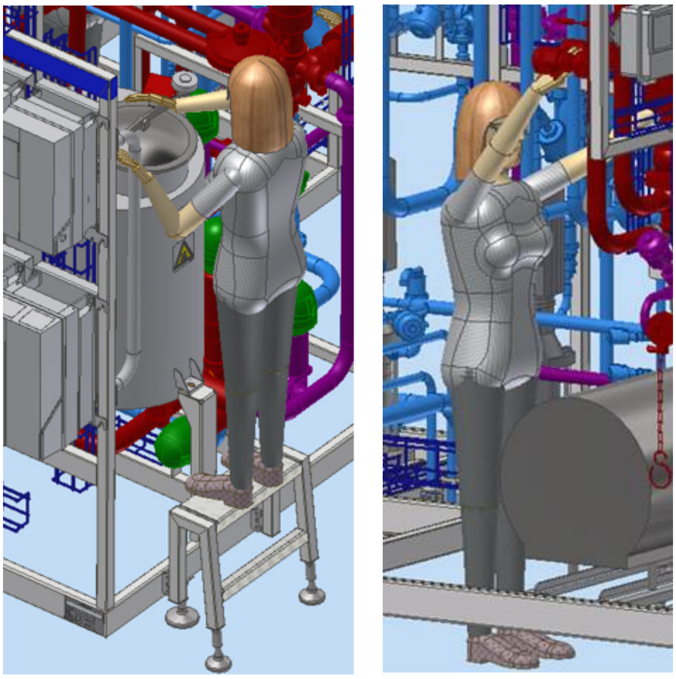
The DTA-forum group held a case-meeting where the current stage of IPS at Scania was presented. The purpose with the meeting was to compare the behavior of cables, including forces and measurement, physically and digitally managed in IPS. The aim was to show that the digital environment could imitate the physical. The cases presented showed that forces and measurement were very close to the actual situation, but behavior of the soft material was not entirely presenting the real situation. A reason for this could be that not the exact material properties of all parts of the cable were included in IPS. There are also several ways of connecting parts and material in the software which requires good knowledge within it. The personnel at the DTA-forum are still learning and getting to know the software. However it was stated that there are great possibilities with IPS and that it should start to be implemented within the company.

4.6 Benchmarking at other companies

4.6.1 **Tetra Pak, Lund**

Tetra Pak is a company designing machines for food packaging. Except from offering packaging equipment for liquid foods, they also cater their customers with solutions for processing, packaging and distribution. A meeting at Tetra Pak in Lund was held to get an insight of their digital working approach. The meeting was held at the part of the company called processing, which produces processing equipment.

The processing part of Tetra Pak is working totally paperless. This means most of the information is communicated digitally in both production and at the offices. They are using lightweight files when examining the 3D models making it easy to handle and manoeuvre. Configurable manikins are also used to evaluate space, reach, height and visibility at the machine, an example of this can be seen in figure 4.10. The production is also equipped with screens where the operators can see articles and machines fully in 3D. However, drawings are still produced since all information given on traditional 2D drawings is not available in the 3D model, for example tolerances and audit material. Another obstacle is the legal aspect since contracts with suppliers normally are written through the drawings.



4.10 Manikins managing the machine, demonstrating space, height, reach and visibility.

Tetra Pak are using a regular CAD program, inventor, for their models, except from when designing and constructing pipes. A new program was developed within the company since the CAD program did not live up to the standards needed for their pipes. The new program enables experiments with measures and having total control of the pipes.

5 Analysis and result

In this chapter the analysis and result are presented. A gap analysis has been carried out investigating the current state of physical and digital work. The gap constitutes of deficient areas existing in the digital environment. Possible solutions and prerequisites for the identified gap and impacts of a more digitalized working method are presented. The result is analysed with the literature study, the empirical data obtained from Scania and external companies in mind.

5.1 Gap analysis

5.1.1 **Analysing the current state of physical and digital work**

In order to analyse the current situation at DEPB, regarding physical and digital work, a deep investigation and comparison has been done. The investigation is founded on the present circumstances and the opportunities available for DEPB to perform the work. The evaluation is therefore only reflecting the possibilities at DEPB and not possibilities in general. The analysis is based on the DFA checklist that is a foundation for the list used when test assemblies are performed. Each task that is included in the checklist has been further evaluated from both a physical and digital perspective. The evaluation has mainly been carried out through observations, but also from information given on interviews and meetings. Each task has been assessed and thereafter given one of the three judgments; possible, possible but not optimal, or not possible. Possible indicates that the task can be managed. Possible but not optimal means that the task can be performed, but it is not the best way and has opportunities for improvement. Not possible means that it cannot be carried out. The judgments are shown as colors of green (possible), possible but not optimal (yellow) and red (not possible). The entire DFA table with tasks and judgments can be seen in appendix F.

The table below consists of all tasks that have been judged as either possible but not optimal, or not possible from both a digital and a physical point of view.

Table 5.1 Evaluated DFA checklist of the activities that is difficult to perform digital or physical.

Task	Physical	Digital
Is the article constructed in a way that no sharp edges exist?		
Are the tolerances of the article set so that no problems occur when placing the article?		
Are the covers constructed so that there is no risk for the article to be mounted with the cover still attached?		
Is the article mounted without rotation?		
Can the article be mounted with existing tools and fixtures?		
Is the article constructed so that the assembly time is better or the same as the previous construction?		
Is the article constructed so that it stays in position when placed?		
Does the article have self-positioning characteristics when assembled?		
If the article needs to be masked, is there access to do it manually?		
Is the article constructed so that it can be assembled within the cycle time?		
Is the O-ring in the correct size?		
Is the O-ring still in place when the article is turned or pushed?		
Is the O-ring avoiding sharp edges when assembled?		
Does the pipe/hose/cable touch any other parts?		
Is there space for hands when connecting the engine in the engine test?		
Is it constructed so that the total connecting time in the engine test is not increasing?		
Can a SES evaluation be performed?		

These tasks have been summarized into deficient areas since some of them are covering similar issues. Information obtained from interviews and observations that are not included in the tasks above are also added as deficient areas. The areas that have been compiled are established below.

- Sharp edges
- Tolerances
- Force measurements
- Material behavior
- Incomplete range of 3D tools
- Time calculation
- Positioning of article
- Accessibility
- Soft material
- O-ring
- SES
- Documentation

The deficient areas occurring in both physical work and digital work will be further explained under the following paragraphs. This to enlighten the areas that have deficiencies in both working methods. A deeper analysis of the advantages and disadvantages with each working method will also be included.

5.1.2 **Physical work**

5.1.2.1 Deficient areas

5.1.2.1.1 Sharp edges

Sharp edges are easy to evaluate physically at a test assembly. However the outcome from manufacturing of prototypes can differ. Physical prototypes made in a non-serial tool can have sharp edges, which does not exist when made in a serial tool. The articles are only made in a serial tool in the last generation, thereby a fair evaluation of the edges can only be obtained at the end of a project.

5.1.2.1.2 Tolerances

Measuring and testing tolerances is one of few areas where deficiencies occur in the physical work when test assembling. When physical test assemblies are managed, a single article is ordered and tested when arrived. If the article is possible to mount, no measurement of tolerances is made. The only situation in which tolerances are measured is when the article cannot be assembled. Thereby, an article with different tolerances are usually not tested. Nor is it tested with tolerances set at its maximum positions.

5.1.2.1.3 Force measurement

A dynamometer is used when there is a need for knowing the force arising when assembling an article, this is needed for instance when a SES evaluation is made. However, the measurement of the force is arbitrary. When there is no possibility of measuring the force directly on the article, an appraisal of the force required for mounting is applied on to the dynamometer to get an estimation of the force. The meter is sensitive and it is hard to get a correct measurement out of an appraisal. An estimation of the contact surface between the hand/finger and the article is also estimated and this is a factor affecting the force highly.

5.1.2.1.4 SES

When a SES evaluation is performed not all different body shapes are tested. The evaluation is carried out by one person assembling the article and the result is mainly based on this person. As mentioned earlier, there are several parameters included in the SES that needs to be fulfilled in order for the SES to be approved. An approved evaluation may therefore not reflect all body types.

5.1.2.1.5 Advantages and disadvantages

There are several advantages and disadvantages with physical test assemblies. One of the advantages with the activity is the presence of all concerned departments that can give valuable input from their point of view. When a physical test assembly is held the departments are gathered and can discuss possible improvements. This meeting can however be very time consuming since the test assembly is performed in detail and everyone involved has to be there. Another advantage with physical work is the ability to get a feeling of the size and weight of the article in reality. Even though both weight and size can be seen in the 3D environment, it is difficult to get an idea of how it feels when assembling the article. For example it can be hard to grab, or ungainly because of the size etc. Furthermore, the physical working process is standardized and the milestones established are applicable for the physical test assemblies.

There are also some disadvantages with physical work. To begin with, the lead time for ordering and receiving a physical prototype is relatively long. A long lead time entails longer time to market, which is a competitive disadvantage, and increased costs for late changes. Moreover, due to the long lead time it is also difficult to judge investment costs for the project, for example if lifting tools will be needed. A prototype that is 3D printed has a shorter lead time than a prototype made out of the intended material. However, a 3D printed prototype does not reflect the actual article since it is not manufactured in the same way and does not have the correct material properties. Another disadvantage is the cost of physical prototypes. Prototypes can never be sold to customer, they are only used for development purpose.

5.1.3 **Digital work**

5.1.3.1 Deficient areas

5.1.3.1.1 Sharp edges

Sharp edges can be seen in the 3D environment but only to a limited extent. Articles and models can be examined and evaluated through the digital material, but it cannot give an entirely reality-based perception. However, as a complement for the 3D model there is a 2D drawing. If there are sharp edges on the article there is a requirement for marking them as broken edges. Broken edges is an ISO standard ensuring smoothening of the sharp edges. This information can also be seen digitally and give indications of the edges. Despite the information available in the digital environment, manufacturing of the article has a great impact of the actual outcome.

5.1.3.1.2 Tolerances

3D models are nominal and are not showing any tolerances. Articles can therefore not be tested and evaluated in their outer tolerance positions. Thus, this gives an optimal situation of the assembly and shows no indication of being feasible with some adjustments in dimension. Information about tolerances can however be seen in the 2D drawing.

5.1.3.1.3 Force measurement

Force measurements cannot be carried out in the 3D environment. The program has no features that can perform the measurement of forces that arises when assembling articles. Since the forces are also dependent of the human interaction when mounting, manikins based on the real situation would be needed in order for the right force to be possible to measure.

5.1.3.1.4 Material behavior

During the assembly, material properties can affect the mounting of articles. No friction can result in unwanted and unexpected motions of the article when, for example, tightening screws. There is no ability to see properties or behavior such as this digitally.

5.1.3.1.5 Incomplete range of 3D tools

To test if articles can be mounted with existing tools and fixtures all these need to be complete in 3D. A problem is that they are often not created and available in the 3D environment. But if they are, there is a possibility to see the assembly with the intended tool and fixture to see if it is feasible to mount. The evaluation can however only be managed static and not dynamic with movements.

5.1.3.1.6 Time calculation

It is possible to simulate the most optimal mounting path for one article in the program. However, this takes a lot of time for the program to analyse. Also it cannot calculate the actual time for the mounting path since the surrounding environment and working process are not visualised as in reality.

5.1.3.1.7 Positioning of article

The program cannot evaluate if the article have self-positioning characteristics when assembled. Moreover it cannot see if the article stays in position when placed without support from hands or tools. However, a brief analysis can be made by reviewing the surrounding of the article to get indications of the positioning. For example an evaluation can be made if there are guide pins or if the article is mounted on a horizontal surface and cannot fall down.

5.1.3.1.8 Accessibility

The digital environment enables an overall view of all the articles. This includes measures, sweep volumes etc. that can give indications of the accessibility when assembling. However, to get a realistic view of the situation manikins and tools need to be used within the 3D environment. Even though all measurements are available it can be difficult to examine if, for example, a hand or arm would fit and be able to assembly the given article, which a manikin would enable. Manikins are currently not used and fully developed within the digital environment.

5.1.3.1.9 Soft material

Soft materials in this scenario refer to articles such as cables and hoses. They are behaving as hard, non-flexible material in the current digital environment. It is therefore not possible to make a reality-based analysis of how they will behave when assembled. For example, it cannot be seen if they will collide with other parts or if tension will occur within the soft material.

5.1.3.1.10 O-ring

O-rings are critical when it comes to analysing their behavior digitally. They are made out of rubber material and used as sealing. When assembled they are exposed to a lot of pressure which leads to tensions in the rubber. Since force loads cannot be carried out it is not possible to determine how the O-ring will behave when exposed to pressure. The O-rings are also often lubricated which makes it even harder to evaluate digitally. It is therefore difficult to determine if an O-ring is the right size or if it will remain in the correct position when it has been assembled. There is no possibility to check this in the 3D environment.

5.1.3.1.11 SES

In order for a SES evaluation to be conducted, a human must perform the assembly. Since there are no digital manikins who can perform this task, the evaluation is impossible to carry out in a corresponding manner to the physical SES assessment.

5.1.3.1.12 Documentation

The documentation of an article is available in different places since drawings and 3D models are not compiled into one document. This implies a risk for not having all documentation updated to the latest version, the 3D model could be updated without the drawing being updated.

5.1.3.1.13 Advantages and disadvantages

One of the greatest advantages with working with a more digital approach is the opportunity to early in the product development process influence the design. The 3D models would be evaluated and more complete earlier on. Several iterations of evaluations and re-designs could also be managed in a shorter time of period. Putting much effort in the early stages of the development process could also result in all big problems being eliminated and only focusing on details at the end of the project. That would lead to better products that have been properly processed and therefore better quality. Doing work digitally could also enable to do investment appraisal earlier. Information regarding all relevant tools needed, how the line would need to be adjusted to the engine etc. would be discovered early and not at the end of the project.

Another advantage with working with a more digital approach is the time aspect. Doing test assemblies in detail in the 3D environment instead of performing them physically can save a lot of time. As mentioned before, the lead time for getting physical prototypes to a test assembly is very long. If the same outcome from the physical test assembly can be achieved from the digital, it could shorten the time of the product development process. Since time is money, it can also reduce total costs for the company. By not making any physical prototypes, further costs will be reduced since the only work tool needed is the software with 3D models. Another aspect resulting in saving time is that the need for calling for physical test assemblies is not required. The person doing the assembly can sit by the computer and perform it by itself. It is also beneficial working digitally because of the late changes that can be made. Since there are no prototypes that need to be ordered, the model can be changed and test assembled whenever needed.

However, there are also some disadvantages with digital test assemblies. When the test assembly is performed and evaluated by only one person, there is no other giving their input, which can be very valuable. Another disadvantage is that the programs CATIA and DELMIA are not that user friendly. They can be hard to operate since they are not customized for the work being done by DEPB. Since the test assemblies are primarily managed physically there are no clear milestones or working process for performing digital test assemblies.

5.1.4 **Identified gap**

After investigating the deficient areas, advantages and disadvantages with the current physical and digital working methods a gap has been established. A list of what cannot be evaluated digitally today and constitutes the gap follows below:

- Sharp edges cannot be analysed digitally. The programs are not providing an entirely reality-based perception of the sharp edges on an article or model.
- The 3D environment is not showing tolerances. Articles are not tested and evaluated in their outer positions.
- Force measurements are not possible to perform.
- Material and assembly behavior cannot be visualised correctly.
- All tools needed for each article are currently not available in 3D and therefore it is not possible to evaluate tool demand and accessibility.
- Time calculation for assemblies is not possible to follow through. The surrounding environment and needed tools cannot be simulated based on the real assembly process.
- Positioning of articles is difficult to evaluate and simulate.
- Accessibility for narrow space with tools, hands and arms cannot completely be visualized.
- The program cannot simulate soft material behavior.
- Behavior of O-rings cannot be evaluated or simulated in the digital environment.
- Dynamic evaluation with digital manikins is not possible to perform in order to conduct a SES.
- All information regarding the article is not gathered and available in one document that is always the latest version.

For a digital test assembly to be fully executed and to obtain the same, or better outcome than a physical test assembly the above identified gap need to be eliminated. Since the mentioned deficiencies in the list addresses various kinds of problems, two potential development areas have been established. These are presented in the following chapter. Each area consists of a proposal to a solution that could be a first step to a more digital working approach.

5.2 Solutions for the identified gap

5.2.1 **The digital environment**

For the gap to be non-existent a lot of improvements in the digital environment have to be put through. The environment overall must be more reality based and reflect the actual situation of the engine and the assembly. The meaning with reality based in this situation refers to the environment to be as the real one. Material properties should be included giving the right weight and behavior, all articles and tools involved need to be available and manikins who can perform assemblies should also be used. Furthermore, forces and tensions also need to be obtained in the program.

Scania is already, as mentioned in chapter 4.5.3, looking at the software IPS as a simulation program. They have taken a decision that this software will be implemented in a bigger scale. Since Scania wants to minimize the number of software used and not implement several new ones, no other programs will be investigated. A potential future opportunity for IPS might even be to replace the current programs. Scania also have the opportunity to affect IPS with further development. Due to these facts, IPS is the software that will be further investigated of what opportunities it has to solve parts of the gap.

5.2.1.1 IPS

Some of the features needed for the digital environment to improve can be solved by the program IPS, which was also mentioned at the visit at chassis. It is a software tool based on math used for verification of assembly feasibility, design of flexible components and motion planning among others. The software has several functions covering different areas of the product development. All the functions together could solve several of the features required mentioned in the identified gap. The functions available in IPS are presented below (Fcc.chalmers.se, 2017).

- Cable simulation – Can perform simulations of flexible structures. It is including material properties and can analyse forces and torque.
- Path planner – Provides simulations of collision free efficient paths for any part of the assembly.
- Robot optimization – Provides collision free and optimal paths for robot stations.
- Paint-spray – Performs simulations of the accurate spray painting. Allows great preparation to find-tune the robot paths and an overall optimization of the process.
- Paint-sealing – Allows simulations of sealing spray.
- IMMA – Intelligently moving manikin (IMMA) is still under development and is to be released in May 2017. The goal is to develop a path planning tool that enables collision free paths for both component and human's geometry and minimizing biomechanical load on the body.
- IBOflow – Enables simulations of objects in fluid flows including different types of multiphysics problems.

5.2.1.1.1 Impact on gap with IPS

- Soft material behaviour

One of the main features with IPS is the soft material simulation. The software is developed specifically to enable this, and it is therefore possible to analyse soft material behaviour. The software can show the actual movement of the cable or hose when it is bent in different positions. The pictures below are demonstrating examples of how the software is showing soft material.

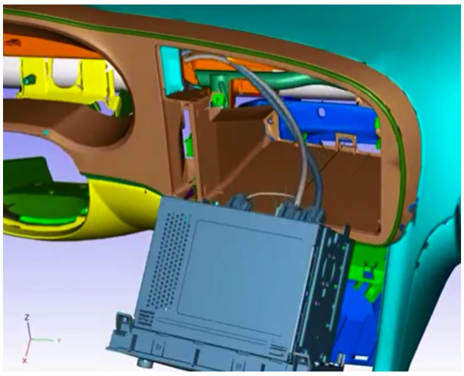


Figure 5.1 Soft material simulation (Industrialpathsolutions.se, 2017).

- Force measurement

Force measurements are also possible to manage in IPS. The software can show exactly how a part is behaving when assembled or moved and what forces are arising in the entire part. One of the cases at the IPS-meeting showed that the force measured physically corresponded very good with the digital measurement.

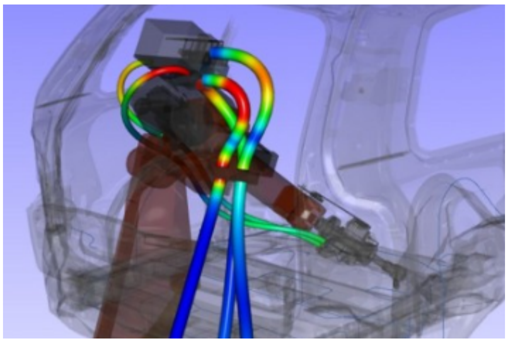


Figure 5.2 Force measurement (Industrialpathsolutions.se, 2017).

- SES

The release of IMMA will enable good simulation of moving manikins. The intelligently moving manikins will consider human diversity, minimize biomechanical load and enable collision free motions for the human when assembling. Different types of manikins can be used representing various body types. (Industrialpathsolutions.se, 2017). The left picture below shows an example of a manikin assembling and the right the different types of manikins that are available to use.

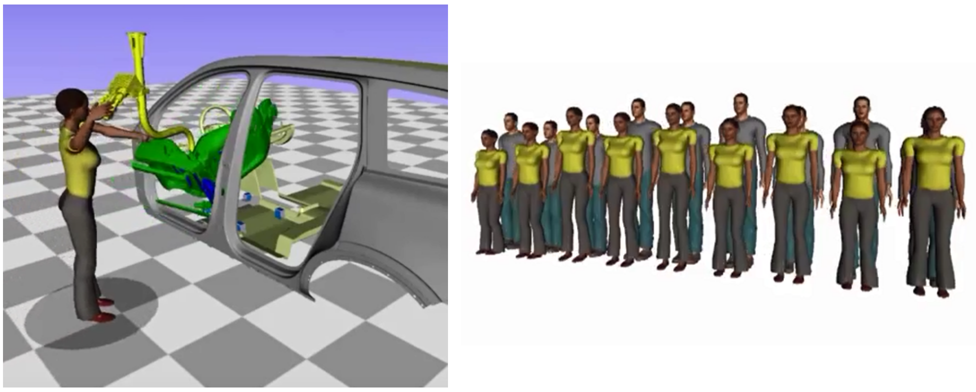


Figure 5.3 Manikin assembling and the variety of possible manikins to simulate (Industrialpathsolutions.se, 2017).

- Accessibility

IPS enables simulations of assemblies which means it can analyse the accessibility of parts when assembled. Since manikins can soon be used, it enables for both the manikin and the object to be analysed with respect to accessibility. The pictures below are showing that different types of grips that can be chosen for analysis and a manikin assembling in the most optimal and collision free mounting path.

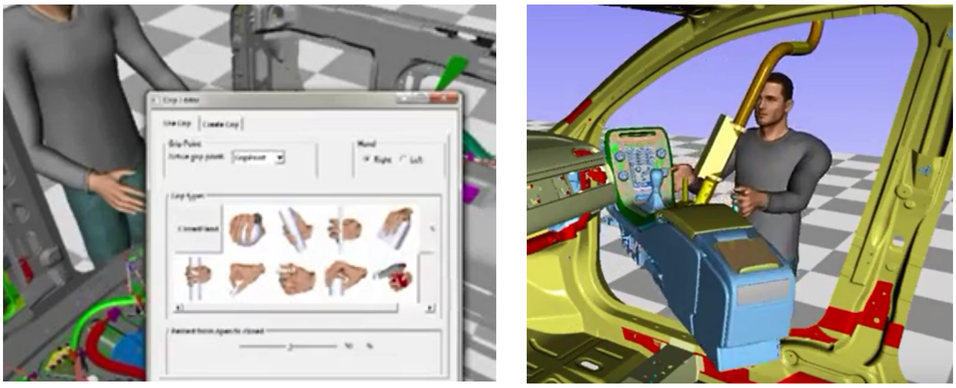


Figure 5.4 Manikin with different grips and manikin finding a collision free mounting path (Industrialpathsolutions.se, 2017).

5.2.1.2 Model Based Definition

Another solution for covering up parts of the gap is to implement the working method MBD. It is assumed to be a foundation for working with a more digital approach. Having all information regarding an article combined into one document primarily enables for early discovering of design intents, as can be seen in the literature study. Since all information is combined in one model, including tolerances, this is a basis for further evaluation and simulation of the article. By having only one document containing all information, all personnel involved are sure about always dealing with the updated document. There is no risk for managing an old version that has been updated in another document.

5.2.1.2.1 Impact on gap with MBD

- Tolerances

MBD enables the GD&T information to be included in the 3D model. Tolerances can be seen and tested in their maximum positions in the program. Hence, the article can be evaluated in an early stage if it is possible to assemble in outer tolerance positions (Quintana et al., 2010). This is one of the areas where deficiencies occur in physical test assemblies. Physical prototypes are, as mentioned above, usually not tested with different tolerances, meaning MBD would not only solve the gap but also enhance the working process overall.

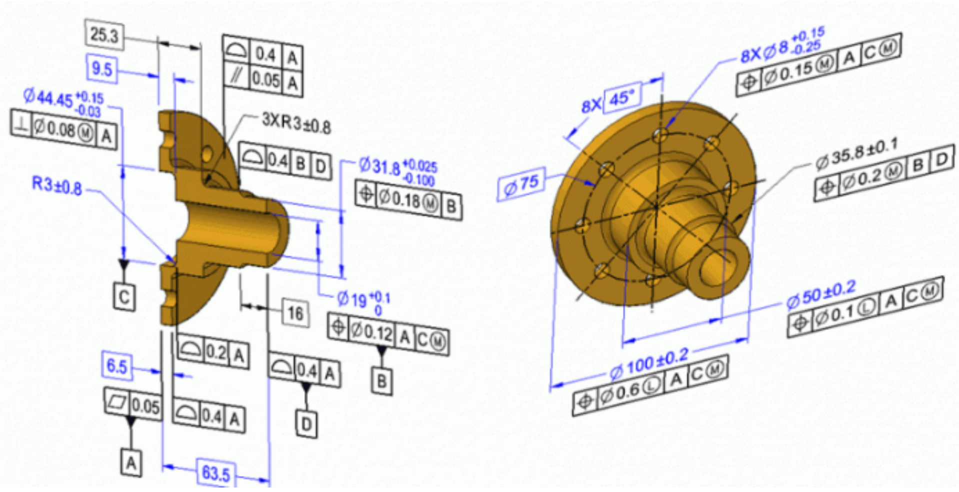


Figure 5.5 The tolerances are included in the 3D model (Crawforddm.com, 2017).

- Documentation

The documentation of an article will only be available in one place. With MBD all information needed regarding an article is gathered in the 3D model. This reduces the risk of conflict between 2D drawings and 3D models and not having the latest updated version (Olson, 2015).

5.2.2 **Further investigation**

Improvements of the digital environment by the above mentioned methods and functions could solve parts of the identified gap. However there are still some points that are not included in the solutions due to various reasons. These are in need for further investigation in order to be solved. The points will be presented and evaluated below.

- Sharp edges

Neither IPS or MBD will solve the problem regarding sharp edges. IPS may give a more realistic view of the article than the current programs used, but it will not provide a possibility of getting a feeling of the sharpness. If it were to be solved in the digital environment the articles would need to be realized as if they have been manufactured and processed. Either way, the physical evaluation of articles made in a serial tool is the best possible.

- Incomplete range of 3D tools

This is a matter that needs to be addressed within the engine department. All tools needed for assemblies needs to be provided. For assemblies to be simulated they have to be available.

- Positioning of articles

Since complete assembly simulations and can be made in IPS and material will be included, the positioning characteristics of articles should be possible to visualise. Self-positioning characteristics can reasonably be seen when a part is assembled and also if the article stays in place when assembled. This is however a hypothesis since it has not been proven or tested in any way.

- O – ring

IPS cannot solve all the problems related to an O-ring assembly. O-rings are made out of rubber, which is a soft material and can therefore be analysed in IPS. IPS can analyse the tension that will arise in the O-ring. However, if the O-ring will remain in the correct position when assembled or the need for lubrication cannot be evaluated in IPS.

- Material behavior

Material property data is possible to upload in IPS. The material properties that are included in IPS are stretching stiffness, stiffness for bending, torsion stiffness and length density (Fcc.chalmers.se, 2017). As with soft materials, non-flexible material can also be simulated. Although there are still movements of articles that can be difficult to evaluate in IPS, which has not yet been proven to be possible. For example if friction will occur when mounting articles and if they will rotate when tightened.

- Time calculation

IPS enables real time calculation of deformation of various types of material (Industrialpathsolutions.se, 2017). Another possibility is calculation of automated assemblies and optimizing the assembly time. Manual assembly calculations are currently not manageable, though it is under development to realize it.

5.3 Prerequisites for the identified gap

In order for the solutions to be possible to implement, the right prerequisites must be provided. The prerequisites presented are focused on the working process that is carried out and changes that need to be achieved within this area.

5.3.1 **Working process**

The current working process at DEPB is mainly designed and customized for a physical working method. The milestones that are established are not created and applicable for a more digital approach with digital test assemblies. In order to work more digitally the working process need to be changed. All concerned departments need to take part in the alteration. It is not enough that only DEPB implement the change. Since everyone is working towards the same goal the different departments must have the same working approach and understand the purpose of why they have this working method. DEPB is the first department concerned in the product development process when it comes to assembling the engine. However they are dependent on many other departments. If a more digital working process is accomplished DEPG must add the tools needed for assembling in the digital environment. An essential part is also that the design engineers have all the parts created and ready in the program before the project goes into the green development phase. Apart from just having all parts ready, the engine should also be examined at the design department before it is handed over to production. It could be very advantageous if the models were complete already in the yellow arrow for the production to start giving input to the design at this early stage. If the models are not complete and ready to work with in the beginning of the project it is difficult for DEPB to perform their working tasks properly. Another important aspect is the documentation of articles, it needs to be updated and always available for the personnel at the production.

Inspiration can be taken from Chassis where digital working methods are more established. Chassis have introduced a working process where they after a VB perform a digital test assembly, DTA, and not a physical. The purpose with the DTA is to find deviations on specific articles or environments by mounting these digital. After the DTA they carry out an additional VB until there is no deviations detected. They then go through with a physical test assembly as a final verification. A proposal is that the engine manufacturing department can implement something similar to this. Chassis do have different articles than the engine, however this should not be an obstacle since they are still investigating similar assembly problems. In order to change the working method, milestones in the development phase need to be updated. It has to be milestones for a digital working process. Since the decision recently was made to start implementing IPS, the working process needs to be customized for the adaption of using IPS.

5.4 Impacts of a more digitalized working method

5.4.1 **Impacts of eliminated gap**

Eliminating the gap and implementing the suggested solutions mentioned above will make impact on the company. If it would be carried out, there are big opportunities to gain profit. Since this thesis is focused on the product development process at the assembly department, the impacts presented is from a production point of view.

5.4.1.1 Ergonomics

Evaluating ergonomic factors when parts are assembled have great potential in the digital environment. The evaluation could be managed in a manner that is even better than the one used currently. A big advantage is due to simulations with manikins that can be done early in the development phase. This can give indications of articles not being ergonomic to assemble and has the possibility to be re-designed early on. It also allows for different types of article designs to be tested directly in order to measure the ergonomic impact of each design. Another great benefit with digital manikins is that several body types and shapes can be tested and evaluated by just switching the manikin. The evaluations would also be a lot more precise than the ones managed today. Forces occurring in the body and in the article could be carried out as well as access with different types of hands. This way the SES evaluation could give better, more applicable and general results.

5.4.1.2 Cost efficiency

There are several aspects showing that a more digitalized working method would imply cost savings, as also mentioned in the literature study. To begin with, the costs for physical prototypes will decrease since there is no need for prototypes when performing a digital test assembly. Furthermore, engineering changes will be easier to perform at an early stage. If a digital test assembly is performed it can identify assembly constraints, equipment selection, etc. which enables for investment assessments early in the project. The earlier a redesign is conducted, the less costly it will be.

Increasing digital work with digital test assemblies is also something that affects the quality of the product. The earlier an engineering change is found from a digital simulation, the better design can be achieved. If MBD is realized, tolerances will be included in the program. This will increase the quality and save costs since tolerances can be tested in their outer positions. This enables for discovering the possibility to assemble earlier. Tolerances are not tested in their outer positions today and if an article cannot be assembled in its outer position it will be discovered on the production line, resulting in high costs. MBD will enable this to be detected earlier in the product development process when performing a digital test assembly.

5.4.1.3 Lead times

The lead times for ordering and receiving physical prototypes is, as mentioned earlier, usually between 8-20 weeks. This time can however vary a lot depending on the article and the manufacturing method. Since articles are ordered once in every generation, in total three times during a project, a lot of time is consumed by lead times. A chart has been compiled showing the time saving that could be obtained by doing only digital test assemblies in the two first generations and ordering physical prototypes for verification in the last generation. The chart is showing times related to test assemblies for medium projects, therefore all assignments for a project are not included. Only activities affecting the test assembly are included since they are the ones influencing the potential time saving by reduced lead times. Time estimations have been made for medium projects, meaning the presented time saving is reflecting this type of project. A medium project entails 25-60 new articles and a few new types of assemblies. Since digital test assemblies are currently not fully performed, time estimations for the different tasks have been difficult to determine. An estimation has therefore been made that all activities carried out before, during and after the test assembly are approximately the same since the milestones involved are identical. The purpose with the chart is to visualise the time saving due to reduced lead times, therefore all activities in the development phase are not of interest in this case.

The presented reduced lead time is time that could be saved from a production point of view. All concerned departments would need to change their working methods in order for the deadlines within a project to be set earlier. R&D are currently doing performance tests on the engines in all generations and are therefore in need of physical prototypes. In order for the project to be shortened the R&D department would also need to work more simulation based without physical prototypes. This is something that is under development and a goal that

R&D are aiming for. Since the idea is to implement MBD in the future this will enable a more simulation based product development. With regard to this, the chart below has been compiled. It demonstrates the potential time saving that can be achieved if there is no need for physical prototypes in the first two generations. The time saving occurs when there is no need for ordering physical prototypes (1 week) or lead time for receiving articles (20 weeks). The lead time has been set to 20 weeks since the test assemblies are dependent on the article with the longest lead time. The chart shows two paths, the upper for digital test assemblies in two generations and the lower for physical test assemblies in all three generations. This situation enables a time saving of 42 weeks. Decreased lead times would imply a shorter product development process with reduced time to market. Introducing new products to the market earlier gives a major competitive advantage.

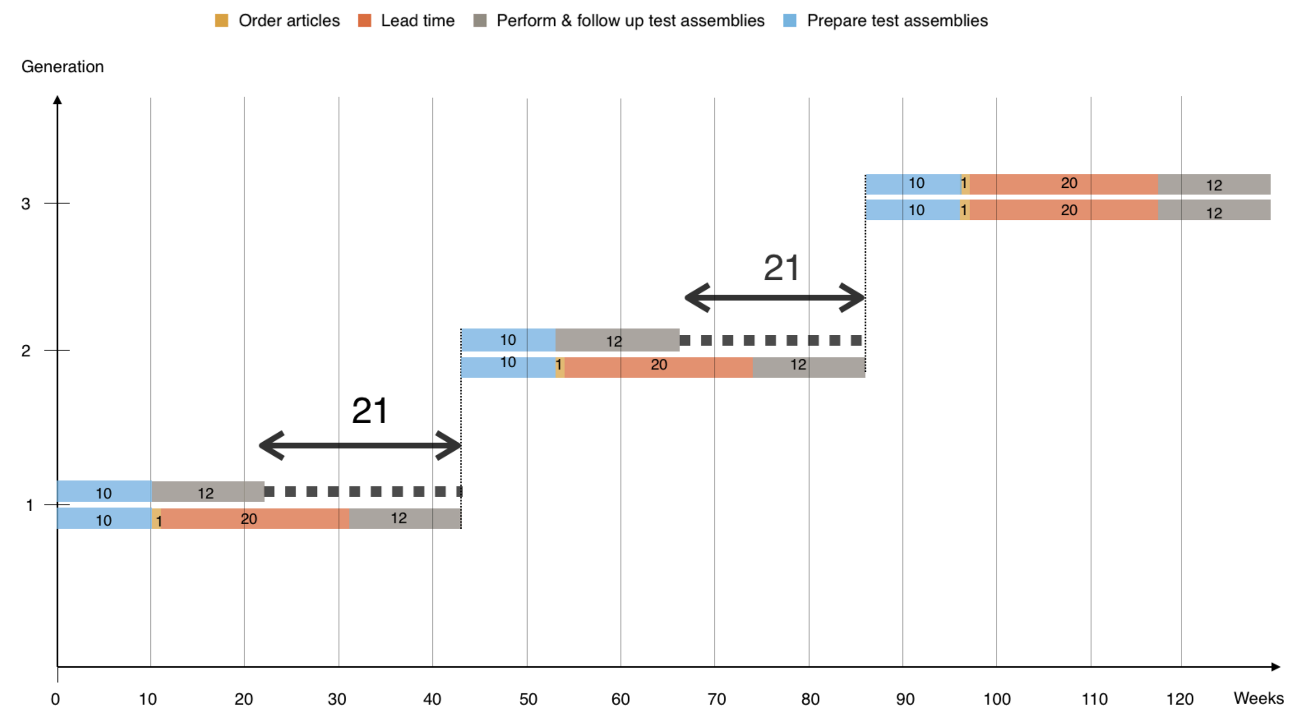


Figure 5.5 Chart describing the potential time saving by doing two generations digital

5.4.2 **Gap not eliminated**

Since the thesis has been carried out in the group of DEPB some impacts regarding their current digital work have been compiled. An investigation of what the impact would be if DEPB started to do digital test assemblies today has been made. It assumes that the gap has not been eliminated and that the work would have to be managed under the current circumstances. Neither MBD or IPS have been implemented. It is also presumed that a physical test assembly for verification is made in the last generation.

As the identified gap shows, there are areas that are deficient in the digital environment. But there are also many activities that can be managed, as can be seen in the evaluation of the DFA checklist. It is therefore not impossible to start doing digital test assemblies even if there still are deficient areas. As mentioned earlier, all activities raised in the checklist are not well managed physically either. Some evaluations are best performed in the third generation due to the right manufacturing methods and material. Therefore, some test assemblies that are managed in the first generations can be replaced by digital. This includes areas that already have the possibility to be evaluated digitally and articles that are similar to the existing versions or that are not in need for a SES evaluation. However, there are areas that need to be evaluated in the first generation that is currently not possible to manage digitally. This includes for example soft materials, pipes with a lot of bends and SES evaluations.

If digital test assemblies are fully managed, DEPB can give input to R&D earlier in the development process since there is no need for receiving physical prototypes. Also the knowledge of the employees in the group within CATIA and DELMIA would increase by performing it regularly. This can lead to better and more detailed assessments. Although, there is information that cannot be obtained and evaluated digitally which would lead to loss of information. Since Scania is working towards a more digital approach and planning to implement MBD in the future, the group would be prepared for this adaption. However, if DEPB is the only group changing their approach to more digital work it would not make a great impact overall. The lead times cannot be reduced due to the deadlines in projects being dependent on all departments. If all articles are not completed in the 3D environment digital test assemblies cannot be performed. This would lead to DEPB not having the opportunity to give input and influence the design without physical prototypes.

6 Discussion

This chapter covers the discussion regarding the carrying through of the entire project. The authors' thoughts about the working methods will be lifted. A discussion regarding the analysis and result will also be presented.

6.1 Evaluation of methodology

The methodology utilized throughout this project's empirical data collection was a case study. A case study was suitable and applicable for this project since the purpose was to gain an in-depth knowledge of a company's working process and what was needed in order to improve the process. However, there are some disadvantages with this type of study that were discovered throughout the research, but also some previously known general weaknesses. The study was performed on a single case and therefore reduces the generalization. Due to this it is difficult to know if it is applicable in other areas, both at Scania and at other companies. This decreases the area of use for the thesis. However, this was not the aim with the study. The case study also gives a more qualitative research than a quantitative which also reduces the generalization. The data collected was more qualitative and was not based on a large sample of sources. Although, this was useful in this case since it was an in depth-study and the interviews held with different personnel at DEPB gave similar answers, indicating it was qualitative.

The methodology that was applied gave a well-defined working process and a good foundation on how the empirical data would be collected. The three different types of gathering information for the empirical study; interviews, observations and archive analysis was good ways of collecting information. However, a workshop was also held at the end of the project. A lot of the data collection was made in the beginning, therefore it was decided to conduct a workshop at the end of the project to ensure that the study had covered the most relevant parts. The interviews that were held were semi-structured. Ten of the interviews were held at DEPB, three at other departments of Scania and one at another company. Since the majority of the interviews held were with employees working at the same department it might be a quite subjective assessment. However, the empirical study was also based on observations and archive analyses. It included observations of how the test assemblies were performed and also observations from just being located in the facility during the thesis work. The authors spent the majority of the time located in the engine assembly building and attended many relevant meetings which has also given a greater understanding of the company and the working process. The archive analyses that were conducted also gave an objective view since a lot of it was obtained from Scania's intra network and not written by DEPB itself.

A methodology was also used for planning and conducting the literature study, presented in the methodology chapter. The method was a good way of beginning the initial phase of the study since it had great structure and guidelines. Further ahead in the study the method was a good base, but did not improve the study or the data obtained in any way. Nevertheless, the method did not help this specific case in figuring out which areas should be investigated and further studied. A deep evaluation of the aim with the project and different areas had to be managed before the topics could be selected. Furthermore, the literature study could not begin before the areas to be studied were set.

6.2 Analysis and result

6.2.1 **Identified gap**

The aim with the study to identify the gap was achieved and presented in the result. This gap showed all the deficient areas where the current digital environment was not fulfilled. However, what is needed to be emphasized is the different significance of the areas lifted. Some of the areas may be of great relevance in order to perform a digital test assembly and others not as important. Some of the areas are not even fulfilled at a physical test assembly. Therefore it can be discussed whether all the areas lifted are required for a more digital working method. Sharp edges is an area that might not be as relevant to investigate digitally since this is currently evaluated in the end of the project when the article is manufactured in a serial tool. An example of an area that it is of great importance to examine early digitally is the SES evaluation. This must be managed digitally since it is a very important and crucial part investigated early in the process.

6.2.2 **Solutions obtained**

Model Based Definition was a part of the presented result and one of the solutions to the identified gap. However the authors of the thesis had, in advance of the project, the idea of MBD being a great essential part of the digitalization. As the project proceeded the authors got the perception of MBD being a foundation and a part of the solution for further development within the digital environment, but not that MBD itself would eliminate the identified gap. A study visit was planned at Saab in order to understand their digital working methods. Saab is in the far edge when it comes to digitalization and is one of the companies who have implemented MBD. However, this study visit was not possible to carry through due to time limit and resources. The visit would probably have widen the authors understanding for MBD and the impacts of implementing it in a larger industry company and also strengthened the result.

Presented as a suggested solution was also the use of the software IPS. There was no thorough benchmarking made exploring and investigating different types of software that could fit for the given purpose. The reason for this was that IPS is already under development at Scania, why the possibilities with only this software were investigated. Another reason is that the authors of the thesis have inadequate knowledge about the possibilities with different software and what would suit the production best. Mentioned in the result is also that IPS could cover up a lot of the gap, this is however an estimation made from research about the software, own impressions from observations and information given from the DTA forum at the IPS workshop. It is therefore not proven to solve the gap since the deficient areas have not been tested in IPS. Since it is a new software under development it was difficult to get the real perception of the possibilities with it. Some of the areas mentioned in chapter 5.2.2 that needed further investigation may already be possible to solve with IPS but could not be confirmed. However, if they are not possible to solve, they could be discussed with the developers of the software in order for the functions to be available in the future. Another aspect is that the engine is a very complex product with many small articles and limited spaces. Therefore an entire engine has to be tested in IPS to prove that the functions needed are applicable on the engine.

6.2.3 Identified challenges

A challenge that the authors have noticed is the implementation of an entire new working method. This would require a major adjustment and could even entail some risks. It would also imply for the personnel to adapt and learn a new way of working and to be introduced to new software and programs. Changes in working methods and programs usually entail higher costs in the beginning of the change because of the investment cost for the program and the time for the personnel to learn. However, if the change is feasible and for the better it will pay off in the long run.

Another challenge noticed regarding the implementation of MBD, is the user accessibility. This is something that is lifted in the literature study. When implementing MBD it requires that everyone has access to the CAD system or that the information in the CAD system can be converted to a non-CAD file format.

Downstream users who today have access to the 2D drawings must have access to the information in the CAD systems. This may result in high costs for the company.

6.2.4 General reflection

This thesis does not solve any problems Scania is facing but it may act as a support for future development. The project does not explain in detail how Scania should implement improvements for their product development process with a digitalized working method. Instead, it highlights the most important challenges related to a more digitalized working method, and suggests in which areas that Scania's engine department should lay its focus. The authors' perception is that it would be very advantageous for Scania to work with a more digital approach, but it would not make a big impact if only DEPB implemented the new approach.

The analysis that was conducted was the basis for the final presented result. The analysis was however fairly severe to carry through since the used material was obtained from different kind of sources and gathered in several ways. The data that had to be analysed was other people's thoughts, the authors own impressions and also compiled published material. Nevertheless, the literature study that had been performed turned out to reinforce the result that the analysis led to. Some of the results could be confirmed by the information presented in the study. The four research questions that were established in the beginning of the project, were all answered. Since the research questions were formed with the purpose in mind, the aim with the project is considered to have been achieved.

7 Recommendations

This chapter will present proposals for implementation of a more digital working approach. Future recommendations will also be discussed.

7.1 Proposal for implementation

Concerning the digital test assembly that will replace the physical test assembly meeting, the authors have created some recommendations for how this will be operated. If this activity will be replaced by a digital test assembly the input from other departments will still be of great importance. A suggestion is that the digital test assembly is still performed as a meeting when needed. The concerned departments can gather around a screen and conduct the test assembly digitally. If the article tested is a simple construction and not a complex assembly, DEPB may execute the test assembly digital and send a video of the test assembly to all the concerned departments. The different departments can then give input based on the video. In that case the digital test assembly meeting will not be as time consuming as the physical.

Another proposal is to start implementing the new working method in a smaller scale. To make sure the new method is well established and well working it would be preferable starting with implementing it in the first generation of the green development phase. Minor projects are also good to begin with. When it is ensured that there are no major difficulties with the new working method, it could be implemented in the second generation and in bigger projects. However, it is important to do the third and the last generation with physical prototypes. The engine is a very complex product and it is therefore important to verify the assembly with the actual material before it goes into production.

7.2 Future recommendations

Through the project several sources of information have given the authors ideas about future development. These will be presented and discussed as future recommendations for Scania. The first area that was encountered was virtual and augmented reality. During the literature study these areas were mentioned in several sources and gave the impression of having great future possibilities. Augmented reality seemed to be better suited for assembly planning than virtual reality, but both areas are still developing and have good future opportunities. Augmented reality is combining both real and visualised artificial environment presenting the surrounding from the viewer's perspective. In assembly this could be presented with a real engine and an artificial article to be assembled by the viewer. This could entail good analyses of ergonomic situations, the possibility to check for potential errors in the real environment without a manufactured prototype and also easily to plan the assembly sequence.

Another future recommendation that was raised during several interviews, was the wish for the entire environment in the facility to be added in a digital program. In order to assemble an engine in the most similar way as on the production line, the digital environment need to include surroundings of the engine and all the stations in order. By visualizing the whole production line environment it would enable the product development process to be more reality-based and easier to find better solutions of the assembling. The digital environment should include everything exactly as it is in the reality. This is something that is not possible today when performing a physical test assembly on the development area, but may be possible in the digital environment in the future.

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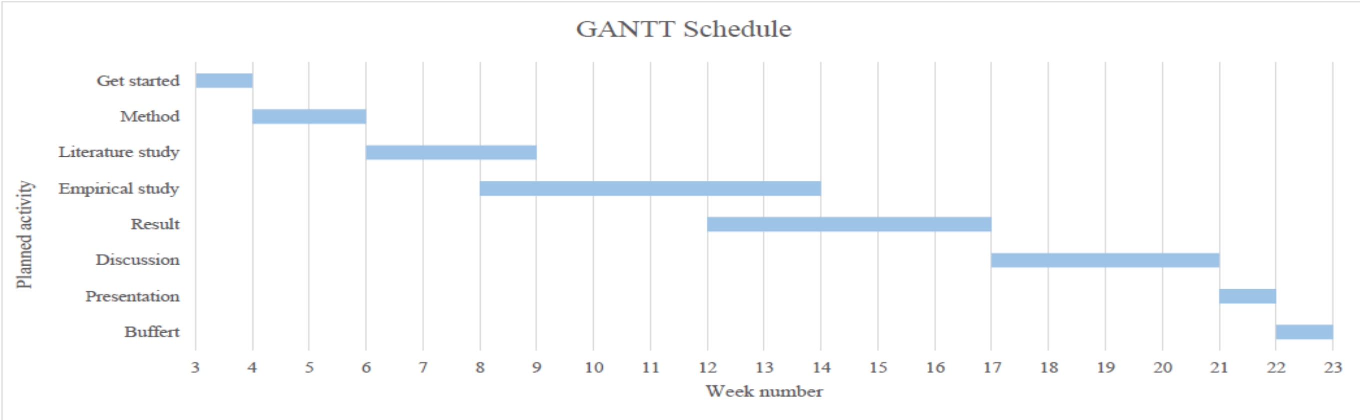
Appendix A Work distribution and time plan

A.1 Work distribution

The work distribution has been equally distributed between the two students. Both students have taken part in all activities and performed them together in order to learn as much as possible. Everything written individually have been discussed together to ensure a uniformed and streamlined project. The working hours have been normal business hours located at an office at Scania.

A.2 Project plan and outcome

The figures below are presenting the planned project plan and the real project outcome. The carrying through of the project has roughly followed the project plan but with some minor adjustments. The time consumption of the start of the thesis was estimated good in the plan. The bigger changes between the plan and the outcome are at the later parts of the thesis. The empirical study was not overlapping with the literature study since the authors made the assessment that it was preferable finishing the literature study completely before starting with the next activity to not interfuse or forgetting information. The result was not overlapping that much with the empirical study either. The gathered data was needed in order to start with the result. However the result and discussion overlapped more than thought. This was due to a lot of thoughts and ideas that came up during the result part was conducted. They were then directly inserted into the discussion. The discussion and the end of the report was carried out at the planned time. The buffer week was aimed for when it was needed. In this case it was added to the presentation preparations for both company and university presentations and for finishing up the report.



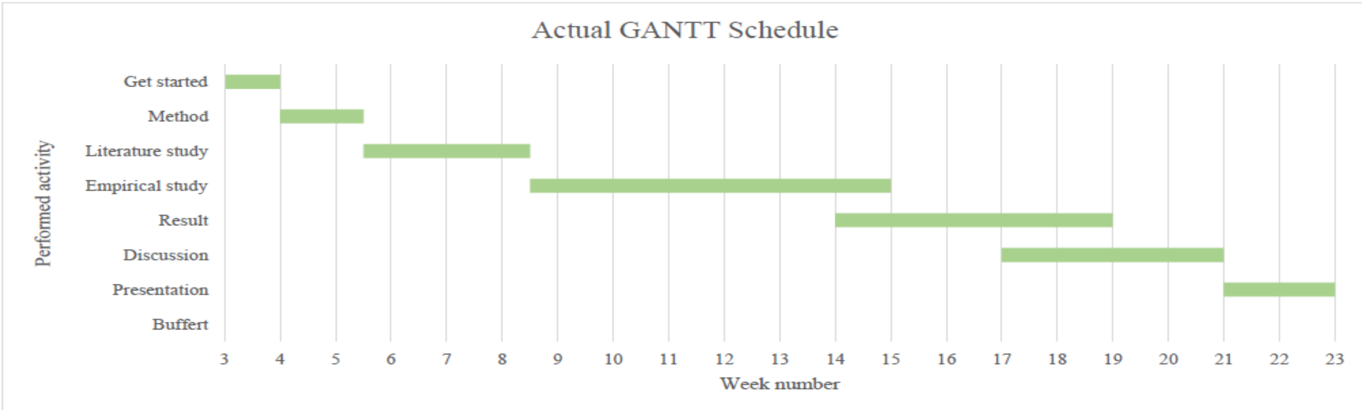


Figure A.1 Planned project plan to the left and performed project plan to the right.

Appendix B Interviews

B.1 Interviews with employees at DEPB

Name and job title:

Daniel Ekholm – Global product & process engineering
Eric Sjöstedt - Global product engineer
Jan Johansson – Global product engineer
Johan Jönsson - Global performance engineer
Karl Wiklund – Global product engineer
Kevin Berg – Global product engineer
Martin Jidegren – Global product engineer
Mikael Carlsson – Global product engineer
Tobias Nilsson - Global product engineer
Örjan Bergstedt - Global product & process engineering

Questions asked:

What do you think about your working process?
Do you think anything could be better?
What do you feel about working more digital?
How much of your daily work is digital today?
How are you using DELMIA and CATIA?
What are your thoughts about working more digital?
Is there anything that could be done better digitally?
What do you wish you could get out from a digital test assembly that isn't possible today?
What problems would occur if one generation would be replaced by digital work?
What do you most often miss when you work digitally?

B.2 Interview MBD

Name and job title:
Kent R Johansson - Senior Technical Advisor – Simulations

Questions asked:
What do you work with at Scania?
What is MBD for you and/or the company?
When is MBD planned to be introduced at Scania?
How will it be introduced?
What challenges have you identified by an introduction?
What needs to be done in order for MDB to be possible to introduce?
How do you get all the information from 2D-drawings to 3D-environment?
How could MBD ease the development of product introductions?

B.3 Interview at Chassis

Name and job title:
Joakim Wahlström Chassis - Digital test leader

Questions asked
What do you work with at Scania?
How is your digital working process structured?
How do you perform a digital test assembly?
How much can you see digitally?
What programs do you use?
Do you see any problems with the digital work?
Do you see any potential with the digital work?
Is there anything special that can be seen at a physical test assembly but not at a digital?
How do you document the digital test assemblies?
What do you think needs to be improved in the digital environment?

B.4 Interview Tetra Pak

The interview held at Tetra Pak

Name and job title:
Kuno Löfgren - Co-ordinator Tetra Pak

Questions asked:
What is your position at Tetra Pak?
How do you work with MBD at Tetra Pak?
What kind of information do you have in 3D?
Do you use 2D drawings? If yes, in what purpose?
What do you think needs to be done in order to skip 2D drawings?

Appendix C Workshop DEPB

The workshop started with a short presentation summarizing the purpose, goal and background of the project to give the employees at DEPB an update. The identified gap was also brought up in order for the employees give further input. After the presentation was held the group was divided into three smaller discussion groups. Three different stations each consisting of one question were set up. The groups had 15 minutes at each station to discuss the subject and to give their thoughts and reflections.

Questions discussed:

- What do I currently need to conduct a digital test assembly?
- What would I, as a global product engineer, gain by doing digital test assemblies?
- How should a digital test assembly be conducted?

Appendix D Engine factory

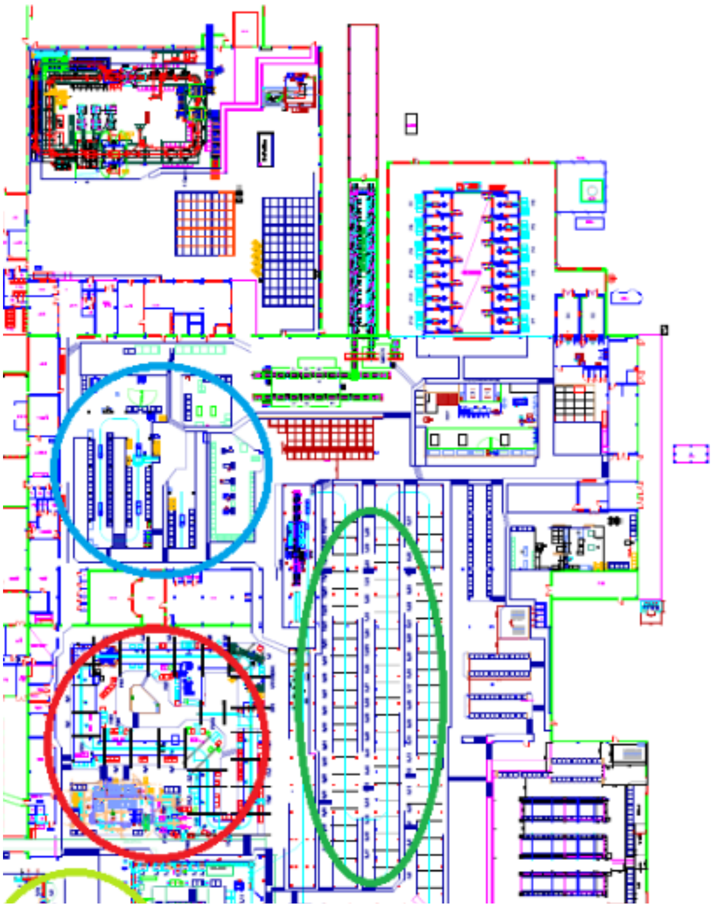


Figure C.1 Yellow shows the straight assembly line for the base engine, green is the straight assembly line for the final assembly, red is the V-engine assembly line and blue is the development line.

Appendix E Observations

E.1 Protocol for test assemblies

Before the test assembly
How do you prepare yourself before a test assembly?
How much do you prepare digitally?
Do you wish that you could be more prepared? Or be prepared in any other way?
What do you expect to obtain from the test assembly?

During the observation
What is being tested and why?
Who are attending the test assembly?
How thoroughly is the test performed?
Was is possible to do the evaluation of the physical test assembly digitally?

After the test assembly
What do you think about the outcome of the test assembly?
Did everything turn out as you thought?
Do you think it needed to be tested physically?
Do you think that the things discovered on the test assembly could have been seen digitally?
If not, why can you not discover it digitally? (lack of knowledge, program issues etc.)
Do you think you could have done anything differently?
Do you think anything could have been done more effective?

Appendix F SES

UTVÄRDERINGSMALL
ARBETETS FÖRUTSÄTTNINGAR

SES
KONSTRUKTION
STD4323-1 sv utg 3

A :

3.2.1 Förekommande arbetställning

		A	B
Bekvämt stående/gående *och/eller* sittan	Grönt		
Obekväm *eller* böjd/vriden ställn.ståender	Gult		
Ligg, knästå, huksitt, halvligg, ett ben, stilla	Rött		

Anteckn:

3.2.2 Rygg – Statisk arbetsställning

		A	B
0°–20° framåtböjning eller 0°–20°sidböjn./-v	Grönt		
20°–45° framåtböjning	Gult		
> 45° framåtböjning *eller* > 20° sidvridning *eller* >0 bakåtböjning	Rött		

Uppmätt:

3.2.3 Nacke – Statisk arbetsställnin

		A	B
0°–45° framåtböjning *eller* 0°–20°sidböjn./-	Grönt		
> 45° framåtböjn. *eller* >20° sidböjn. *eller* > 20° sidvridning eller > 0° bakåtböjn.	Rött		

Uppmätt:

3.2.4 Axel, arm – Statisk arbetsställ

		A	B
< 45° överarmslyft (framåt/utåt)	Grönt		
45°–90° överarmslyft (framåt/utåt)	Gult		
> 90° överarmslyft (framåt/utåt)	Rött		

Uppmätt:

3.2.5 Handled – Statisk arbetsställn

		A	B
Neutral handled	Grönt		
Ej neutral handled	Rött		

Uppmätt:

3.2.6 Vertikal höjd

		A	B
> 900 *och* < 1200 mm	Grönt		
600–900 mm *eller* > 1200 *och* < 1400 mm	Gult		
< 600 mm *eller* > 1400 mm	Rött		

Uppmätt:

3.2.7 Horisontellt arbetsområde

		A	B
< 300 mm	Grönt		
300–600 mm	Gult		
> 600 mm	Rött		

Anteckn:

3.2.8 Åtkomlighet/dold montering

		A	B
Ovandel eller front med fritt tillträde *och* inga hinder i arbetsvägen.	Grön		
Sidan, hinder i arbetsvägen	Gult		
Under *eller* bakom	Rött		

Anteckn:

3.2.9 Klättra och kliva

		A	B
< 0,4 m/min	Grönt		
0,4–0,6 m/min	Gult		
> 0,6 m/min *och* ≤ 1,2 m/min	Rött		
> 1,2 m/min	DRV		

Uppmätt:

B:

3.2.10 Tvåhandslyft (lyftmoment)

		A	B
< 10 Nm	Grönt		
10–35 Nm	Gult		
> 35 Nm *och* ≤ 70 Nm	Rött		
> 70 Nm	DRV		

Uppmätt:

3.2.11 Enhandslyft

		A	B
< 2 kg	Grönt		
2–5 kg	Gult		
> 5 kg *och* ≤ 10kg *eller* (0,5–1) kg överh.	Rött		
>10 kg *eller* > 1 kg överhandsgr.	DRV		

Uppmätt:

3.2.12 Tryck-, drag-, retardationskrafter hel

Initialt	*Kontinuerligt*		A	B
< 100 N	< 50 N	Grönt		
100–150 N	50–110 N	Gult		
>150 N *och* ≤ 300 N	> 110 N *och* ≤ 220 N	Rött		
> 300 N	> 220 N	DRV		

Uppmätt:

3.2.13 Frigång för hand/ finger, verktyg

Hand	*Finger, verktyg*		A	B
≥ 2,5 cm	≥ 1,0 cm	Grönt		
< 2,5 cm	< 1,0 cm	Rött		

Uppmätt:

UTVÄRDERING

	GRÖNA	GULA		RÖDA		GULA+ RÖDA	
	Antal	Antal	Färg	Antal	Färg	Antal	Färg
A							
B							

	DRV	
	Antal	Färg
A		
B		

DRV- Dubbla Röda Värdet

RESULTAT Arbetets	
	Färg
A	
B	

LATHUND

ANTAL	GULA	RÖDA	GULA+ RÖDA	DRV
0	Grön	Grön	Grön	Grön
1 - 3	Grön	Gul	Grön	Röd
4 - 5	Gul	Röd	Grön	Röd
6 - 13	Röd	Röd	Röd	-

Appendix G DFA checklist

G.1 Evaluated checklist

Task	Physical	Digital
Is the article constructed in a way that no sharp edges exist?		
Is the article constructed so that it is impossible to be assembled incorrectly?		
Is the article constructed so that marking of article number or other identification can be placed on it?		
Are the tolerances of the article set so that no problems occur when placing the article?		
Are the covers constructed so that there is no risk for the article to be mounted with the cover still attached?		
Is the article mounted without rotation?		
Can the article be mounted with existing tools and fixtures?		
Is the article constructed so that the assembly time is better or the same as the previous construction?		
Is the article constructed so that it stays in position when placed?		
Is the article possible to mount without demounting other parts?		
Does the article have self-positioning characteristics when assembled?		
If the article needs to be masked, is there access to do it manually?		
Can the article be mounted in accordance with the master sequence?		
Is the article constructed so that it can be assembled within the cycle time?		

Are the fastening elements integrated in the article?		
Is the article constructed with minimum number of screws?		
Is there access for a socket when placing the screw?		
Are standardized screws used?		
Is the O-ring in the correct size?		
Is the O-ring still in place when the article is turned or pushed?		
Is the O-ring avoiding sharp edges when assembled?		
Is the “dickflärp” visible when assembled for enabling control of the sealing?		
Is quick connection used?		
Is there a marking for the hose clamps position?		
Does the pipe/hose/cable touch any other parts?		
Are there two holes in the gear, to be used as a counter hold?		
Are control pins integrated in any article/ is it possible to assess their position to the assemblers on line (risk of injury)?		
Is angle union avoided?		
Is banjo screw/union the only connection alternative?		
Is the clamp integrated in the articles?		
Is quick connection used for the engine test?		
Is the connection for the engine test standardized?		
Is there space for hands when connecting the engine in the engine test?		
Is it constructed so that the total connecting time in the engine test is not increasing?		
Can a SES evaluation be performed?		
Is it constructed without affecting the delivery pallet, V-bock & struts ?		