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A framework for enabling operators to use simulation for continuous improvement

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This final thesis has been carried out at the School of Engineering in Jönköping within the main area of Production systems. The work is a part of the two-year university diploma program of the Master of Science program. The authors take full responsibility for opinions, conclusions and findings presented.

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Abstract

In a time where digitalization is becoming more and more necessary to work with, tools such as simulation is becoming more of a standard to be able to make decisions made on facts. Within previous research there is a gap in the research, as the factors enabling operators to use simulation is an unexplored topic. Therefore, to fill this gap and provide the industry with help, this study fulfills the purpose:

Create a framework for enabling operators to use simulation for continuous improvements.

By looking at the different areas in the production and identifying challenges within the production, information handling between the departments and the structure of the company, the purpose of this study is fulfilled. The purpose was achieved through the usage of two research questions.

What are the challenges in practice for enabling operators to use simulation for continuous improvements?

How can these challenges be overcome, to enable operators to use simulation for continuous improvements?

To answer the research questions, a case study was performed alongside a literature review. The case study consisted of interviews performed at a case company within the automotive industry. The gathered empirical and theoretical data was then analyzed trough a thematic analysis.

The conclusion of this study was that, for enabling operators to use simulation for continuous improvements, companies must first have the right organizational structure, were a foundation for continuous improvement is present. The reason for this being that if a company desires to work with simulation tools, they must first work in an environment where suggestions and improvements are supported.

Keywords: Discrete event simulation, Simulation, Continuous improvement, Operators

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1 Introduction

The following chapter introduces the study. Firstly, the background to the study is described, where the theoretical background, case background and the problem formulation is presented. This is then followed by the purpose and the research questions this study answers. Finally, the delimitations and outline are presented.

1.1 Background

1.1.1 Theoretical background

There are several different challenges facing manufacturing companies today; resource handling, flexibility, customization of products and the ability to change (Mayer & Fettke, 2021). The trend is going towards a more globalized and decentralized world which requires real time information handling between different departments such as set-ups, set-up planning, assembly, machining, and planning of production (Mouritzis & Doukas, 2014). According to Liker and Morgan (2006) a company's ability to continuously improve and learn is one of the most sustainable ways for a company to create and keep a competitive advantage.

Companies also needs to have the right employees with the right skills and have an organization with the ability to improve continuously (Williams, 2014). Some of the specific challenges facing companies today are higher quality requirements, higher flexibility in both output and variety, and an overall uncertainty in the market (Mouritzis & Doukas, 2014). These challenges therefore put pressure on the companies to become more resilient to handle changes in their production departments (Kahn & Turowski, 2016). To overcome some of these challenges companies apply the usage of simulation tools to create a better suited production environment. Simulation is used to model and describe the behavior of a real system, with the aim of either describing how it works or suggest changes to improve the system (Baines et al., 2004). Today most of the simulation tools available have environments that integrate model building, model debugging, animations and input and output data-analyzer (Banks et al., 1999).

By using discrete event simulation (DES) the difficulties in designing and improving a production system can be solved through simulating different outcomes. Simulation tools can be used to monitor factors such as: machine down times, set up times, unplanned stops, planned stops, automation, buffer sizes, push pull systems, automated guided vehicles, and work-in-progress (Song et al., 2016; Law & McComas, 1998). Used correctly, DES can benefit the company, but if not used correctly it can be time consuming and lower the efficiency and output of the company. DES uses algorithms and statistics to analyze and optimize the best solution to a specific system. DES also verifies and controls new conceptual production systems (Silva & Botter, 2009).

In most cases a team conducts the simulation studies typically consisting of people internally that understand the system, such as system designers, system engineers, manufacturing engineers or process engineers (Silva & Botter, 2009). The team should also include people that have the knowledge to formulate and model the system. The people involved in the simulation must have the necessary skills and knowledge to be able to perform the task (Banks et al., 1999). The difficulty in putting the team together can be that the skills for modelling and formulating the model does not exist internally (Manlig et al., 2011). To solve this problem the company can either hire consultants who have the expertise or train some of the employees (Shannon, 1998; Law, 2007).

Over the last 20 years there has been a change in who performs the simulations, where the shift has been from user who are specialists in simulation, to users who are specialist in other areas than simulation, so called non-specialists (Banks et al., 1999). The nonspecialists have a higher expertise in their respective areas but lack the expertise within using the simulations tools, therefore resulting in difficulties in correctly using the tools and potentially reaching the wrong conclusions of the results, which may in turn affect the company negatively (Hollocks, 2001). Therefore, spreading the knowledge and expertise about simulation is vital for company's performance. Since the people operating internally within a company compared to external people such as consultants have a greater understanding and expertise about the processes and are better suited for using the simulation tools, but they need the right knowledge to be able to perform it (Baines et al., 2004). The people with the highest expertise about the single processes are the people working with the processes in the production, therefore including them, and giving them the right knowledge about simulation can be vital and give companies a competitive edge, but it remains as a challenge for the industry today to create a simulation-educated workforce (Collins et al, 2021).

1.1.2 Case background

This study was performed at Volvo Group Trucks Operations, shortened Volvo GTO in Skövde, Sweden. Volvo GTO is a manufacturing company that is a part of the larger Volvo group and produces the engines and engine parts for Volvos trucks. At Volvo GTO, the knowledge and usage of simulation tools and its function was centred around the experts, which is the common situation at most companies. Volvo GTO had identified the possibility to expand this knowledge to employees within the production as a possible improvement. Therefore, Volvo GTO were a suitable case company to use in this study.

Volvo GTO as the rest of the Volvo group works according to the Volvo Production system (VPS) which is a Lean production system like the Toyota Production system, with similar ideas such as continuous improvements. This is one of the reasons for the desire to implement and use Simulation tools at floor level within the production.

1.1.3 Problem formulation

With the challenges facing companies today, such as resource handling, flexibility, customization of products and the ability to change (Mayer & Fettke, 2021), companies need to be able to adapt quickly to changes and constantly improve. Simulation tools helps companies to monitor the behavior of their production system, to identify possible areas of improvement and provides companies with an environment to test improvements before implementation (Baines et al., 2004). But it remains a challenge for companies to have a simulation educated workforce who can perform the simulation work (Collings et al., 2021), which can result in a negative effect from using the simulation tools (Hollocks, 2001). Therefore, there is a need to investigate how companies can enable their operators to use simulation. To achieve this the challenges surrounding the enablement of operators to use simulation needs to be addressed and investigated.

1.2 Purpose and research questions

This leads to the purpose of this study: *Create a framework for enabling operators to use simulation for continuous improvements.*

To be able to fulfil the purpose of this study, first there is a need to understand what the obstacles and limitations, hence called challenges, are that may hinder an implementation and usage of simulation tools amongst operators. Therefore, the first research question is:

What are the challenges in practice for enabling operators to use simulation for continuous improvements?

When the challenges have been identified in research question one, the next step is to investigate how these can be overcome, which leads to the second research question:

How can these challenges be overcome, to enable operators to use simulation for continuous improvements?

1.3 Delimitations

This study focuses on manufacturing companies with a physical output, meaning that companies without a physical output is not considered in this study. This study focuses on the creation of a framework, which aims at aiding companies in preparing for implementation and usage of simulation tools in their production. Therefore, this study is placed in the planning-phase, which means that the process of the actual implementation and usage of simulation tools are delimited in this study.

1.4 Outline

Initially the method of the study is presented. In this chapter, the method of choice for this study is described, and how the case study and the literature study was performed. Further, this chapter presents the methods for ensuring the validity and reliability of this study.

Followed by the method chapter is the theoretical background. The theoretical background consists of several different sub-heading, where each sub-heading describes a topic of interest for the study. The data in the theoretical background was collected using a literature study, and the data will be used in the analysis to answer the research questions and fulfill the purpose.

After the theoretical background, the results are presented. This chapter consists of the empirical data collected during the case study. The chapter is divided into different subheadings, where the case company is presented and the results from the different interviews.

Followed by the results, the analysis is presented. This chapter is divided into two sections, the thematic analysis, and the theoretical analysis. In the thematic analysis, the themes identified in the empirical data is presented. In the theoretical analysis, the themes are then connected to theoretical data from the theoretical background.

The final chapter is the discussion and conclusion chapter. In this chapter the research questions are answered, and the purpose fulfilled. Included in this chapter is also a discussion about the method, implications and limitations of the study and further research presented.

2 Method and implementation

The method chapter presents which methods were used to conduct the study. Initially the research design and the work progress are described. This is followed by a description of the different methods used for data collection and how the analysis was conducted. Finally, the progress of securing the validity and reliability of the study is presented.

2.1 Research design

This study can be classified as an exploratory study, as the aim of the study was to seek new insight on a phenomenon that has in previous research been sparsely researched (Saunders et al., 2007). The progress of the study can be divided into to four distinctive moments, *Determine the scope and method, Literature review, Case study,* and *Analysis.* The four steps lead up to the final result of the study. The first step of the study was to determine the scope and method of the study. To fully understand the subject, a background search was conducted, with the aim of understanding previous research related to the subject. This was performed similarly to a literature review, where databases were used to find previous research of the subject. Based on the findings from the background search, the scope of the study was determined. The findings from the background search were also used to determine the most appropriate method to be used for this study. Previous research showed that a case study was the appropriate way to go to fully understand and research the subject.

Following the completion of the first step, the progress of the study moved into the literature review. The literature review was used to collect theoretical data about the subject and is in detail described in chapter 2.3**.** The literature review was conducted first independently, but at the end simultaneously as the case study. The reason for this was that there was a need to complement the theoretical data following the initial collected empirical data from the case study. The reason for this was that some phenomena's that were found in the empirical data had not been previously covered in the literature review, but to be able to fulfil the purpose of the study they needed to be added. The case study is more in detail described in chapter 2.4.

Throughout the case study there was simultaneous analysis of the data that where collected. The analysis is in more detail described in chapter 2.5. When the case study was complete most of the analysis was performed, where the research questions was answered, and the purpose of the study fulfilled. The research design is visualized in Figure 1.

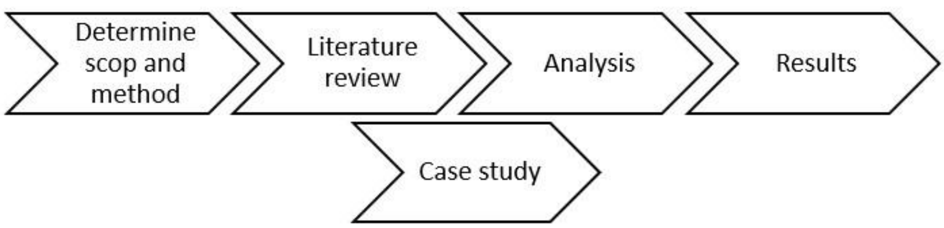

Figure 1. Research design.

2.2 Qualitative research

A qualitative research approach is one of two different approaches that a study can take alongside quantitative approach. When using a qualitative approach, the researcher aims at answering questions such as *How, Why* and *What* with focus on finding meaning in the social context of a phenomena. The researchers aim to get a deeper understanding of the deeper meaning of words, situations, circumstances, and how people see and interpreted different objects (Hesse-Biber & Leavy, 2011). In a qualitative study the researcher wants to blend in as much as possible into the subject's natural environment. The aim is also from the researcher to restrict the subject as little as possible, one example of this can be giving a respondent in an interview or questionnaire the ability to use own words for answer rather than pre-determined options (Chesebro & Borisoff, 2007).

This study was approached through a qualitative research standpoint. To achieve the purpose of this study there was a need to understand how the operators within the production units perceive simulation and understanding their knowledge about simulation. This is questions that can be best answered through interviews since the aim was to understand in depth through giving the employees the chance to express and describe their feelings and ideas.

2.3 Literature review

The literature review was conducted to collect theoretical data about the subject. A literature review is suitable to use when the purpose is to gather previous research about a subject to fully understand the subject, with for example models, previous studies, trends, what methods that has previously been used and what result previous studies has stated (Saunders et al., 2007). The literature review was conducted in two major steps, where the first was a literature search. In the literature search several different databases was used, primarily Scopus but also Google scholar, Emerald, and Proquest. The method for searching in these databases was that several keywords were derived from the purpose and subject of this study, which then was used in different combinations to find and identify relevant sources. Apart from using data bases to find relevant articles and previous research topics, the reference lists were examined in the chosen articles. This was done to validate the quality but also to identify further research articles that could be relevant (Wellington et al., 2005).

When the literature search was complete, the second step of the literature review was conducted, where all the relevant sources was compiled in the theoretical framework. To ensure no recent publications has been missed out searches were made from time to time during the study.

2.3.1 Process of conducting the literature review

Search terms

The first step in the literature review was to identify search terms that were to be used in the searches. The search terms were devised based on the research questions at start. The search terms that were initially used was:

Simulation, Simulation Project, Lean management, continuous improvements, Operators.

These search terms where combined with additional search terms to narrow down the searches and to identify references connected to specific areas of interest. These search terms were:

Knowledge, Education, Implementation, Production, Manufacturing, Manufacturing system, Simulation experts.

When a relevant reference had been identified, new search terms were added based on the keywords used in the identified reference(s). This was done to further widen the initial scope of the search, with the aim of not missing relevant resources that used possible synonyms of the initial search terms. The search terms that were added in this process was: *Discrete event simulation, DES*

Boolean logic was used for the searches. Boolean logic is a technique for combining the search terms to either widen, narrow down, or include terms in a search. This is done through combining the search terms by using Boolean operators which is AND, OR, and NOT (Booth et al., 2016). For this study multiple different combinations of the keywords/search terms were used in the searches using the Boolean operators.

Snowballing/Citation search

A citation search process was used in this study to further widen the range of possible references alongside confirming the validity of the collected references. The process of a citation search begins with the identification of key article(s) within the subject of interest. Following the identification of the key article(s), the next step is to conduct a search and locate articles that have referred to the key article(s). By doing this process, it is possible to identify all the relevant references within the subject and this process is repeated until there is a saturation and no more relevant references is located. This process can also be described as *snowballing* (Booth et al., 2016). This technique was used in this study to locate relevant references within the subject alongside confirming the validity of the identified references.

Selection of literature

When the literature search was completed, the next step was to sort out the relevant references that were to be used to answer the research questions. This process was conducted using the model of the selection process presented by Booth et al. (2016). This is presented in Figure 2.

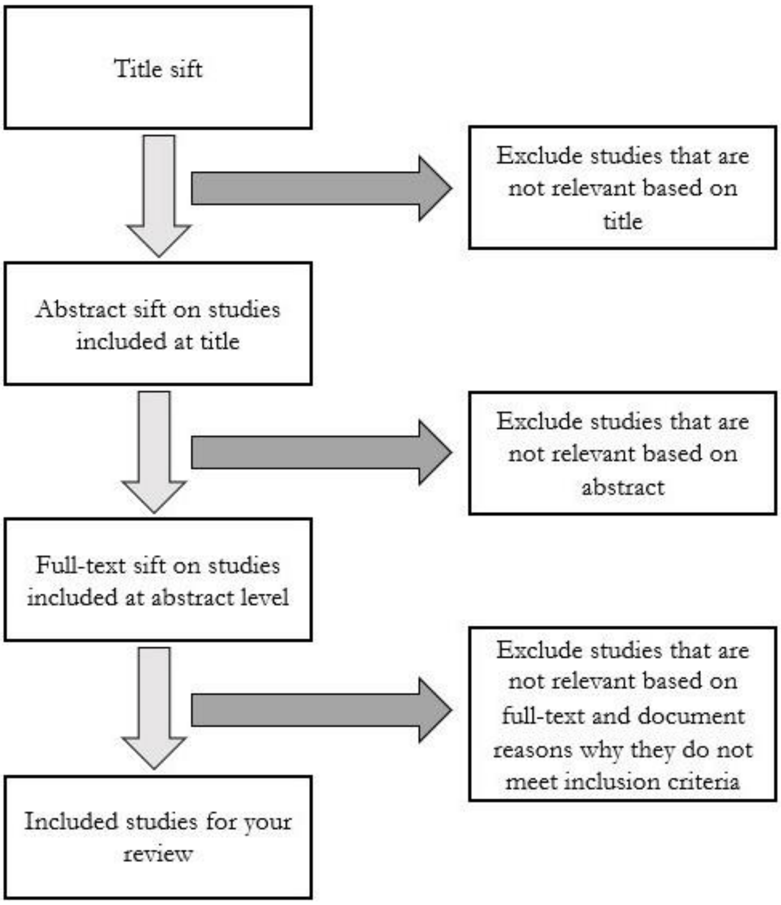

Figure 2. The process of selecting literature adapted from Booth et al. (2016).

This process is done by initially screening the titles of the references. This step is usually performed in combination with the next step which is to screen the abstract of the references. The final step is to read the entire text to determine the relevance. Usually, the relevance of a reference can be determined by screening the title and abstract, but if that's not enough to determine the relevance, then the final step is necessary (Booth et al., 2016). When the relevant reference was identified after the process was complete, the remaining references was used in the theoretical background.

2.4 Case study

A case study is a method used for collecting data when there is a desire to investigate a specific group, a so-called case group. In a case study the goal is to create a fully covered understanding of the case group to be able to study a process or change (Patel & Davidson, 2016). Case study research is a type of qualitative research, where a bounded system is explored in depth through a variety of methods, which results in a case description and case-based themes (Cresswell et al., 2007). For a study to be classified as a case study the most vital factor is the boundaries of the phenomena that is studied. If there are infinite numbers of possible phenomenon to study, it is not classified as a case study. Therefore, the phenomenon needs to have clear boundaries to be classified as a case study (Merriam, 2010).

When designing a case study, according to Yin (2006) there are three steps that needs to be taken. First, the case that is going to be studied needs to be determined. The case for this study was determined as Volvo GTO in Skövde. This acts as the boundaries for this case study. After the case has been determined, the next step is to decide whether to do a single case study or a set of case studies. For this study, a single case study was chosen. The reason for this was that there was a desire to understand the phenomena at the case setting in depth instead of using multiple cases where the same depth in understanding would not be possible to reach. The final step in designing a case study is to determine whether to use theory development or not when developing the data collection protocol and to organize the initial data analysis strategies. For this study theory development was used, since according to Yin (2006) it will help increase the reliability of the results and findings from the study.

2.4.1 Interviews

For a case study, interviews are commonly used to collect the data. Interviews can be performed in several different ways depending on the level of standardization and structure. For this study the type of interviews used were highly standardized and semistructured, implying that every single respondent received the same question but was able to answer the questions using their own words (Patel & Davidson, 2016). The structure of semi-structured interviews is that generally there are a set of pre-determined questions that are open-ended, but during the interviews the interviewer have the possibility to ask questions that emerge trough the dialogue (DiCicco-Bloom & Crabtree, 2006). Most of the questions was also open-ended, meaning that the respondents could answer with full descriptions and explanations, rather than only yes and no (Patel & Davidson, 2016).

The interviews were devised based on the theoretical data, where drawing from interviews used in previous studies and the structure and questions used there inspired the interviews of this study. The theoretical data collected from the literature review also gave inspiration to the interviews concerning which topics that where of interest and which subjects to focus on. This information was used to create the first interviews. When the first interviews were completed the questions where revised based on the new knowledge gathered from the conducted interviews. During the first interviews it was clear that some questions were irrelevant and that some topics were missing from the interviews. The final version of the questionnaire is presented in the appendix. Therefore, the interviews were revised and changed to go even deeper in the understanding. This process was repeated until it was a saturation in the interviews, meaning that no new information was added (Staller, 2021).

Correspondents

The purpose of the interviews was to gather empirical data for the study, mainly focusing on the work method of the employees, their knowledge and perception about simulation and other tools and issues they have recognized in the production. Therefore, semistructured interviews with open-ended questions were used, since the idea was to encourage and give the opportunity for the interviewees to speak freely and elaborate with their answers, rather than limiting them. To get a full understanding of the situation at the case company, the interviews targeted different people from different hierarchical levels, such as operators, production technicians and simulation experts. A visualization of the correspondents and the levels is presented in Figure 3.

As depicted in Figure 3 the hierarchical level within simulation work consisted of three different levels. At the top there was the simulation experts. The simulation experts consisted of those employees with the highest level of skills within simulation, alongside the designated work tasks cantering simulation. The simulation experts were the driving employees in the simulation work and are therefore placed at the top in the hierarchical chain. In the middle of the hierarchy was the production technicians. The production technicians were placed in the middle of the hierarchy chain as they acted as the interchange in communication between the simulation experts and the operators. Information regarding the improvement work and simulation work went through the production technicians, booth upwards and downwards. The production technicians had different work tasks, different backgrounds and different knowledge regarding simulation. Lastly and at the bottom of the hierarchy is the operators. They are primarily concerned with the work at the production level. In the hierarchy they primary communicate with the designated production technicians for each production department.

The arrows in Figure 3 depicts the communication flow between the different departments. As depicted in the figure, the communication between the different hierarchical levels primarily went through the production technicians, and seldomly did the operators come into direct contact with the simulation experts.

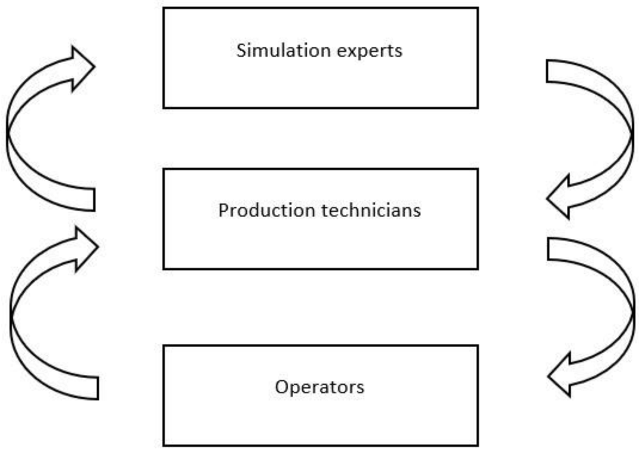

Figure 3. Hierarchical levels within simulation.

The method of sampling used in this study was a Snowball sampling. According to Saunders et al. (2007) Snowball sampling is used when it is difficult to identify possible interviewees. This method consists of four steps:

1. Contact one or two cases in the population.

2. Ask these cases to identify further cases.

3. Ask these new cases to identify further new cases (and so on).

4. Stop when either no new cases are given, or the sample is as large as is manageable.

By doing this method it was possible to identify possible candidates to interview. On an operator level this was done through first interviewing those operators with most responsibility and letting them suggest other operators that might be of interest based on their age, experience, and education. On a production technician level, the correspondents were chosen based on the insight from the simulation experts. Parameters for choosing the production technicians to interview where based on experience, daily work tasks, and education. The idea was to find a suitable correspondent to interview that could represent the larger population.

The interviews focused on understanding the usage of simulation amongst the three hierarchical levels, the knowledge amongst the employees at the three hierarchical levels, the continuous improvement work and how the three different hierarchical levels managed and work with continuous improvements, and the support provided for the three hierarchical levels regarding the simulation work. The questions was based on these subjects, and the empirical data presented in chapter 4 is divided into these subjects for each hierarchical level.

2.5 Data analysis

The process of analyzing the data gathered from the case study will be a thematic analysis approach. Thematic analysis is used for analyzing qualitative data and is a method used for identifying, analyzing, organizing, describing, and reporting themes found in data (Nowell et al., 2017). A theme is something found in the data that captures something important related to the research questions and/or may be something that frequently appears in different places in data, such as from different interviews. According to Braun and Clarke (2006) a Thematic analysis is performed in 6 steps, which are the following:

Familiarizing with found data. In this step the researcher transcribes the data, reads it, and makes notes of initial ideas and areas of interest.

Generating initial codes. In this step the researcher codes the data into different groups.

Searching for themes. In this step the codes are grouped together into different themes.

Reviewing the themes. In this step the researcher checks if the themes work in relation to the codes and the entire data set.

Defining and naming themes. In this step the researcher reviews the themes and generate definitions and names for each set of themes.

Producing the report. In the final step the researcher performs the analysis using the themes and research questions and the gathered literature.

2.6 Validity and reliability

To achieve a high state of validity and reliability, this study has used Guba and Lincoln (1982) and the criteria for achieving validity and reliability presented in their research. Guba and Lincoln (1982) have summarized it into four different criteria, *Credibility, Transferability, Dependability* and *Confirmability*, that needs to be fulfilled to achieve validity and reliability in a study.

Credibility. Credibility concerns the internal validity of the study and how well the collected the data represents the reality. To ensure the credibility of this study the researchers used *Prolonged engagement*, which means that enough time was spent in the data collection to ensure that the phenomenon where fully understood. The researchers also used *Triangulation*, which means that different methods and sources was used to collect the data. Finally, *Member checks* was used to verify the data collected, this means that the individuals involved in the study was given the opportunity to verify their answers in interviews.

Transferability. Transferability concerns the ability to perform an identical study in another setting and receive the same results. To ensure the transferability of this study two methods was used *Theoretical-purposive sampling*, which means that as much data as possible was collected to maximise the amount of information and *thick description*, which meant that the entire study is described in detail.

Dependability. Dependability concerns the ability for the reader to judge the reliability of the study. To ensure the dependability of this study *Overlapping methods* was used. Overlapping methods means that different methods of collecting data was used on the same subject.

Confirmability. Confirmability concerns to which degree the results in the study can be confirmed by other researchers. To ensure this *triangulation* was used alongside *confirmability audit* where the study is validated by other researchers with similar knowledge to establish the truthfulness of the results.

2.7 Ethics

To ensure that this study was performed in the right way, and did not break any ethical standards, several measures of ensuring this was taken. Before the start of the interviews, each correspondent was informed that the results from the interviews were to be anonymous and that the correspondents names were not to be used. The only information about them used in the final report would be their role, which they shared with several other employees. *Anonymity* is one of the core concepts of research ethics, and it is important as researcher to clearly demonstrate how anonymity will be achieved (Greaney et al., 2012). Another important concept of research ethics is *informed consent.* Informed consent implies that the researcher thoroughly describes the objectives and implications of the research, for the participants to be fully informed when deciding whether to participate in the study (Doyle & Buckley, 2016). In this study the correspondents in the interviews were given a description of study consisting of how they could contribute, what the areas of interest was, what the goals was and how their answers would be used. For each correspondent it was made sure that they understood this and were aware of that they did not need to participate if they did not desire it.

3 Theoretical background

This chapter presents the collected theoretical data. The chapter is divided into sections, where each section describes a specific topic.

3.1 Link between research questions and theory

To fulfill the purpose of this study, two research questions were investigated and answered. The first research question investigated the challenges that can be found in practice and was therefore solely based on empirical data. The second research question investigated how the challenges found in practice may be overcome. To answer this research question, theoretical data was used. Figure 4 presents the link between the research questions and the topics that can be found in the theoretical background.

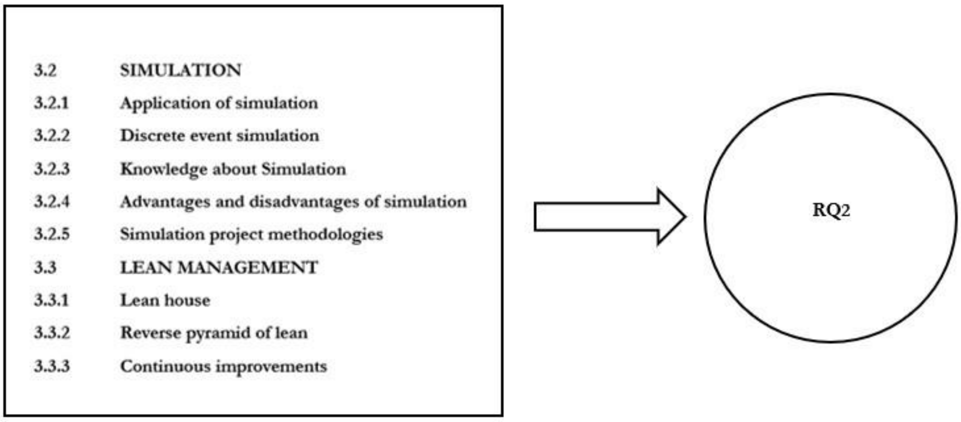

Figure 4. Link between theory and research questions.

3.2 Simulation

Simulation can be defined as *"the imitation of the operation of a real-world process or system over time"* (Banks et al., 1999). According to Banks et al (1999) different types of approaches is suitable for different types of problems. When working with systems of larger scale, with a high level of complexity, it is more suitable to collect data over time and analyze the data and try to estimate what level of performance the chosen system would have. Therefore, by using simulation the complexity can be solved (Song et al., 2016). The second approach would be a more statistical approach counting probability theories and algebraic methods (Banks et al, 1999).

A production system consists of multiple processes containing many different steps with different needs. In today's market and economy, the processes need to be optimized and modified continuously over time to stay competitive. Besides from current products the market also demands new products with other needs than the current ones. Therefore, companies need to develop new and optimized production lines parallel with optimizing current lines (Steinemann et al., 2013; Afazov, 2013). Companies often establish Lean tools combined with performance systems that monitors different parameters such as waste, cycle time, waiting and rework (Silva & Botter, 2009). To be able to create and control a system there must be different variables defined. A definition of this would be to define the system as an entity and recognize its attributes. Because an attribute is a part of the entity. For example, if a company is analyzing a food truck company. The customers would be entities and the amount of buying power they had would be one attribute.

Modern Manufacturing systems, especially in automotive industries can be extremely complex. This is due to the level of steps that are included, about 500 steps is not unusual. New manufacturing system also have complex equipment with a lot of data concerning batch processing, maintenance, and downtime just to name a few (Fowler & Rose, 2004).

3.2.1 Application of simulation

According to Banks et al (1999) the application of simulation is vast. It can be applied to many different areas, not only production. Examples of this is presented in Table 1.

Table 1. Descriptive table of the different applications of simulation.

Business processing	**Decision support tool**	**Manufacturing applications**
Simulation can be used for forecasting the demand of products.	Logistics, Transportations, and distributions	Using simulation to select the most efficient and optimized buffer size or WIP in the system.
Taking into consideration factors such as, seasonal demand.	Operating policies	Optimizing and analyzing stops, planned stops and plan for maintenance.
Construction engineering and project management.	Forecasting	Can provide the company with a holistic view of their manufacturing systems.
Scheduling over building sites	Real time data	

3.2.2 Discrete event simulation

According to Holst (2004) there are three important characteristics of discrete event simulation: the answering of questions, the imitation of systems and an increased understanding of the world.

Discrete event simulation or DES is one the most popular simulation techniques. DES have several areas of application and possible functions that can help a company.

Generally, DES is used to model, simulate, optimize, and visualize production processes, systems, material flows and logistics activities (Huynh et al., 2020). DES is a powerful tool when used for analysis of problems or forecasting if there will be any problems in the future. It also verifies and controls new or current systems. It is often used in the decision-making process to support any decision with facts (Silva & Botter, 2009).

3.2.3 Knowledge about Simulation

According to Banks (2001) a simulation analyst needs to have several different skills to be able to work properly with simulation tools. The different skills are divided into three different categories *Required skills of a simulation analyst, Desired skills of a simulation analyst* and *Acquired skills of a simulation analyst*. The required skills of a simulation analyst are that the person is detail oriented, organized, analytical and have a logical thinking. The desired skills of a simulation analyst are that the person is sceptical, pragmatic, and have experience about simulation. The acquired skills of a simulation analyst are that the person should be patient, flexible, and be able to present the performed work.

Carson (2004) suggests further that a simulation analyst needs to have good communication skills alongside knowledge about programming, modelling, and some knowledge regarding probability and statistics. A simulation analyst cannot be afraid to ask questions and not be quick to jump into conclusions. Adding to the findings of Carson (2004), Robinson and Davies (2010) divide the skills needed of a simulation analyst into two segments, technical and socio-political. A good simulation analyst needs to have a mix of both, with technical skills in computing, statistics, data collection, modelling, analysis and implementation and socio-political skills in project management, people management and communication.

3.2.4 Advantages and disadvantages of simulation

There are different advantages and disadvantages with simulation according to Banks et al. (1999). One of the reasons for using simulation is that it can accurately represent a real system. Simulation makes it possible to develop a system without assumptions. This process of changing inputs and different characteristics of either an existing or new system in different scenarios can result in a new implementation of a system, depending on what type of results is presented.

According to Pegden et al. (1995) simulation has for the most part advantages but also some disadvantages, which is presented in Table 2.

Table 2. Descriptive table of the different advantages and disadvantages.

Advantages	**Disadvantages**
New policies, operating procedures, decision rules, information flows, organizational procedures, among others, can be explored without disrupting ongoing operations of the real system.	Simulation results may be difficult to interpret. Since most simulation outputs are essentially random variables, it may be hard to determine whether an observation is a result of system interrelationship or randomness.
Hypotheses about how or why certain phenomena occur can be tested for feasibility.	Model building requires special training.
Bottleneck analysis can be performed and other optimization tools indicating where work in process, information, materials, and buffer size.	Simulation modelling and analysis can be time consuming and expensive.
A simulation study can give a holistic view of how the system is performing and compare it how the workers think it operates.	Simulation is used in some cases when an analytical solution is possible, or even preferable.
Insights can be attained about the importance and interaction of variables.	Variation in human judgement when conducting decisions
"What if" questions can be answered, the most useful in the design process of a new system.	Model building requires special training.

3.2.5 Simulation project methodologies

According to Banks et al. (1999) there are 12 steps when conducting a simulation study, and, similar figures and steps can be found in Shannon (1975), Law (2007) and Gordon (1978). This is also presented in figure 5 and figure 6. The models presented by Banks et al. (1999) and Law (2007), showcased in this study, shares many similarities. The steps presented in the models are like each other and presented in the same order, do they do not share the same description. In the model presented by Law (2007) some of the steps have been merged, in comparison to the model by Banks et al. (1999). This concerns the steps of problem formulation and objectives, data collection and modelling. Besides those steps the models share the same steps, but the model presented by Banks et al. (1999) showcases a more in-depth processes of conducting the simulation project, through several guidelines aiding the performer in which direction to move. The model presented by Law (2007) provides less aid for the performer, trough showcasing the steps to go back and forth in the model.

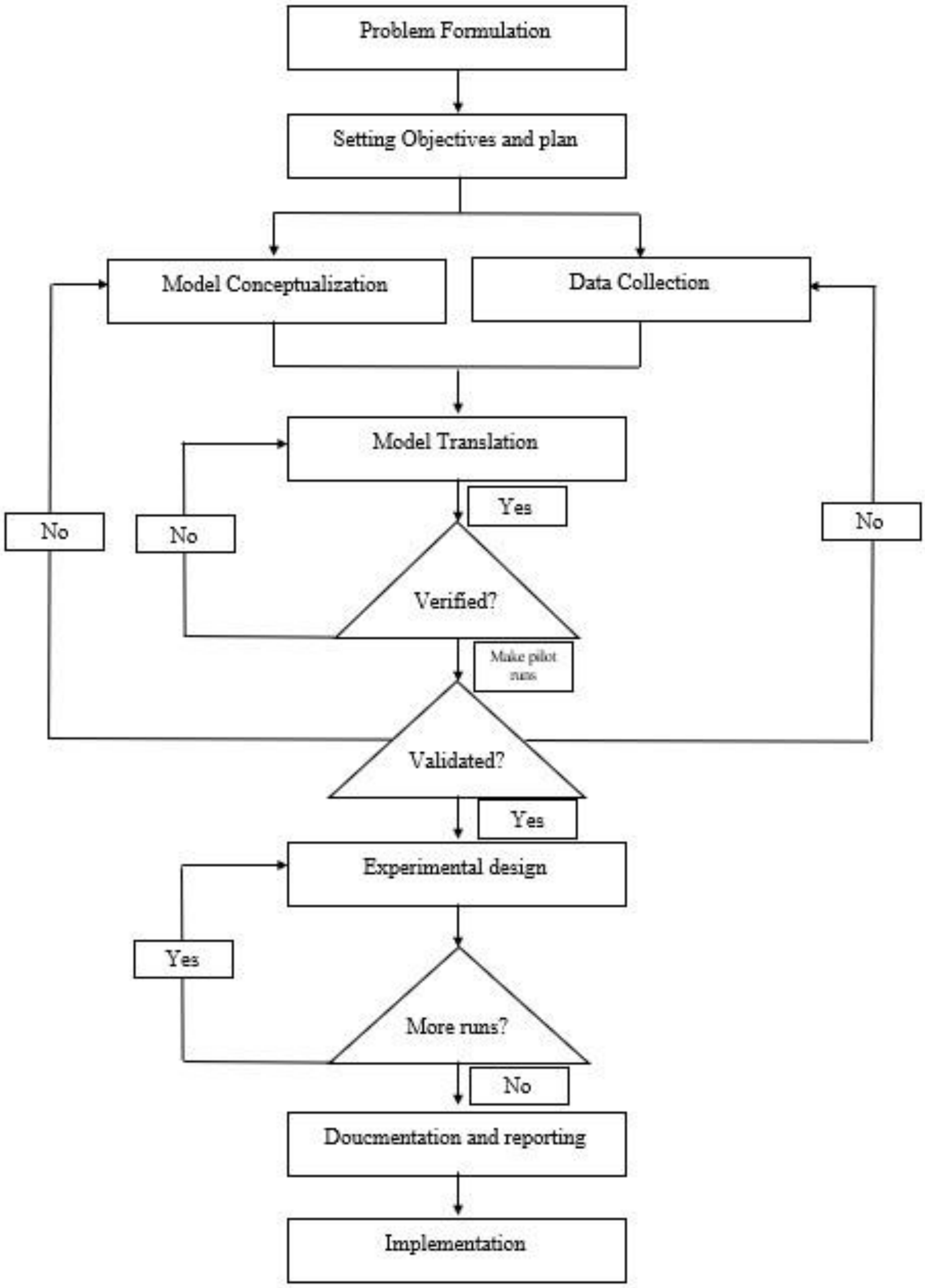

Figure 5. Steps in a simulation study adapted from Banks et al. (1999)

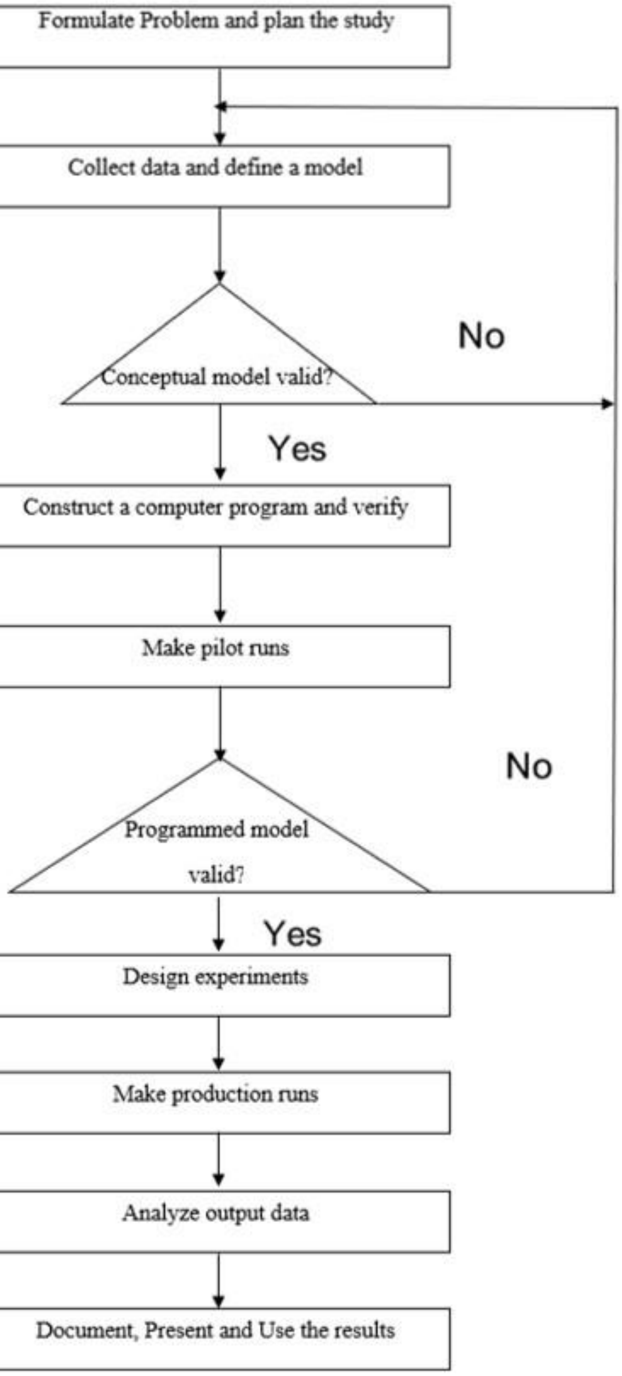

Figure 6. Steps in simulation study adapted from Law (2007).

1. Problem formulation

With every project there needs to be a clear and well formulated problem statement.

The analyst should have prepared and make sure that there is no gap between client and analyst, and that the goal is clear. In most of the cases according to Banks et al. (1999) it is necessary to have specified goals and a strategic consensus because of minimizing misunderstanding within the project and view of the goal (Manlig et al., 2011). According to Baer and Nickerson (2013) there is different types of problems and problems with a higher number of variables often need more precise and based on facts formulated question.

2. Setting of objectives and overall project plan

When deciding if simulation is necessary or not there should be an evaluation on setting the objectives. The objectives give an indication if a simulation study would be a suitable approach to chosen problem. The different requirements should be clear after this stage, how much people needed, expected result and number of days to accomplish each stage (Banks et al, 1999).

3. Model conceptualization

At this stage the actual system is created if possible. It is not a certainty that a simulation model can be created but there are some guidelines that can be followed to give best condition to create one. The best choice is to start with a simple model and then build the system with information towards a system with higher level of complexity. The process of modelling is based on the ability to comprehend different essential variables of a problem. To base decisions on fact on basic assumptions that it is certain to characterize the system. And as mentioned, to enrich and elaborate the model until it is useful (Banks et al, 1999).

4. Data collection

There is always an ongoing process with creating the model because it always changes in some way. Compared to the beginning of modeling with a simple model and a more complex model the amount of data needed can change drastically (Shannon, 1975). It is necessary to start with the data collection as early as possible in the simulation modeling phase. The data collection is often the most time-consuming phase of every project. It is often called Input Data Management and it is crucial to input high quality data to have a successful DES (Skoogh & Johansson, 2008; Banks et al., 1999). The data collection methodology is presented in Figure 7.

There exist different tools that can be used for automating the data input process such as Generic Data Management. It is commonly used on a frequent basis in manufacturing companies (Bokrantz et al., 2015).

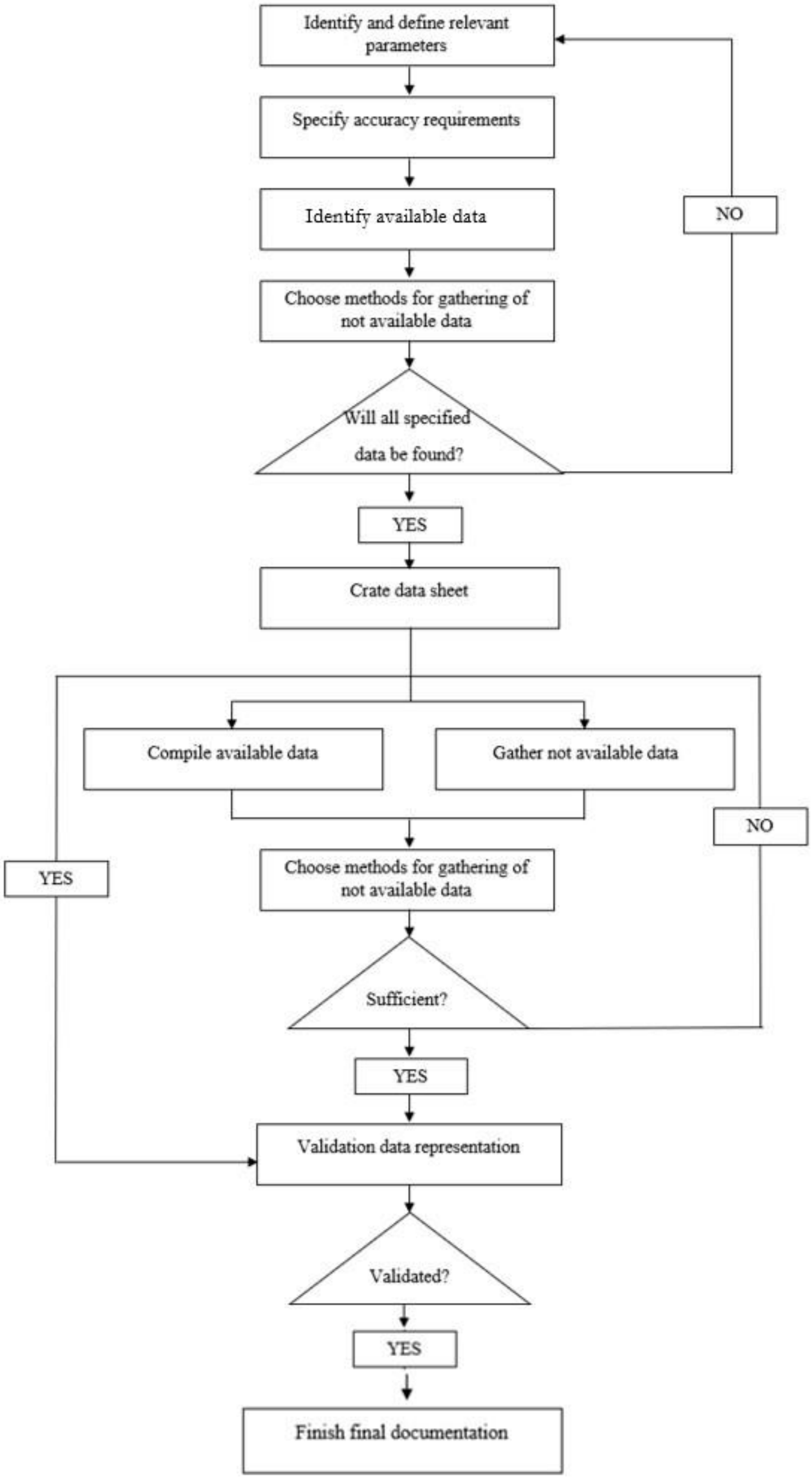

Figure 7. Steps in data collection adapted from Skoogh and Johansson (2008).

5. Model Translation

There will be a high level of information and calculations in the model. Because of this there is a need of a program than can handle these as effective as possible. Examples of programs is Plant simulation and Facts analyzer. There are different simulation languages such as GPSS/H for special purposes and for the manufacturing material handling department there is AnyLogic, Arena, Automod, and Enterprise Dynamics. It is almost always a better option to go with the coding alternative, but it can be made with little coding or in some cases no coding at all (Banks et al., 1999).

6. Verified?

In this stage common sense is used for completing translation the model into the program. Because of different languages or information missing it could be necessary to compare the model to see how it is performing in the program compared to expected results to find and debug the errors. If there are any errors than there would be a need to correct these to be able to verify a model and determine it as acceptable. If all the parameters and structure of the model is in the program, the system is verified (Banks et al., 1999).

7. Validate

Validation of a model is completed through calibrating the model over and over. To improve the model by using and comparing inconsistencies between actual system behavior to the model (Banks et al., 1999). To find the most crucial factors a sensitivity analysis is recommended. If the crucial factors are found the factors with the most impact on the performance on system is found (Law, 2007).

8. Experimental design

The experimental stage is where different alternatives of a solution is presented. By simulating different alternatives, the most efficient one can be found through calculations and algorithms. The length of the simulation should be decided and number of replications of the test runs. The more test runs that is made the more accurate is the results (Banks et al., 1999; Law, 2007; Manlig et al., 2011).

9. Production runs and analysis

The production runs are made and monitored to be able to analyze the performance of the systems different scenarios (Banks et al., 1999).

10. More runs?

If there is necessary to do more runs there should be additional experiment runs. The analyst of the study should decide if it is needed and what should be tested. Examples of when more runs should be made is when the results differ to much from the reality, or the variation is too big. (Banks et al., 1999; Law, 2007).

11. Documentation program and report results

There should be a routine for documenting the results concerning when and how it should be documented. It is crucial for future use of any model to know where the documentation is, and how to use it (Manlig et al., 2011). For other future use there should exist a detailed standard created with an old result (Law, 2007).

12. Implementation

When all the twelve steps have been completed there should be a model that can be presented for the stakeholders/client if the previous steps have been successful. And if accepted there should be an implementation of the model (Banks et al., 1999).

3.3 Lean management

In the 1950s the Japanese automobile company Toyota developed the Toyota Production system, was later to be adopted in the west under the name of Lean. The idea of the Toyota Production system was to enable the company to produce several different products on limited equipment, which lead to several innovative ideas both technical and organizational. The system introduced the production on a single line based on demand as well as it put much emphasise on the involvement of employees to come up with possible improvements, instead of the usage of experts in this area. Over the years the Toyota Production system spread from Japan to the rest of the world and the term "lean" was coined in 1990s to describe the way of thinking (Jones & Womack, 2017). The term lean can be described as "doing more with less", which applies to the entire organisation.

3.3.1 Reverse pyramid of lean

Creating a lean culture is not an easy task. Many traditional companies today work with the view of the CEO on top of everybody, managers under the CEO and at the bottom all the other employees (Found & Harvey, 2007). This type of organizational structure was created as a result of that in the past it was believed that only a handful of people could understand certain type of questions which had a higher level of complexity (Liker, 2006). It was also believed that it was more flexible and a more efficient idea to process reality if the ideas came from above and went through the hierarchal pyramid from top to bottom (Chou, 2016; Johnson, 2016).

The best ideas will generally come from the people doing the work closest to the production. The people in the pyramid are the foundation of the company and the greatest asset. By flipping the pyramid communication can be supported through the enterprise between all workers and create a more flexible and responsive company. This is presented in Figure 8.

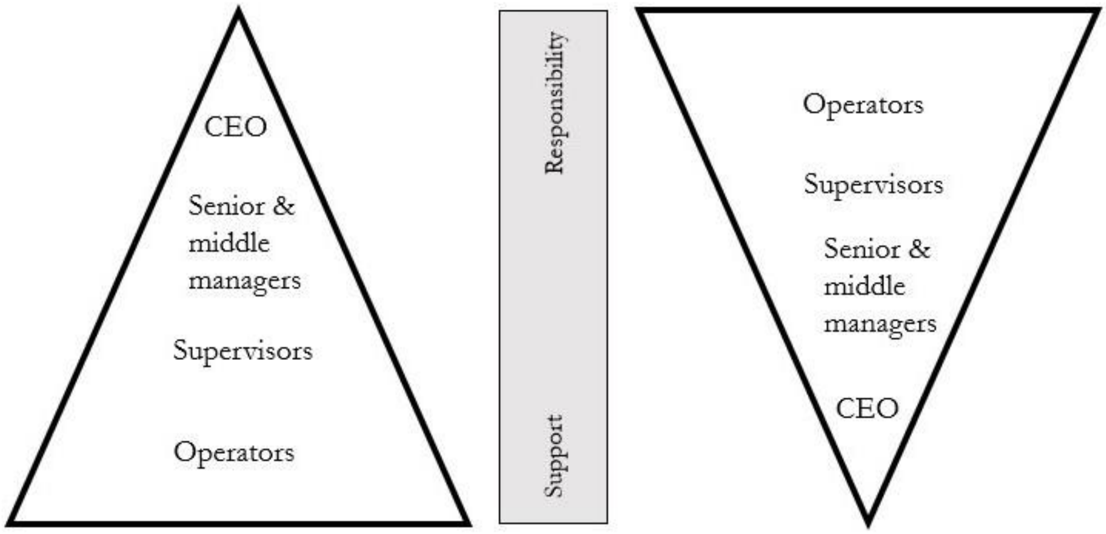

Figure 8. The reverse pyramid of lean adapted from Found & Harvey (2007).

3.3.2 Continuous improvements

Continuous improvements are a tool often used for improvements work in management (Bergman & Klefsjö, 2007; Petersson et al, 2010). Within Lean one of the main goals is to eliminate waste through improving the value stream by applying different tools such as continuous improvement (Petersson et. al, 2010; Likert, 2004). Continuous improvement focuses on the improving the processes rather than the products. By improving the process, the company will likely get a better product (Petersson et al, 2010). According to Womack and Jones (2003) and Petersson et al. (2010) is said that kaizen, in specific must come from the process itself because it is where the identification of waste happens. There cannot be an improvement if there is no existing standard (Backlund and Sunqvist, 2018). According to Berger (1997) there is two different types of categories when looking at the continuous improvements' standard. The categories are related to level of standardization. High level of standardization means that continuous improvement is more integrated and originates from individuals, while work in a less standardized environment with parallel improvement processes often works in project and the continuous improvements work does not come from the individuals. The picture in Figure 9 defines the relationship. In Figure 9, continuous improvements is shortened to CI.

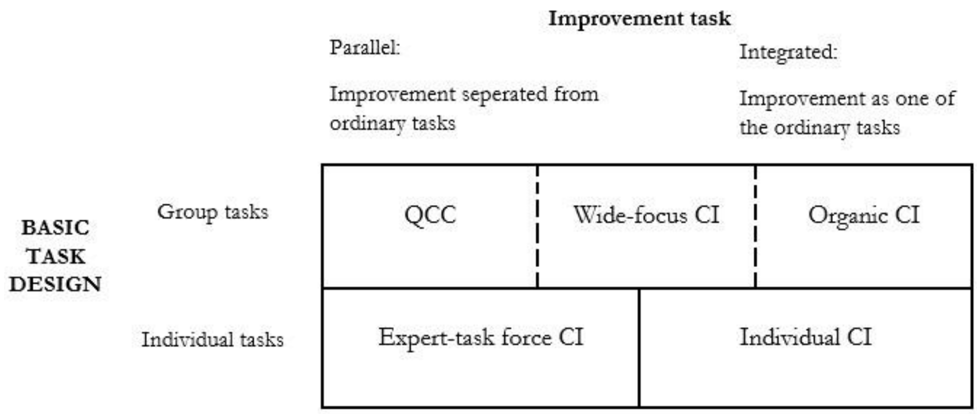

Figure 9. Different organizational structures for continuous improvements adapted from Berger (1997).

According to Berger (1997) the organizational structure for continuous improvements typology states that the design is based on the two dimensions mentioned in Figure 9 in Table 3.

Table 3. Table of the different task groups and description of the link to Figure 9.

Quality control circles	**Wide-focus CI**	**Organic CI**	**Expert task force CI**	**Individual CI**
A group of employees who meet regularly to discuss, investigate, and find solutions to qualityrelated problems.	A combination of organic CI and task force CI. By combining continuous improvement process team, it is used for temporary operations and CI in self-managed work groups.	Improvement operations are combined with multifunctional work groups. Organic CI differs from conventional CI models in that improvement activities are not delegated to specialists for design and planning, and decision-making is not delegated to outside authorities.	This type of CI is based on the use of a temporary expert task force comprised of different competences such as quality engineering, and maintenance professionals, and hence the scope of improvement tasks necessitates a significant amount of time and cost.	Individuals initiate improvements, which are then organized into a proposal system. Individuals come up with ideas, but it is up to specialists to put them into action.

There are different tools used for continuous improvements such as PDCA within total quality management or within lean called Kaizen (Liker & Morgan, 2006). Both tools are used for continuous improvements. Edwards Deming first created the Deming cycle which most of continuous improvement tools today are based on Deming (1982).

According to De Jager (2004) there are four different components of continuous improvements, show in Figure 10.

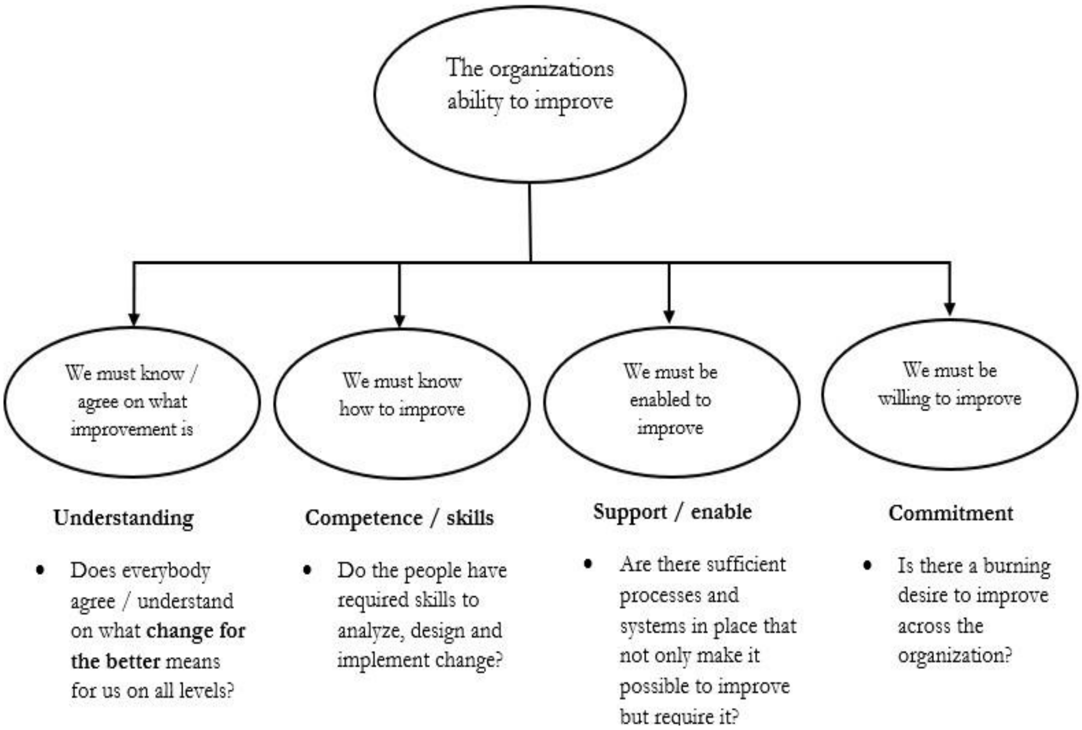

Figure 10. Different Components of continuous improvements adapted from De Jager (2004)

According to Besterfield et al. (1999) and Bergman and Kefsjö (2007) using this type of problem-solving method can give great results.

4 Results

The following chapter presents the results from the case study. Firstly, a description of the case company is presented. This is followed with the results from the interviews, which is divided into sections based on which interview the result is connected to.

4.1 Case company description

The case company for the study was Volvo Group Truck Operations, shortened Volvo GTO. The company is located in Skövde, Sweden and has approximately 3 000 employees. The plant produces and exports engines and engine components for Volvo trucks, buses, and construction equipment and to other Volvo production sites all over the world. The plant produces more than 100 000 engines each year. The main processes are foundry, machining, and assembly. Volvo GTO has a simulation department working with projects concerning current and future production system designs and forecasting.

4.2 Simulation experts

The interviews consisted of interviews with two simulation experts. The experts had different backgrounds, where one had been employed at the case company for several years and the other one being newly hired but with several years of experience working with simulation in another automotive company. The interview guide can be found in the appendix. Following is a summary of the interviews, where the answers have been divided into four separate topics: usage of simulation, control and information flow, support, and continuous improvements.

4.2.1 Usage of simulation

When asked about the usage of simulation, both simulation experts stated that the usage of simulation tools was primarily connected to larger projects. Larger projects in most cases concerned the implementation of new production systems or new products. Outside the larger projects, the usage of simulation was limited. The individual departments themselves did not use simulation on a set interval or was required to use simulation when making improvements. The simulation experts were primarily involved in the larger projects but stated that on request they could perform smaller simulation tasks, but this was unusual and did not occur frequently. The simulation experts stated that this was due to mixed interest and lack of competence in using simulation amongst the employees making the requests.

When asked about if their work was used for other purposes, such as education and information the simulation experts stated that the primary use was testing possible changes within the organisation and that only on rare occasions their work was used in educational purposes. These rare educations were primarily related to larger projects, where the people involved in the projects needed to understand the work. Outside the larger projects, the simulation experts seldomly showed their work to the operators that were not involved in the projects. The production technicians were more frequently presented with the work by the simulation experts.

4.2.2 Control and information flow

When asked about the information flow concerning the simulation work, the simulation experts stated that in general, the information from them reached the production through the production technicians. Within the larger projects, the production technicians and operators involved in the project received the information first hand. They were then intended to transfer the relevant information to the employees not involved in the project but affected by the outcome of the project. The simulation experts stated that there is no set structure for the information flow within the company, but that the employees that needs to receive the information, at minimum, will receive it.

Outside the larger projects, the simulation experts seldomly share their work first hand with the employees within the production and there exist no standard for how and when this should occur. One of the simulation experts estimated that they show their work to the employees within the production approximately two times per year. When the employee within the production is shown the simulation work, the focus is primarily on project leaders and production technicians, with the aim at giving them the knowledge and understanding about how the production systems performs. The simulation work is shown to the operators on request.

4.2.3 Support

When asked about what type and amount of support the simulation experts have access to, the simulation experts stated that they have several different options. The most important and comprehensive support they have is in the Master process level, which is a handbook. The Master process level consists of three levels, A, B and C and consists of a framework for working with simulation. This includes for example support for technical aspects of using the simulation software alongside different challenges that the simulation experts may encounter in their work. Besides the Master process level, the simulation experts have support from the developers of the simulation software's alongside IT support, concerning more technical questions they might have. Finally, the simulation experts work closely with the local university, where they can exchange ideas and find solutions to different problems. The simulation experts also stated that they work closely with each other and that they help each other if needed.

4.2.4 Continuous improvement

When asked about the amount and frequency of improvement suggestions that they receive from the production departments, the simulation experts stated that this occurs approximately once a year. The improvement suggestions can in theory come from anyone within the departments. The simulation experts also stated that there are no constraints that limits improvement work to be completed without the usage of simulation and that simulation is rarely used to make minor improvements. The amount of improvement suggestions received by the simulation experts depends on the desire to test the change within a simulation environment before actual implementation. Since there are no constraints hindering improvement work to be completed without simulation, it is up to the employees to ask the simulation experts for help and request simulation to be used.

Most of the improvement work is conducted within the larger projects, where most of the simulation work is performed. The reason for the usage of simulation in larger projects is mainly due to the reason that Volvo wants to base their decisions on facts.

4.3 Production technicians

The interviews consisted of five interviews with different production technicians at the case company. The production technicians had different background whereas they had worked at the case company spanning from 5 years to 30 years and had different educational background. The interview guide can be found in the appendix.

4.3.1 Usage of simulation

Overall, the consensus amongst the production technicians was that simulation is something that can be used to increase productivity and the common understanding within the company. When asked about where they saw the potential of implementing simulation, the correspondents recognized that simulation can be implemented in some instances, but also recognized that implementing simulation would require time and resources. When asked about if simulation can be used for their work, the views amongst production technicians were different. Some already used simulation in their work and saw the value of using it in their daily operations, and some did not see the value to use it individually in their work. All the production technicians stated that the amount of work and resources it takes to implement simulation might be an issue. The level of work that needs to be put in the models for them to be validated and easy to work on, were recognized as a very complex and time-consuming task.

All the correspondents stated that some people work with simulation but not all, and not all feel the interest or need in their daily work. The first and second production technicians used simulation in their daily work. It was common between the correspondents to feel that simulation is something good if used right, but it was also stated that it is not that easy to just implement and start using it. They all recognized that is takes lots of resources to be able to work with simulation efficiently and without frequent use of the tools they felt that they would not be able to perform the best results. Two of the correspondents stated that they feel that it would be too time consuming to implement simulation into their daily work, since they now already have too much to do and that giving them more work would be too much for them to handle. Most of the simulation work today is within different projects. Simulation is used in almost all projects when planning for new production lines or products.

Overall, the correspondents had some type of education except for one. They all had some type of introduction in simulation taken at either Volvo GTO or Skövde University. Most of the correspondents felt an interest or acknowledged that simulation would be something that could improve their work.

4.3.2 Simulation Knowledge

The knowledge about simulation and simulation work varied amongst the correspondents. When asked about what type of education or knowledge about simulation they had, it was stated that two of the production technicians had a bachelor's degree that encompassed simulation, one had gone through education about simulation at the case company and two had limited to no knowledge about simulation and had no formal education within it. The two correspondents with a bachelor's degree that encompassed simulation had high knowledge about simulation and can be described as simulation experts. The other correspondents stated that if they needed help with simulation or needed simulation in their work, they asked the more skilled simulation users for help. The production technician that had completed education at the case company, had some knowledge within the subject and where able to perform simpler tasks using simulation as a tool. For instance, the correspondent where able to run simulations and analyse the result but lacked the knowledge to perform more demanding tasks such as optimization or modelling larger models. The production technicians that had no education within simulation and did not use simulation in their daily work and had limited to no knowledge about simulation. When asked about how they had encountered simulation most of them stated that they had come in to contact with simulation through projects, and where aware of how and why simulation is used within the company, but they were unable to perform the work themselves. Instead, they used either those production technicians with high simulation skills or the simulation experts if simulation was needed within a project.

4.3.3 Support

The production technicians stated that there exists support from Volvo GTO with education and IT support from a third party. Even do this support is available. the production technicians in most cases ask the simulation experts for help or guidance when help is required.

4.3.4 Continuous improvement

When asked about their knowledge about the process of improvement work at Volvo GTO the technicians stated that it is used in the daily work, but not in a standardized way. Most of the correspondents stated that Volvo production system (VPS) is something that is printed into them and that they are all working the Volvo Way subconsciously. Sometimes the improvements suggestions come from the operators but most of the times there is an existing problem that needs to be fixed. For example, a bottleneck or machine breaking down too often. Most of the production technicians stated that before doing any improvement work suggested from the operators, it must be prioritized and depending on if there are issues elsewhere, these types of improvements have low priority. In most projects concerning the production, simulation is being used either as an educational tool to demonstrate how the systems are performing or for optimization of different lines. Projects often concern larger scale improvement work and implementations, and when it comes to smaller improvements, simulation is rarely used.

When asked about how the improvement work information is spread out within the company most of the technicians stated that within the project everyone is updated and often team leaders are present in the projects. And the production technicians hope that the team leaders spread the information to the workers. One of the production technicians stated that Volvo GTO has competitions about improvement work every month on their intranet. It was stated that the information flow is traditional, coming from the upper management travelling down to the shop floor workers.

4.4 Operators

The interviews were conducted at one of the production departments and consisted of four separate interviews with four operators. The operators had different backgrounds and experiences. The operators consisted of one team leader and three operators, where the most senior member had been working at Volvo GTO for 17 years and the least senior for shorter than one year. The interview guide can be found in the appendix. Following is a summary of the interviews, where the answers have been divided into two separate sections.

4.4.1 Continuous improvement

When asked about how the process of making improvement suggestions was designed, the answers differed amongst the operators. There exists no clear process description for the operators that should be followed when making improvement suggestions. Instead, the operators stated that they report their improvement suggestions to the managers and production technicians, where all the operators gave different answers to the question. All the operators were also unaware of the process of realizing the improvement work after they had submitted their suggestion. One operator stated that it can take up to three years before anything happens, and that the operator needed to push for something to happen. Usually, the operator would ask what was happening concerning the improvement work on a frequent basis and in most cases the employee would not hear any news and never see the improvement idea fulfilled. It was generally accepted amongst the operators that the people in charge of following up and implementing the improvements were too busy and therefore their improvement suggestions wouldn't be realized.

When asked about how often the operators experience an improvement being implemented and if they are informed about the changes, the operators gave different answers. Most of the operators stated that they were aware of that improvement work was being implemented at the time of the interviews and that major changes were ongoing, but neither of the operators could give a precise answer to what the changes where.

4.4.2 Simulation knowledge

When asked about their previous knowledge about simulation, most of the operators stated that they had no previous knowledge about simulation and were unaware of what simulation was used for. Some of the operators were aware of that Volvo GTO used simulation but could not specify which areas simulation was used in and how it was used to improve the company. Out of the four interviewed operators, only one stated that they knew what simulation was and could give examples of how it was used.

When asked about how often they come in contact with the simulation work being performed at the company, the operators stated that they had not been showed any simulation work. They stated that they had not been introduced to the simulation work at the company or received any education within simulation.

5 Analysis

The following chapter presents the analysis of the empirical and theoretical data. The chapter is divided into two sections, where the first presents the thematic analysis of the empirical data. The second section presents the analysis of the result from the thematic analysis and the theoretical data.

5.1 Thematic analysis

As described in the methods chapter, the first step of conducting a thematic analysis was to familiarize with the data. This was performed shortly after the completion of the interviews. In this step the empirical data gathered was transcribed and read through multiple times to identify possible areas of interest. When this step was complete, the data was coded into different codes, based on the similarities found in the data. Following this, the process of finding themes was initiated. Initially, six different themes were identified from the empirical data. Using a thematic map, the links between the six themes was investigated. In this process it was identified that one of the themes, *little to no knowledge about simulation*, was present in all the other themes and was therefore discarded as its own theme. Following this process, the result was five different themes that were to be analyzed. The thematic map is presented in Figure 11.

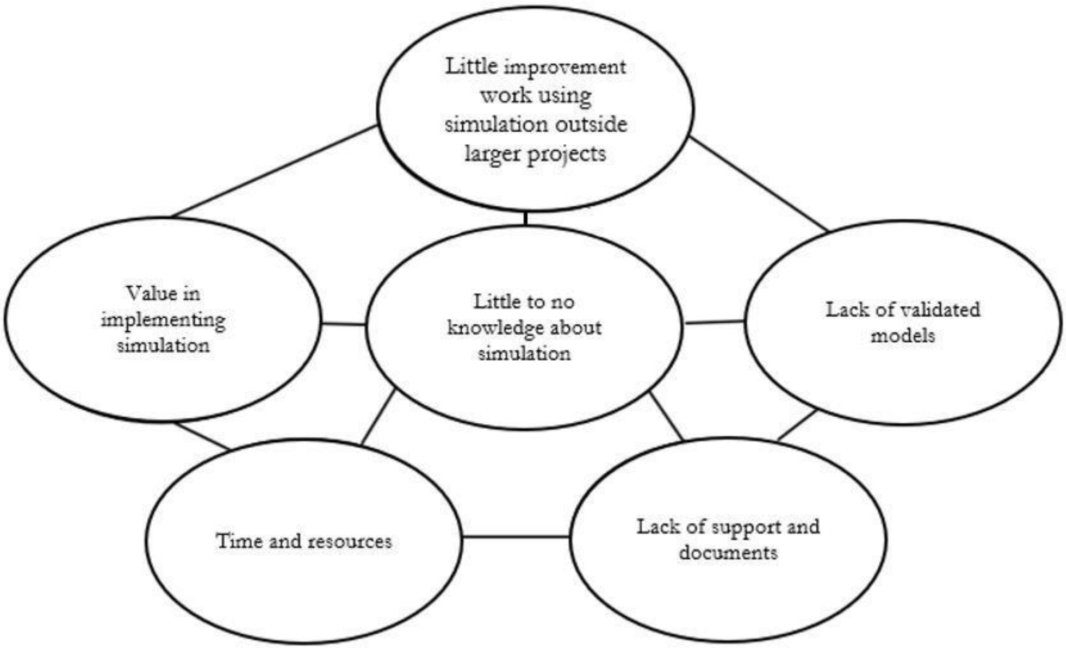

Figure 11. A thematic map over how the different themes are connected.

Little improvement work using simulation outside larger projects

The first theme, *little improvement work using simulation outside larger projects*, was present in all five interviews with production technicians. It was stated during the interviews that simulation was typically used in larger projects. The larger projects concerned for the most part larger scale improvement work or implementation of new production systems or products. When it comes to minor improvement work, on a more frequent basis most of the improvements was done without the usage of simulation.

Typically, in the larger projects there are cross-functional teams involved, where there were simulation experts present. The smaller improvement work was not prioritized and often handled by either the operators or the production technicians, where there was a lack in experience and expertise in using simulation. Therefore, most improvement work was completed without the help and usage of simulation. This situation applies to most of the daily work completed by the operators and the production technicians, as simulation was not used in a standardized way. Of the interviewed production technicians, two had extensive knowledge concerning simulation, and was therefore the only two of the production technicians that works with simulation frequently outside larger projects.

The operators stated that if they had any improvement suggestion, they could contact someone of the technicians. There was no standard of who they should contact and one of the correspondents even stated that it can take up to two years to get something done. There seems to be a gap in the information between technicians and operators concerning improvement work. Operators stated that they can give improvement work suggestion, but the process can be long and is not standardized. Same goes with the information. If there would be an interest the technicians stated that anyone could get a hold of this information. The simulation experts stated that they hoped the technicians would present project information or results to the members that was not involved in the project but would be affected by the results of the project.

Time and Resources

The second theme, *Time and resources* was present in the interviews amongst all the operators and the majority of the production technicians. Amongst the operators there was a lack of expertise and experience in working with simulation. The operators do not come into contact with simulation on a daily basis. The only instance where operators come into contact with simulation, was if they were involved in larger projects. There was a limited information flow, going from the simulation users down to the operators, including simulation work at the company. This had resulted in an unfamiliarity with simulation amongst the operators, which had led to a barrier in understanding how and why simulation may be used. Most of the operators lacked the understanding of what simulation is. This created a barrier in a possible implementation of simulation as tool to use for operators, since the basic knowledge was not present.

Amongst the production technicians, simulation was implemented to some degree. Depending on interest and time, as well as previous knowledge, the production technicians had the possibility to work with simulation on a frequent basis. Here, the views about simulation split between the production technicians. Those production technicians that had previous education within simulation saw a larger value in working with simulation and did so on a frequent basis. The production technicians with less knowledge about simulation could not see the value of using simulation in their daily work but recognized the importance of simulation on a larger scale within the company. Production technicians that were negative towards simulation stated that the reason for this was the already heavy workload and the high skill barrier required to be overcome to be fully capable in using simulation.

A common theme amongst the operators and production technicians was that the lower the age the higher the knowledge and interest in simulation was. This was also in line with the background amongst especially the productions technicians, as the youngest of the production technicians had an engineering education and background.

Lack of supporting documents and general support

The third theme, *Lack of supporting documents and general support*; was not present in all the interviews but was present in the interviews with the production technicians. When asked about what support they had in their simulation work, the production technicians that worked with simulation stated that the only help they could receive was from the simulation experts and IT-support concerning the simulation software and that they had no documents that could help and guide them. The production technicians with most knowledge about simulation also acted as a help and support for the others. The production technicians had the possibility to undergo education within simulation if they desired. This opportunity has been used by some of the production technicians, but not all due to a lack of interest and available time to undergo the education. The limited support for the production technicians limited their ability to further develop their skills within simulation work.

The simulation experts on the other hand had access to a larger amount of support. They had the possibility to directly contact either the developer of the simulation software for more technical support or the local university if expertise within simulation was needed. The simulation experts also had access to supporting documents, with detailed information about simulation.

Value in implementing simulation

The fourth theme, *Value in implementing simulation*, was present during the interviews with the production technicians. All the interviewed production technicians recognised to some degree that implementing simulation could benefit the company, but at different scale. Production technicians that did not work with simulation on a daily basis, recognised the value to use simulation on a large scale within the factory, but did not see the value for them to use it on a daily basis due to the complexity of simulation. It was also visible that there was a correlation between age, education and desire, and the potential value recognised in using simulation. The younger production technicians where the more positive towards simulation and to use it on a daily basis, as opposed to the older production technicians. Concerning the operators, it was difficult to evaluate their response as they lacked the understanding of what simulation was and how it was used.

Lack of validated models

During the interviews the production technicians stated how good a validated model would be. Not only to have something to compare with during improvement work but also into the daily work. Same goes with the simulation experts. But most of the production technicians and all the correspondents that knew the benefits from using simulation stated that it would be very time consuming and complex to make validated models on the different production lines. This led to a higher level of resistance in implementing simulation to be used on a daily basis. Also, the lack of current validated models does not support implementation of simulation but rather makes it more difficult and time consuming. The younger technicians were more probable to use simulation even though the level of complexity was high. Compared to the older technicians that did not have an interest or saw no real value for them specifically.

5.2 Theoretical analysis

Little improvement work outside larger projects using simulation

The first theme *little improvement work outside larger projects using simulation*, concerns the lack of structure concerning the CI work. Most of the improvement work performed was completed without the usage of simulation as a tool to aid the work. The reason for this was a lack of structure and standardization concerning how an improvement suggestion was proposed and then realized.

For an organisation to enable its operators to use and benefit from simulation when working with continuous improvements, there is a need for a set and standardized structure (Backlund & Sundqvist, 2018). Berger (1997) stated that there are two types of continuous improvement work, where the preferred type has a high level of standardization and is highly integrated into the daily operations of the employees.

Figure 9 shows the different organizational structures that concerns how companies operates when working with continuous improvements. As Berger (1997) states the desire is for a company to have a highly standardized and highly integrated continuous improvement work. Therefore, companies that are present in the left side of the model, where the improvement work is parallel to the daily tasks and have a low standardisation needs to move towards the right of the model to improve. This implies that the companies need to standardize their way of working with continuous improvements and integrate it to the daily tasks of the employees.

The exchange of information between the different hierarchical levels concerning simulation work and continuous improvements goes between the simulation experts and production technicians and the production technicians and the operators. Between the different hierarchical levels, the continuous improvement work needs to be standardised and integrated into the daily operations. Between the simulation experts and production technicians the preferred working method is called *Organic CI* and involves working with continuous improvements in multifunctional teams (Berger, 1997). This is like the method of working with improvement work in larger projects but should entail working with continuous improvements outside larger projects in an integrated manner.

The standardised working method in the exchange between the production technicians and the operators is called *Individual Ci* and it is the preferred working method for a highly standardised and integrated working procedure. This method involves that the individuals initiate the improvements in an organised proposal system. Through the proposal system, the suggestion for improvements is brought to and then handled by the specialists who act (Berger, 1997). A presentation of the work is presented in Figure 12. The figure depicts the desired communication ways between the different hierarchical levels. The different hierarchical levels should be able to communicate with each other directly, i.e. the lowest level should be able to communicate with the highest. This is showcased with the arrows. Between the different hierarchical levels is also the desired type of continuous improvement method showcased.

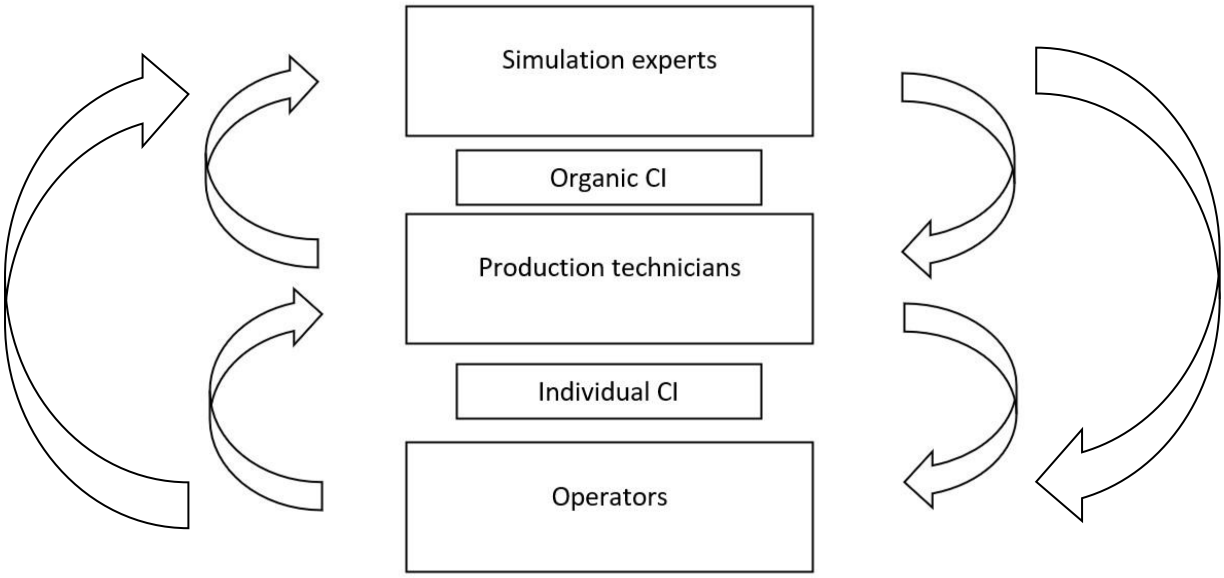

Figure 12. Simplification of standardization within the production for a company with low level of standardization.

By implementing a highly standardized and integrated working method for the continuous improvement work, the lack of usage of simulation in improvement work will be improved. This will aid companies in increasing the amount of improvement work and suggestions, leading to a better environment and conditions for enabling the usage of simulation.

To further improve the environment for continuous improvements, a change in the organizational structure is needed. Instead of the operators and supervisors (production technicians) acting as support for the CEO, the responsibility should shift towards the operators and supervisor having the responsibility and CEO acting as the support. The CEO in this case being the simulation experts. As shown in Figure 13 communication going from the operators and supervisors, increasing the speed and responsiveness, and an increase in improvement suggestions (Found & Harvey, 2007; Liker, 2006; Womack & Jones, 2003).

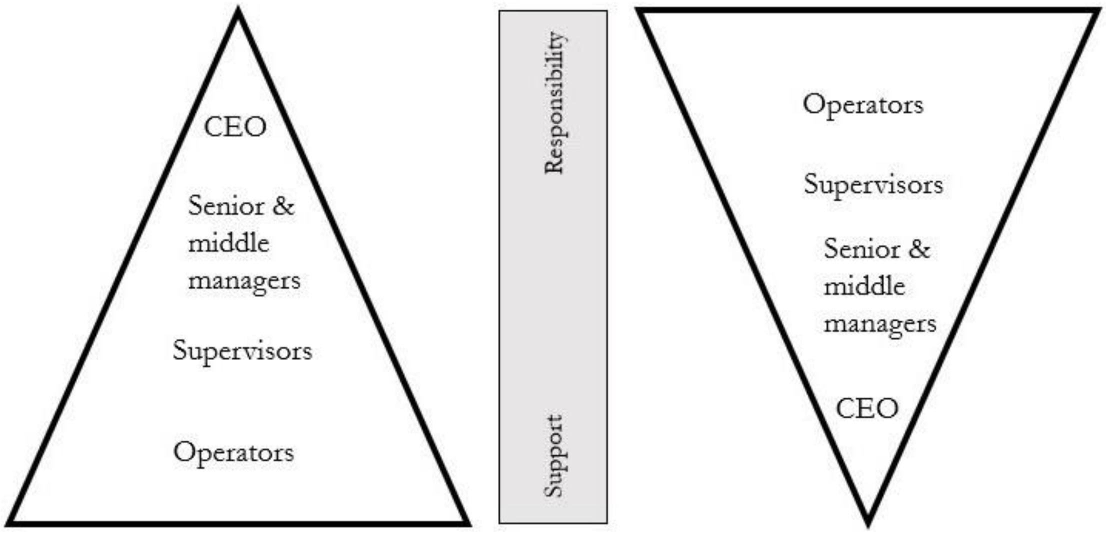

Figure 13. The reverse pyramid of lean adapted from Found and Harvey (2007).

Time and resources

Enabling simulation as a tool for operators requires time, resources, and effort from the operators as well as the company. Applying simulation have several upsides and advantages, but also several disadvantages which could discourage and prohibit an implementation. The mayor disadvantages with simulation, which can be seen in Table 2, is that model building requires special trading and is time consuming and that simulation results can be difficult to interpret (Pegden, 1995). This is strongly correlated with the required skills and knowledge for working with simulation discussed by Carson (2004) and Robinson and Davies (2010). To be able to work with simulation an employee needs to have skills within programming, modelling, statistics, data collection, and analysis (Banks, 1999; Carson, 2004; Robinson and Davies, 2010).

Enabling operators to work with simulation on a frequent basis and in a standardized way requires increased resources and time. This is due to the need to educate operators within simulation alongside setting the proper structures to enable the operators to operate using simulation. This implies that time and resources in the daily operations of the operators needs to be designated to working with simulation. The knowledge and interest in working with simulation may vary amongst operators, which further puts constraints on enabling the simulation to be used.

Providing operators with a specific amount of knowledge specified towards the early and final steps of the simulation methodology, will decrease the amount of time and resources that needs to be put in to enabling the operators and production technicians with less skills to work with simulation. It is highlighted by Pegden (1995) that the most difficult part of simulation work is the modelling and the analysis, giving the operators and production technicians with less skills the tools and resources to perform the analysis and leaving the modelling part to the simulation experts will help enabling simulation to be used. The models presented by Banks et al. (1999) and Law (2007) visualises the methodology of conducting a simulation study. This proposed solution for enabling operators and production technicians with less skills to use simulation would require that the production technicians with high skills and simulation experts perform the steps from the *data collection* leading up to *Experimental design* (Banks et al., 1999) and *Design experiment* (Law, 2007), encompassing of the steps of modelling. The operators and production technicians with less skills should be involved in the problem formulation step, since it will be an improvement suggestion deriving from the operators. The data collection will also be essential in involving the operators, as they have first-hand knowledge about the operations in the production. When the production technicians and simulation experts have completed the modelling, the operators and production technicians are then included again, alongside the production technicians and simulation experts, in steps of running the simulations, evaluating, and implementing the improvements. This would decrease the amount education and knowledge required amongst operators to conduct simulation work and decrease the amount of time spent.

Therefore, a model has been devised based on the models by Banks et al. (1999) and Law (2007) where the steps in the simulation project have been divided into three phases, as shown in Figure 14. The first phase, *Operator/production technician phase* includes the problem formulation and data collection. In this phase the primary involved employees are the operators and production technicians with less skills. The *expert phase*, where the production technicians with high knowledge and simulation experts are the driving employees includes primarily the modelling of the simulation model. The final phase, *Collaboration phase*, includes both operators and the production technicians alongside the simulation experts, and encompasses of the steps of running the model, analysing the results, and performing the implementation. This is also presented in Figure 14

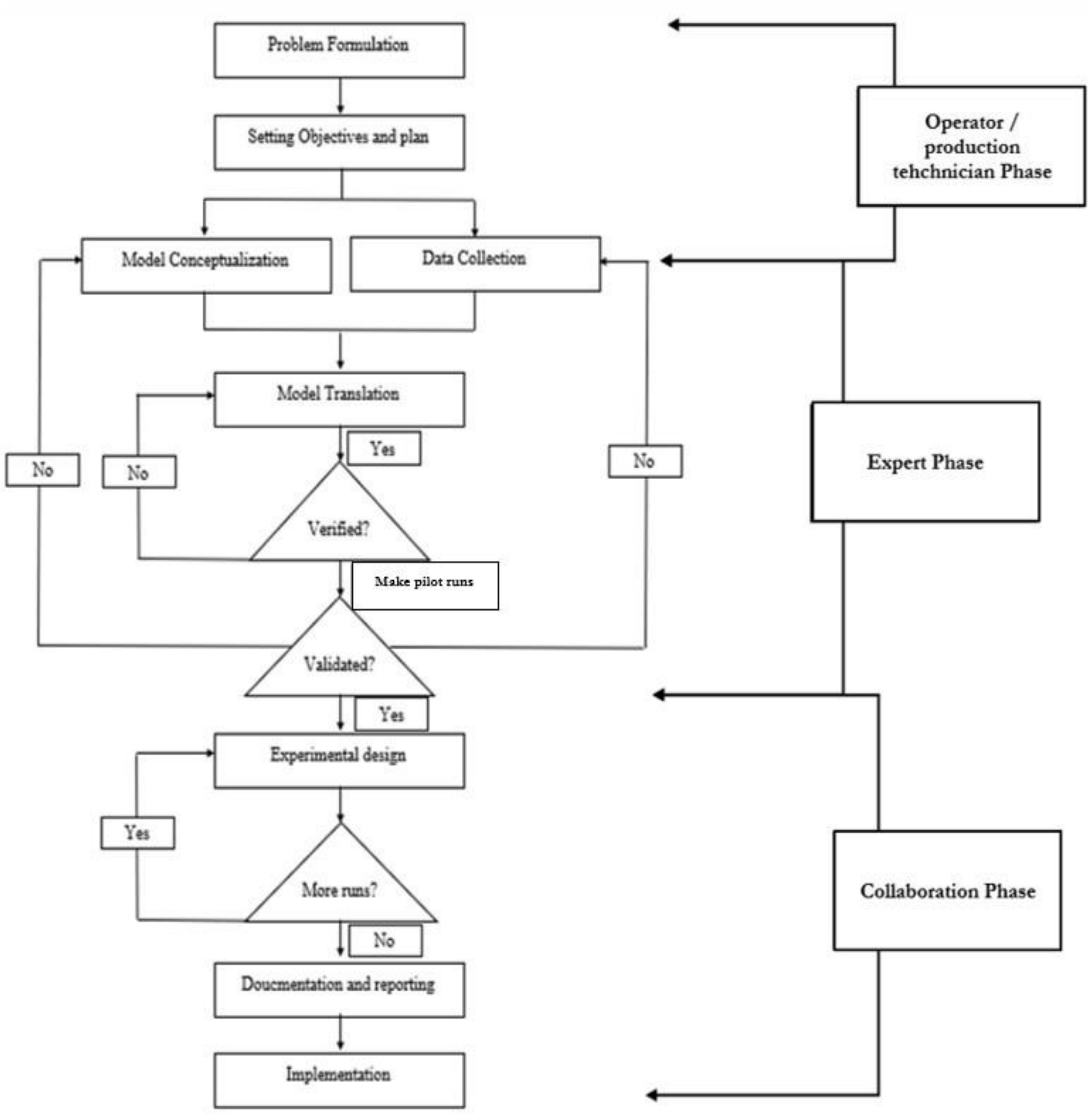

Figure 14. Simulation project methodology with enabling phases based on Banks et al. (1999) and Law (2017).

Further enabling the usage of simulation within an organisation, and decreasing the use of resources and time needed, is possible through designating a few production technicians and operators to working with simulation on a frequent basis. The production technicians and operators had different background and different work tasks, alongside more or less interest in using simulation. Therefore, there will be some production technicians and operators that are more suited and have more interest in using simulation. By doing this, the production technicians and operators without the previous knowledge and interest in simulation can focus on other tasks, and when needing to use simulation they can take help from the designated simulation workers. This will decrease the constraints on the operators and production technicians to perform both their daily tasks and simulation work. As Banks (1999), Carson (2004) and Robinson and Davies (2010) discuss, a simulation analyst needs to have several different skills and achieving this will take time and effort. Therefore, designating a few production technicians and operators to perform the simulation work, and educating those employees will decrease the resources spent by the organisation and at the same time achieving highly skilled simulation analyst, instead of having several employees with little knowledge.

Lack of supporting documents and general support

The model devised by De Jager (2004) describing the organisations ability to improve, presents four parameters that are necessary for the organisation ability, where the third parameter *We must be enabled to improve* concerns the support and processes that needs to be in place. An organisation must provide sufficient support and have processes in place to be able make it possible for the organisation to improve.

Providing the operators and production technicians with the necessary support to enable them to use simulation requires that a shift in the hierarchical structure is in place. Figure 8 presents the reversed pyramid of lean and in this model Found and Harvey (2007) describes the necessary shift to provide operators and production technicians with the support that is needed. The simulation experts should provide the operators and production technicians with the support that is necessary for them to use simulation, not the other way around. By doing this, the operators and production technicians will be able to use simulation. This also includes the supporting documents that the simulation experts have access to, which now the operators and production technicians will have access to as well.

Value in implementing simulation

There must be an understanding regarding if operators and production technicians share the same view on working and improving. It is important for the concerned, that there is a common agreement regarding improvements. It needs to be stated how and what the improvement affects so the concerned can accept and commit. Commitment is another important aspect of the right conditions for implementation. The consensus needs to be that there is a desire to improve. Not only in specific areas of the company but across the organization. According to Found and Harvey (2007), Liker (2006) and Womack and Jones (2003) a reverse type of traditional structure provides better conditions for implementation. Because the revised organizational structure led to a more decentralized and flexible organization with the responsibility placed on the operators, the operators and production technicians will because of the responsibility, suggest their own ideas and will be more prone to commitment and understanding.

Shifting the hierarchical structure at the company will act as one of the initiators for enabling the operators to work with simulation themselves, since they will have more opportunities to make an impact. To further enable operators to work with simulation, and counter the issue of not all having the desire to use simulation or seeing the value in their daily work, will require that the operators and production technicians with interest and desire to work with simulation perform the simulation tasks. This will facilitate so that the operators and production technicians that is interested in simulation work can excel in it, and those with less interest can continue to perform their non-simulation tasks at high standard. For the operators and production technicians not working with simulation, when there is a requirement for simulation to be used, they may assign this work to the designated simulation-workers.

Lack of validated models

As Pegden (1995) and Banks (1999) stated, one of the most challenging aspects of simulation work is the modeling. Modeling takes time and resources and requires high skills, and its vital that the complete model is a valid representation of the real system. If there is a lack of validated models, it makes the process of conducting simulation work difficult and time consuming, and therefore hindering the work to be completed. For a simulation analyst, modelling is one the key skills required (Banks, 1999; Carson, 2004; Robinson and Davies, 2010).

Modelling consists of several steps, where the initial step is to gather the correct data from the production. Skoogh and Johansson (2008) describes the steps necessary to complete to gather the correct data. It is vital that the data collection is standardized and documented, since it important to be able to trace the data in the future (Manlig et al., 2011). Since the data is always changing, the data collection is an ongoing process. This also relates to the complexity of the model, as with time it will be more complex when it is expanded (Shannon, 1975). The data collection is highly time consuming, therefore it could be vital for a company to implement an Input Data Management tool to help with the data collection (Skoogh & Johansson, 2008; Banks et al., 1999).

When the correct data is collected, the next phase is to start modelling and create the model. Banks et al. (1999) suggests that the preferred way is start with a simple model and then expand it until a model with the desired complexity and scale is complete. When the modelling is complete, the model needs to be validated. This is done through analyzing the model and calibrating the model to the desired state where the model represents the reality in the best way (Banks et al., 1999; Law, 2007)

For a company it is important to have validated models of each area where simulation is intended to be used. Since it is a time-consuming process, which requires skills from the employee performing the modelling, the best way for a company to go about this would be to have designated operators and production technicians that continuously work with modelling and validating the existing models.

5.3 Framework

From the results of research question 1 and 2, several challenges and solutions to the challenges has been identified. These results are combined into a framework, which in turn will aid companies in enabling the usage of simulation for continuous improvements. The framework is presented in Figure 15.

The first step in the framework is to complete an analysis of the current situation at the company. The purpose of this analysis is to identify challenges that might hinder an enablement of operators to use simulation for continuous improvements. The framework presents the challenges identified in this study through research question 1. The next step in the framework is to use the results from research question 2, to diminish the impact from the identified challenges. These four are *Validated models, Commitment, Designated operators that work with simulation* and *Continuous improvement work seen as ordinary.* After these steps has been taken, an analysis is needed to make sure that the identified challenges have been handled. If yes, the operators are now enabled to use simulation for continuous improvements. If no, there is a need to go back to the initial steps and look over if all challenges have been identified and handled correctly.

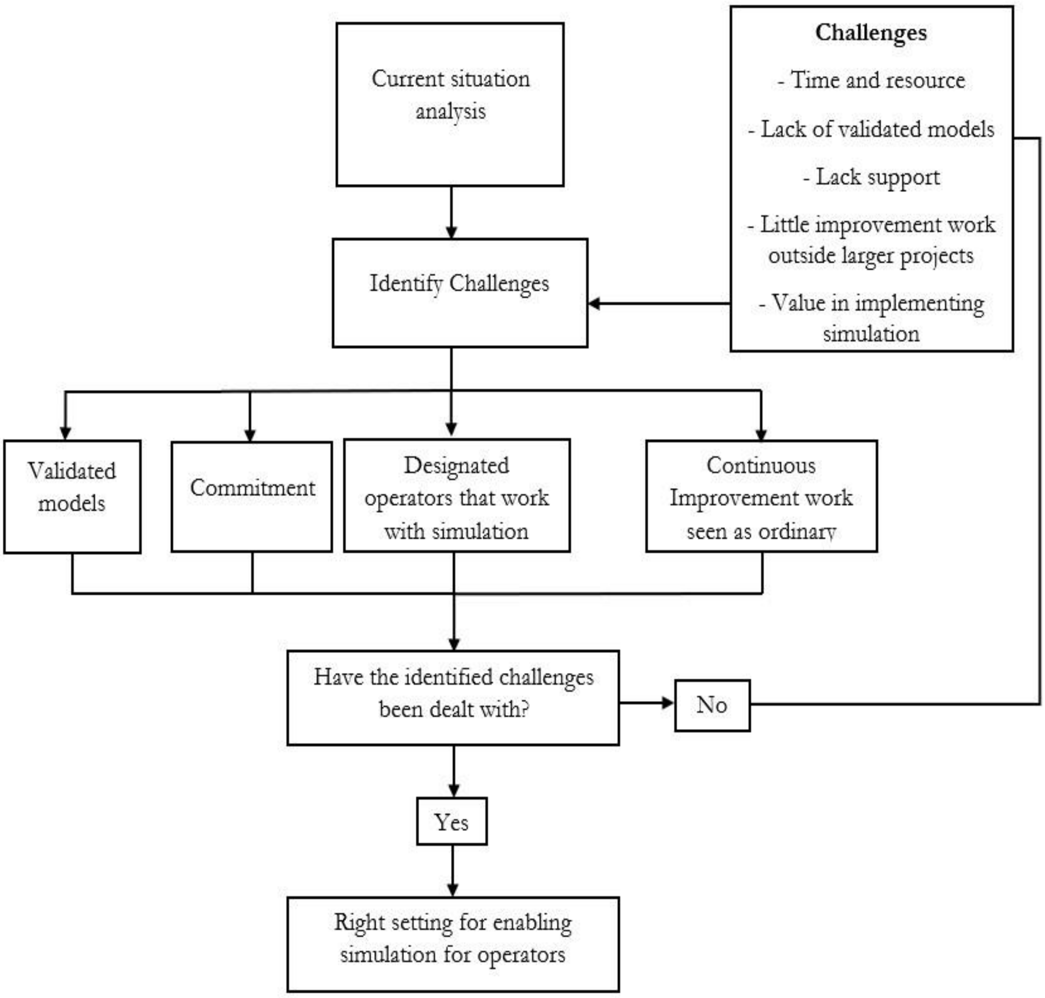

Figure 15. A framework for enabling simulation for a continuous improvement

6 Discussion and conclusion

The following chapter presents the discussion and conclusion. Initially the discussion of the research questions is presented. This section is divided into three sections, were each of the two research questions is answered and the purpose fulfilled. This is followed by the implications of the study, were the implications to theory and practice is presented. Following the implications, the method of the study is discussed. This is followed by the limitations of the study and the proposed further research. Finally, the conclusion of this study is presented.

6.1 Discussion

The purpose of this report was to *Create a framework for enabling operators to use simulation for continuous improvements.* To fulfil this purpose, two research questions were devised:

RQ1: What are the challenges in practice for enabling operators to use simulation for continuous improvements?

RQ2: *How can these challenges be overcome, to enable operators to use simulation for continuous improvements?*

6.1.1 Research question 1

To answer the first research question, a thematic analysis was conducted. For the thematic analysis, the empirical data was coded based on similarities amongst the phenomena's identified in the data. The codes were then grouped together in themes, based on the similarities and connections amongst the codes. The themes represent the challenges that was identified as the primary obstacles for companies to be able to enable the usage of simulation as tool for operators to use. The themes that were identified, and thus the challenges that were identified was:

Little improvement work outside larger projects using simulation

The first challenge identified was *little improvement work outside larger projects using simulation*. Most of the improvement work conducted at the case company was performed through larger scale projects, where simultaneously most of the simulation usage was conducted. Outside the larger scale projects, little improvement work using simulation was conducted. Generally, outside the larger scale projects there was a low level of standardization and structure regarding continuous improvement. This led to an understanding for this study about the importance of having a structure concerning improvement work, since that enables to usage of simulation. To use simulation as a tool for continuous improvement, there is a need for set structure and standardization on how simulation is to be used outside the larger projects. Therefore, this was identified as one of the main challenges a company face for enabling operators to use simulation in this case study.

Time and resources

The second identified challenge was *time and resources*. Enabling operators to use simulation requires resources and commitment. On an operator level, the lack of previous education and knowledge about simulation hindered the operators to use simulation. The limited information flow reaching the operators acted as a barrier for the usage of simulation, since the operators were unaware of the potential in using simulation.

The production technicians faced different challenges than the operators. The main challenges for enabling the production technicians to use simulation was the already high workload alongside the view that simulation would not benefit their daily work. The production technicians were aware of that using simulation is a time-consuming task, and therefore they were reluctant to using it on a frequent basis as they saw that they already had more than enough to do as it were.

Lack of supporting documents and general support

The third challenge was *Lack of supporting document and general support.* Enabling operators to use simulation requires that the proper support is provided from the organisation. It was identified that there was a lack of support for the operators and production technicians in form of documents and structure. Most of the support provided for the operators and production technicians came from the simulation experts, which in turn had access to more relevant documents. When operators and production technicians have little support in forms of documents the ability to use simulation becomes limited and the ability for the operators and production technicians to further develop their skills is hindered.

Value in implementing simulation

The fourth challenge was *Value in implementing simulation.* Enabling operators to use simulation requires that there is an interest and that the operators sees the value in using it. This applies both on the company but also on a personal level. Most operators and production technicians could recognise the value on a companywide level, but similarly to the challenge *time and resources* the operators and production technicians were concerned that using simulation would take too much time and therefore could not see the value for them to individually use it.

Lack of validated models

The fifth and last challenge *Lack of validated models.* If there is a low number of validated models than it will prohibit the enabling of simulation. Having validated models can increase understanding of the different systems and support the learning and enabling of the tool itself.

6.1.2 Research question 2

Based on the identified challenges from research question one, the next step was to present how companies can overcome these challenges to enable operators to use simulation. This was done through answering the second research question, *How can these challenges be overcome, to enable operators to use simulation for continuous improvements?*

Little improvement work outside larger projects using simulation

The first challenge that was identified was *little improvement work using simulation outside larger projects.* For a company to overcome this challenge and thus enabling the usage of simulation for operators requires an implementation of a standardised working method for continuous improvements.

Based on Berger (1997) a model for standardising the continuous improvement work between the different hierarchical levels was presented. This model, presented in Figure

12, describes the exchange between the different hierarchical level and how the improvement work can be standardised. In the exchange between operators and production technicians, the working method *Individual CI* is used. This method implies that the operators initiate the improvement work through suggestions, that are then transferred to the specialist, in this case called production technicians that perform the work. In the interchange between production technicians and simulation experts, the proposed working method is called *Organic CI* and involves working with continuous improvement work in multifunctional teams.

In parallel to implementing these standardised working methods, the environment surrounding the improvement work needs to shift from the operators and production technicians having a supporting role to a role with higher responsibility. These changes will enable the usage of simulation amongst operators and production technicians since they will have a role with more responsibility alongside the proper structure to work with improvements.

Time and resources

The second identified challenge was *time and resources*. The amount of time, skills and resources needed for enabling simulation is vast. Therefore, to overcome this challenge a model, Figure 14, based on Banks et al. (1999) and Law (2007) was presented. The model presents the methodology of conducting a simulation project, where the different steps have been divided in to three separate phases, *Operator production / technician phase, Expert phase,* and *Collaboration phase.* The phases are divided based on the respective employee that will perform the tasks. By using this model, the company's will be able to focus the right resources on the specific tasks that each employee will perform, thus decreasing the number of resources needed. To further enabling the operators to use simulation, the companies should designate a few employees more suited based knowledge, skills, and interest to perform the simulation work and act as simulation specialists.

Lack of supporting documents and general support

The third challenge was *Lack of supporting document and general support.* To enable simulation to be used on a frequent basis the organisation needs to provide the operators with the necessary support. For this to be possible the proper structure needs to be in place within the organisation. Therefore, making the shift from a more traditional hierarchy where the operators and production technicians act as support for the simulation experts, the simulation experts should instead provide the support. This is described in the model presented by Found and Harvey (2007) in Figure 8. This will provide the operators and production technicians with right support and give them access to the supporting documents that simulation experts have.

Value in Implementing simulation

The fourth challenge was *Value in implementing simulation*. To enable operators to use simulation it is important that there is an understanding amongst the operators concerning the value of the improvement work. It must be clear and defined why the work is conducted, so that everyone can understand and see the value (De Jager, 2004). To overcome this challenge, two requirements need to be fulfilled. Firstly, a change in organisational and hierarchical structure, going from the more traditional structure where operators and production technicians acts as support for the higher offices, to a situation where operators and production technicians have most of the responsibility. This will help them improve their knowledge and increase their interest in their work. Secondly, to counteract the fact that every employee is not interested in working with simulation, designating a few operators and production technicians who are the most interest to perform the simulation work will lower the impact of this challenge. The employees that work with simulation can in this situation focus solely on the simulation and improve their skills, and the employees that are not working with simulation can improve their skills in other areas.

Lack of validated models

The fifth and last challenge *Lack of validated models*. To enable operators to use simulation, there is a need for validated models. To overcome this challenge, companies should take several actions. To start with, data collection is a time-consuming process and needs to be regularly updated. Therefore, implement Generic Data management tools will automate the data collection and make this step less time-consuming (Bokrantz et al., 2015; Skoogh & Johansson, 2008; Banks et al., 1999). To further enable operators to work with simulation, the validated models need to be constantly updated and controlled. Therefore, having a few employees that are designated to working with this is proposed, since it is a time-consuming task. Further, the modelling tasks of the simulation project will be in the *expert phase* in the model, shown in Figure 14, which implies that the most skilled employees would be the most suitable to perform this task.

6.1.3 Purpose

The purpose of this study was to *Create a framework for enabling operators to use simulation for continuous improvements*. Based on the identified challenges and the solution to those, a framework has been devised that will enable operators to use simulation for continuous improvements. The framework is presented in Figure 15.

6.2 Implications

The following chapters is divided into two sections. The first sections will include a theorical and the second, practical implication for companies.

6.2.1 Theoretical implications

It remains a challenge for the industry today to have an educated workforce within simulation (Collins et al, 2021). Previous research within the subject of educating and implementing simulation focuses on the effects of using simulation and how it may be implemented and used for companies. Previous research that touches upon the topic of knowledge, skills, and application of simulation concerns primarily work of the simulation experts, meaning does employees with the highest skills within simulation work. Studies concerning the challenges and possibilities with implementing simulation exists in previous research, but this only concerns the wider view about implementing simulation on a company wide scale and how to use simulation experts. This study shifts this focus from the wider view and sole focus on simulation experts, towards a more in-depth analysis of how to enable simulation to be used by those not defined as simulation experts, meaning does employees with less or zero previous knowledge about simulation. The shift in focus from the traditional simulation experts towards all employees, is not previously explored and the new challenges that comes with this shift in focus.

This study also emphasizes and highlights the importance of using the knowledge and expertise of the operators, that are performing the daily operations within the company and can bring insight to the usage of simulation. This is a gap in previous research, as the sole focus is on how companies can utilise the simulation experts, not the wider range of employees.

6.2.2 Practice implications

It is recognised in previous research that companies today face the challenge of lacking a simulation educated workforce, this study provides companies with an in-depth analysis of how to enable their operators to use simulation. This study will contribute to aiding companies that aims at implementing simulation on a wider scale within their organisations alongside highlighting the importance of using the skills and knowledge within the company.

6.3 Method discussion

The methods used in this study was a case study alongside a literature review. This implies that a qualitive approach was taken in this study. This choice of method stems from the need to understand in depth the phenomenon at the case company in depth. Within qualitative research there is the issue of creating a sufficient case study to make the study and its results generalizable to the wider population (Yin, 2013).

To ensure the generalizability, alongside the validity and reliability of this study several precautions were taken. The first measure taken to ensure the generalizability of the study was *prolonged engagement*. This implies that enough time was spent to fully understand the context of the phenomena's studied. Since this study did not use several case studies to investigate the phenomenon, there was a need to fully understand the single case study used, to be able to apply it to the wider population. Combined with the *prolonged engagement, triangulation* was used to further ensure that the finding from this study may be applied to the wider population. Therefore, the interviews that were conducted included several respondents with different backgrounds, age, and occupation. The case study was also supported with a literature review, where to ensure the generalizability of the study, the findings from this study was compared and analysed alongside previous research. Further steps to ensure the validity and reliability of this study was taken and are presented in chapter 2.6.

It would have been preferred that more than a single case study was used to further strengthen the validity and reliability of the study, but due to time constraints this was not possible. Therefore, the precaution measures described above were performed.

6.4 Limitations

The empirical data gathered in this study was limited to a single case company, operating within automotive industry. It is possible that companies operating in other industries, or with different size, have different challenges facing them that is not included in this study.

As a result of the time limits placed on a thesis-study, the possibility of using more case companies and investigate those on the same depth was difficult. It would have been preferred to use more than one case company to further make the study generalizable, as described in chapter 6.3.

6.5 Further research

This study provides the initial step for enabling operators to use simulation for continuous improvements. The next step in research would be to investigate the process of using the ideas from this study and implementing simulation to be used by operators for continuous improvements. In future research it is also necessary to investigate if these challenges found in this study applies to other industries, and if there are other challenges to be found.

6.6 Conclusion

The purpose of this study was to *Create a framework for enabling operators to use simulation for continuous improvements*. The purpose was fulfilled by using two research questions that investigated the challenges and how these may be overcome to enable operators to use simulation for continuous improvements. Five challenges were identified in practice that hindered the operators to use simulation. Most of the challenges that was identified were linked to the company's organizational structure and continuous improvement environment. Each of these five challenges was analysed and provided with a way to overcome them, which in turn resulted in the proposed framework, showcased in Figure 15. The framework aims at aiding companies to enable their operators to use simulation for continuous improvements, through providing help in the processes.

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8 Appendix

Interview sheet operators

1. For how long have you worked at Volvo?

2. For how long have you had your current work assignments?

3. Are you aware that there have been any improvements on or around your workstation or in the production unit overall?

4. Do you believe that you have the opportunity to make improvement suggestions?
    a. If yes, what is the process of making an improvement suggestions?

5. Do you have any improvement suggestions right now that you want to highlight?

6. Are you familiar with the term Simulation and if so, what is simulation used for?

7. Have you ever been showed a simulation model at your current workplace?

8. Are you aware that Volvo uses simulation to make improvements in the production, amongst other places?

Interview sheet production technicians

1. How long have you been with Volvo in your present position?

2. What are your responsibilities in your current position?

3. What was your previous educational and professional background?

4. What may simulation be used for?

5. Do you believe simulation can help Volvo in any way?

6. How do you think simulation can help you in your day-to-day activities?

7. Do you believe simulation is necessary in your day-to-day work?

8. Would you like to work on a simulation project?

9. Have you previously used any simulation software?

   If so, what is the context?

10. How would you describe your simulation knowledge?

11. Have you completed any simulation training?

12. Do you believe your existing work structure and the environment around you support the use of simulation, i.e., would you have the time, ability, and other resources to work with simulation alongside your other responsibilities?

13. What do you require to make simulation implementation possible? (Regarding Work on Improvement)

14. How does Volvo handle continuous improvement and improvement proposals from?

15. production, whether they come from you or from operators or team leaders?

16. How does information flow once adjustments or upgrades are implemented?

Interview simulation experts

1. How is simulation used as a tool for continuous improvements?
2. Describe the process when using simulation.
3. Describe the information flow from you down the operators affected by a change/improvement.
4. How often do you show your work to the operators and production technicians?
5. Is simulation used in any other instances besides modelling and analyses, in for example educational purposes or during presentations?
6. How often is simulation is used to analyse individual departments?
7. How many validated models exist?
8. How often do you receive improvement suggestions from the production departments, which is then tested using simulation?
9. How often is simulation used to make improvements?
10. What type of support do you have in your work as simulation experts?
11. How often do you present/explain your work to employees within the production?