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Mapping and streamlining the Hardware-in-the-loop process

- A case study at Volvo Cars

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Master Degree Project in Logistics and Transport Management GM0560 30 hp

Subject: Internal Logistics

Term Spring 2022

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Abstract

The car industry is in a transition to a new era, where software and electronics plays a significant role. During recent years, software and electronics has increased vastly in cars and new innovations are constantly joining the industry. In order to cope with the fast development and the new innovations of software in cars, the importance of testing these features has become a key factor to succeed. Hardware-in-the-loop (HIL) is one of these tests that can be made, where software is tested in its hardware. Volvo Cars is one of many companies that works with this process. In the development of these HIL test environments at Volvo Cars, a clear mapping of the process was something that did not exist. Consequently, this thesis includes a mapping over a general HIL test environment process at Volvo Cars. The study was further meant to find solutions to streamline the process by mapping it and searching for important KPIs. Further, tools from the literature were used to support the proposed changes and ideas to streamline the process. The study was made through an abductive approach where the authors used both qualitative and quantitative methods to collect the empirical data within this case study. Furthermore, the authors made several interviews from all different areas within the process to gather all perspectives of the process. The result of this study showed that information sharing and lack of knowledge in the process were the difficulties and that measurements was one of the solutions to gather more knowledge and information about the process.

Key words: *KPI, Measurement, Mapping, ETO, Cross-functional teams and HIL*

Acknowledgements

We would like to address our biggest gratitude and thank our supervisor at the School of Economics Business and Law at Gothenburg University Rickard Bergqvist, for his help and support throughout this thesis work. We would also like to thank our supervisor at Volvo Cars, Magnus Wennström, for his support and contribution with valuable comments and input, but also guidance and devotion to our work. Furthermore, we would like to thank everyone that has participated in the conducted interviews and to Volvo Cars that has given us the opportunity to do this thesis in collaboration with them. Also, for giving us access to the facilities, information and equipment needed for this thesis. We would finally like to thank *you* for reading our thesis and we hope that it will give *you* the information that *you* are searching for.

Filip Arousell & Simon Hellgren, Gothenburg, May 2022

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1. Introduction

This section deals with the background to this study, where the development of cars and its software leads into the problem discussion. The studied area is discussed here and will further end up in the research questions for the study with a description of these questions. The section ends with a description of the different limitations of the study.

1.1 Background

The automotive industry is in the transition to a new era, where innovation is important according to Ferràs-Hernández, Tarrats-Pons and Arimany-Serrat (2017). The old mechanical elements are being replaced with computers and electronics and the need for innovation and sustainable solutions are more important than ever before. This is leading the industry into a phase of instability which is triggered by the fast-changing technologies. Car designs and manufacturing processes are in need of innovations since the vehicle concept is going towards a redefinition that is based on features that are offered by digital technologies and software (Ferràs-Hernández, Tarrats-Pons & Arimany-Serrat, 2017).

The cars today are getting increasingly complex because of the increase in software. According to Mallik, Ekere, Best and Bhatti (2011) and Biba, Ancuti, Ianovici, Sorandaru and Musuroi (2020), electronic control units (ECU) have a vital role in modern cars when it comes to control and integration of complex actions. To meet customer demand, Altinger, Wotawa and Schurius (2014) describes that modern cars have around 80-90 ECUs to be able to cope with all the requested functions that customers want. Biba et al. (2020) further describes that some cars have even more ECUs, reaching over 1000 ECUs. These functions can range from simple interior lighting to adaptive cruise control. Thus, software has a high potential for future innovations in cars. A lot of functionalities in a car are connected to software and all these features, infotainment for example, requires software to work. Around 90% of all car innovations nowadays are based on electronics and software, where the softwares in cars are reaching sizes of 100 million lines of codes, and these codes are expected from customers to work perfectly without any faults (Altinger, Wotawa & Schurius, 2014). The amount of software faults in a car is a crucial factor that affects the customers' opinions about the car. Consequently, it is important to avoid these faults, which is a huge challenge since the software in cars is increasing and hence the risk of more faults and bugs. Although, the importance of software in the automotive industry still grows and the risks only grow bigger. Therefore, it is important to take actions by improving the software quality, not only by improving development processes, but also verify and validate activities in the software development. It can get expensive if the bugs are found after a release since the car is already built and might even be out on the roads. Thus, it is important to find the bugs and faults at an early stage to avoid having to bring the car back from the customers or retailers to the factory to fix them. To do that, executing tests of the automotive software is a critical task (Altinger, Wotawa & Schurius, 2014). Beyond the increase in innovation and technology, there has also been an increase in usage of automated tools for testing the software in these ECUs to ensure the validation and verification (Vuli, Badalament & Jaikamal, 2010).

Hardware-in-the-loop (HIL) has become a key part of testing hardware (ECU) and its software within the compilation of automotive vehicle industries (Raikwar et al., 2019). The HIL-testing system is a process within testing industries that is meant to create an environment for the hardware and its software, to believe it is in its right environment (Acar, Güvenç & Altuğ, 2019). This is to be capable of duplicating the tests of the software functions and qualities within a secure environment, to gain a lot of qualitative data. Volvo Cars, a corporation known for its quality of security within the automotive industry, is one of many that is using HIL-testing to develop their products. Since Volvo Cars strives for high quality of security and efficiency, they want to investigate their general HIL-testing process to see if modifications are needed to improve their efficiency and in turn ensure competitive advantage. Therefore, this thesis has studied the general HIL test environment process, which includes the process of planning and making the test environment together with the ECUs. The HIL test environment includes everything that is needed to be able to make the test and it can vary from one test to another, but the main parts that are always included are described in this study in section 5.1. Earlier research of HIL tests has only investigated what the HIL test generates and why that type of test was valuable and has not taken the process of test environment and ECUs into consideration. Therefore, this study adds a new view to the research within this field when looking at the HIL-testing process this way. Furthermore, this study looked at this process with a production perspective, which connected better to the logistics in the process.

1.2 Problem discussion

As mentioned in 1.1, the technology and usage of software increases rapidly in the automotive industry. This leads to cars becoming more dependent on software instead of mechanical solutions when it comes to functions in the car. Because of the quick increase of software, the demand of testing the software has also increased. HIL, which is one of these test processes, thus needs to keep up with the development to secure test validity and verification on the products. Considering the increase in technology, the number of different types of tests has also increased since there are many ECUs that need to be tested, and because of the variety of ECUs the tests vary as well. This makes the HIL process extraordinarily complex which leads to the need of flexibility in the process, hence being able to adapt to all these new tests that need to be done so that the process can take place in an efficient manner. This is due to the fact that the tests could be for an old car where the ECUs need updates, but also to new developed cars and ECUs that are not released yet. This leads to that resources for testing the products need to be planned in another way compared to earlier to meet the new complexity within the HIL test environment process.

The planning of resources in the HIL test environment also needs to ensure that the execution is made in a secure way, since there are existing rules and standards in what kind of security requirement that needs to be fulfilled. Therefore, a detailed plan of resources within the HIL test environment is made to specify which requirements are needed for each test. Furthermore, the resources to build these HIL test environments are expensive since it is a new innovative technology with an advanced way of testing the ECUs. This calls for a critical and exact resource acquisition in the process, to reduce the cost of investing money in unnecessary resources for the HIL test environment. It generates a complexity of producing the HIL test environments which makes it very time consuming. This becomes obvious since Volvo Cars do not have a clear communicated picture of how the general HIL test environment process looks for the moment. In order for the HIL-testing process to work properly, every part of that process needs to be clear. This is due to the fact that the people within the process need to have a clear picture of all stages and the people involved in order to make their work efficient. However, there could be people in the process that have great knowledge about their own part, but less knowledge in parts or departments further away in the process that is not in their field. These people might make great changes on their own part but in the end, it might not be good for the entire process.

Regarding Volvo Cars, they strive to have high quality, security and efficiency in their work which of course also applies to their HIL-testing process. Therefore, the authors believe that a mapping of the general HIL test environment process would give the possibility to easier see how previous, parallel and later processes could cooperate with this process in order to make it more efficient. Furthermore, a map of the general HIL test environment process could make the information flow easier, preventing information from not coming through or taking unnecessary loops before ending up in the right place.

A process can consist of stronger parts and weaker parts and a flow does not perform better than its weakest link in the process. By mapping and clarifying the process, the strong and weak parts can be found easier with help from defining key performance indicators (KPI) that are important within the HIL test environment process. This will in turn show where improvements or adjustment in the process can be done, since KPIs aim to measure and gain numerical data to analyse the HIL test environment performance (Kang et al., 2016). Without the mapping, this is hard to do since the process is noticeably big and complex. Is there any knowledge of where the weakest link in the process is today? Is there any knowledge about who to talk to in the process regarding certain parts in the process? How do you get this knowledge if there are no clear mappings of how the process looks like? The answer to these questions is that they cannot be answered, and that is the reason that this study has made a mapping of the process.

1.3 Purpose

The purpose of this thesis was to study how Volvo Cars general HIL test environment process works and map it in order to see if there were any possibilities of improvements in the streamlining of the general HIL test environment process. By identifying the important KPIs, the right improvements could be made in the right steps of the general HIL test environment process. Furthermore, by looking at the general HIL test environment process with a production perspective, the study has further investigated what kind of tools that can be used to streamline this production.

1.4 Research questions

1. Which stages are included in the general HIL test environment process and how are they connected?
2. What are the most important KPIs in the general HIL test environment process?
3. Based on the mapping, what changes and tools can be used to streamline the general HIL test environment process?

As previously mentioned, there are several types of HIL tests at Volvo Cars, but all these different HIL tests are based on one general HIL test environment process. This general HIL test environment process is not clearly defined, which can become confusing for the people involved. Therefore, this study has investigated the general HIL test environment process and mapped it to make it easier to understand how the process works and how it is used. This means that the process was visualised by drawing it and describing the purpose of the various stages in the process from the start of the general HIL test environment process which is from the need of a test to the end where the ECU is connected to the rig and the test can be conducted. This was done to create a clear picture of the process, not only for the authors but also for Volvo Cars. By simplifying the process through a mapping, the logic of it becomes clearer and it is easier to see how every stage connects and if they are executed in the correct order. The mapping would also be helpful to find where the KPIs belong in the process. Further, the KPIs would be helpful to easier know where and what type of changes that could be made within the process to enhance these KPIs. Hence, suggestions on eventual changes might come up, with help from the KPIs, which can fit for streamlining the process. These changes could for example be to make the process smoother, reduce lead time or increase flexibility. These suggestions will be handled by giving examples of different tools that have been used historically in these matters that could be used when making these changes. These tools could for example be to standardise the process. If the result of the mapping indicates that there are differences in how the various stages in the process are handled, standardising could be a useful tool for solving this.

1.5 Delimitations

This study was conducted at Volvo Cars, in Torslanda Sweden. The study investigated what Volvo Cars calls a HIL test environment and skipped other processes that could be seen as HIL tests but was not defined as a HIL within the company. The scope of the process was to start where a new customer wants to do a HIL test and proceed to where the test can be performed in what is called a rig. Furthermore, it only looked at the general HIL test environment process, i.e., steps that are always included, since there are many different types of HIL processes that exist today and make a common mapping of these. The study looked at the process with a production perspective, which limited the research to the terms and themes from production, hence more related to logistics.

The study was limited from deeply looking into the test object process that is connected to the general HIL test environment process. Although, there was a brief analysis of how it is connected to the general HIL test environment process since the definition of "test environment" at Volvo Cars includes the test object. Furthermore, the study did not investigate how the investment part worked in this process, due to the fact that the investment process is too big to investigate at the same time and was not of interest in this study since it is the general HIL test environment process that was studied. The investment process is a process of its own, connected to this general HIL test environment process and therefore only being briefly described and how it is connected in the process. This general HIL test environment process has had some developments during the time that this thesis was written. Therefore, this study has been limited to what the process looked like at the moment it was conducted.

2. Deductive Theoretical Framework

This section presents the deductive literature that was collected before the empirical data was gathered. It contains what the authors of the study thought would be valuable to use for analysis, but also some descriptive literature to make the study easier to understand.

2.1 Business process mapping

According to Aguilar-Savén (2004), experts from several different industries express that a successful system or process always starts with understanding the company's business processes. A business process is different combined activities in a company with a structure that describes the logical order and who it depends on to get the right results. Business processes are particularly important when it comes to integrating your company (Aguilar-Savén, 2004).

Since Volvo Cars is a large company with a lot of business processes, it is vital that every process is easy to understand for everyone involved. This is a good reason for mapping the general HIL test environment process and justifies therefore the choice for this study to make a mapping of Volvo Cars general HIL test environment process, to create a visualisation which would generate a clearer picture over how the process works in each step. This generates an understanding for people about the process since it gives the correct picture of it (Aguilar-Savén, 2004; Heher & Chen, 2017; Rybicka et al., 2015). Heher and Chen (2017) further describe that by showing a process through illustrations, the understanding register in the human brain quicker than if the process is explained orally or in text.

There are a lot of mapping techniques that exist, and according to Aguilar-Savén (2004) it is therefore important to know the reasons why a mapping should be made when such work is started in order to find the right technique. To be able to choose the right technique for their case, the person making the model must know the purpose of the model for it to be useful. Depending on what the purpose is, there are different techniques that are useful where some models only show what a process looks like, and other models are used to build a system to in turn control the process (Aguilar-Savén, 2004).

Tools for resource flow mapping are well used in the manufacturing industry to optimise manufacturing according to Rybicka et al. (2015). Most often, these tools focus on the material flow when it comes to the production process. These tools are also used to help improve the process and streamline it. The most common mapping tools used in manufacturing are: "*flowchart, material flow analysis, value stream mapping and IDEF0*" (Rybicka et al., 2015).

Flowchart

When mapping a process to get a good representation of the logical order of the various parts involved, a flowchart is a useful tool to use (Aguilar-Savén, 2004; Damelio, 2011). It visualises and describes the process with symbols that represent different things, e.g., operations, definitions and equipment. It shows a flow of actions but does not show breakdowns of these activities. This is well fitted to this study, since a mapping of a general HIL test environment process was the purpose of this thesis in order to understand it without describing the steps too thoroughly.

Flowchart is good to use when flexibility is important (Aguilar-Savén, 2004). The flowchart can be made in different ways, depending on how precise it should be. Nevertheless, it is easy to see and understand the process quickly when visualising it by using a flowchart. It is also easy to use and takes little time to draw it. Aguilar-Savén (2004) mentions that the flexibility on the other hand can be a negative thing since it is too flexible sometimes. It is hard to see the boundaries, and it is easy to get carried away and make it too big. To hinder the flowchart in this study from getting too big, the limitations framed where to start and stop the mapping. Even though it can be too flexible, it is still useful to identify inefficiencies in order to streamline and improve a process according to Aguilar-Savén (2004), which was the purpose of the mapping in this study and thus was a well fitted technique to use.

2.2 Key Performance Indicators

Since the study was trying to come up with improvements to answer research question three, it was clear that this study needed to look at different types of KPIs. It also answers the second question of the study to find the KPIs that are the more important ones for the general HIL test environment process. This was important within this study, since KPIs is a definition with different types of metrics that analyse how various parts within the processes perform (Kang et al., 2016). With KPIs, the aim is to measure and gain numerical data according to Kang et al. (2016), that should indicate the part within the process to see if it accomplishes the goal and vision (Jonsson & Mattsson, 2017). Based on the results, the improvements can be made to accomplish the total goals. Working with material and production management is meant to improve the efficiency within an organisation and can be described by different values of measures (Mattsson & Jonsson, 2013). These could for example be utilisation, delivery reliability, delivery precision and lead times.

Furthermore, the effectiveness and the quality could be important parts to look at in order to come up with faster and more efficient solutions. For example, a HIL test environment that takes too much time to create would not be good for the organisation and that customer satisfaction might decrease. This could result in competitors producing innovative technologies before Volvo Cars. Decreasing the time would give opportunities to work more with for example safety and testing of the environments to make sure that it generates the right values and can be repeatable. An effective HIL test environment process would also enable the customers to test their test objects earlier and offer more quality for the customers and their needs. By measuring the customers' satisfaction, it is possible to see if they fulfil the customers' needs or not. The different types of KPIs that were predicted to be relevant key variables within the general HIL test environment process to eventually be measured were flexibility, lead time and utilisation.

First, the flexibility could be a fair value to measure since this is a process of creating HIL test environments for new innovative technologies, and therefore the HIL test environment needs to adapt to the customers needs of testing their objects. This is based on Mattsson and Jonsson (2013) when they describe flexibility as the ability to quickly and efficiently react and adjust to changes. Although flexibility is a performance indicator that has become increasingly important, clear and easy measurements for it do not exist.

Further, Mattsson and Jonsson (2013) describes lead time which is the time from a requested demand until the demand has been fulfilled within a process. In this study this would be from the request of a test from the customer until the HIL test environment is built and ready to fulfil the customers needs. However, within this general HIL test environment process, different types of lead times can occur. One example of a lead time Mattsson and Jonsson (2013) mentioned was production lead time which can be divided into two different parts. The first part of production time is the administrative things such as planning, controlling and reporting information. The second part is the flow time, which includes the manufacturing time, set up time and congestion time (Mattsson & Jonsson, 2013). The thing about the administrative part is that these lead times can be seen as consistent times compared against the flow times which depend a lot on the production order quantity (Mattsson & Jonsson, 2013).

However, Liker (2013) described that the shortening of lead times within a process gives the best quality and lowest cost, based on lean production. The shortening of lead times is often made by identifying unnecessary parts within a process that do not add any value to the product or customer, and therefore is eliminated (Liker, 2013).

Further, as described earlier utilisation is a KPI that could be possible to measure within this process. This is due to the fact that the utilisation is a great value for capacity costs and production costs (Mattsson & Jonsson, 2013). Utilisation can also give indications about the utilisation rate of the facilities and can therefore increase the usage of capacities and minimise the demand of increasing capacity and therefore can decrease costs. The utilisation of capacity could also be relevant regarding the general HIL test environment since the resources as hardware and software within this process is expensive. Therefore, utilisation could be an important KPI in order to reduce cost and be more efficient of using already existing resources and material.

2.3 Standardising

From the early observations made, where employees at Volvo Cars mentioned the need for decreasing variety and flexibility in the process, standardisation was by the authors thought to be a tool to use for streamlining the general HIL test environment process. This led to the thought that standardisation within the general HIL test environment process might be good to be able to be more efficient in the process.

Standardisation is used as a tool that is executed repeatedly in the exact same way all the time within one workstation and is therefore consistent with the process steps and the procedures (EL-Khalil, Leffakis & Hong, 2020). Koch and Blind (2020) describe that the increased innovation within software and its technology is now putting the standardisation on challenges. The authors of this study thought that this might apply within the general HIL test environment process also since Volvo Cars has mentioned the increase of HIL testing and software development over the last decades.

However, according to EL-Khalil, Leffakis and Hong (2020) standardisation is taking form as the 5S techniques that Liker (2013) mentions are *sort, straighten, shine, standardise* and *sustain*. 5S is meant to visualise operational problems that can be reduced and in result improve operational efficiency and effectiveness (EL-Khalil, Leffakis & Hong, 2020) which lead to better process standardisations.

Liker (2013) describes the 5S and the different techniques. First, *sort* is about sorting out what is needed or not. Secondly, *straighten* is meant to give things a place where it should be geographically. Thirdly, *shine* is working as an inspection, this due to the opportunity to eventually find problems or things that are wrong before it can cause further problems for customers or other quality problems (Liker, 2013). Furthermore, Liker (2013) describes *Standardise* as creating rules, and that it is about creating a system to maintain the first three S´s and their purpose. However, it finally comes to continuously try to maintain and develop workplaces, which always is an ongoing process that the fifth S, *sustain,* symbolise.

2.4 Production

Production is according to Jonsson and Mattsson (2017) the function that adds real value to the product. The implementation of production is affected by, among other things, the chosen manufacturing strategy, how the factory layout is planned and the organisational structure. Generally speaking, production is a process that combines materials, labour and fixed capital to create goods and services. With this view, the concept of production can range from the manufacturing of trucks and distribution of beer, to lectures in logistics and medical examinations. In other words, production occurs in all types of businesses in a way (Jonsson & Mattsson, 2017).

Consumption is the main reason and goal of all production and because of this, the produced goods need to be distributed for consumption in some way. If it is not combined with production services, the production of goods does not add any value and therefore gets uninteresting in most cases. This gets noticeably clear when it comes to the logistics services that are always necessary to be able to distribute the goods to the customer. Furthermore, the production of goods consists of several operations and processing steps according to Jonsson and Mattsson (2017), where the material is transformed from the given state to the desired state.

In logistics, there are a lot of production decisions that are vital to make according to Langevin and Riopel (2005). Product routing decides where the work should be carried out which depends on what characteristics the products have but also the equipment together with the staff. Just as Jonsson and Mattsson (2017) mentioned, Langevin and Riopel (2005) also states that the production layout in the facilities is important and that it depends on earlier given customer service objectives together with the activities and services provided, but also the product routing and the characteristics of production tools and staff. There is also a master production schedule, which is a production plan for every specific product which often is derived from a total production plan at a more extensive level (Langevin & Riopel, 2005).

The reason that the authors of this study have chosen to use literature about production is that the process which is investigated is handled with a production perspective. When looking at what Jonsson and Mattsson (2017) says about what production is, it can be stated that the investigated process clearly is a production since it combines materials, labour and fixed capital to make the different HIL test environments. To use literature about production made it easier for the authors of this study to better connect with the logistics in the process. It also helped to see if this production of the HIL test environment operates in the best way possible.

3. Methodology

This section deals with the methodological approaches chosen for the study and how the empirical data was gathered. Furthermore, it describes the requirements on the literature together with the research design and discusses the quality of this study.

3.1 Literature requirements

When the subject and the research questions were decided, the selection of literature was chosen depending on the field of this study. This generated data from academic literature like peer reviewed articles and books. The literature has been collected through different databases where some have been more field specific and others with broader content. The search was conducted through Handelshögskolans general search engine Primo and Google Scholar. Field specific databases were not specifically chosen, the search results in Primo and Google Scholar were instead sifted and if the literature found was fitting the theme it did not matter which database it came from as long it was information that fitted this study. Words that have been used in the search have for example been production, streamline, HIL, KPI and standardising. The year of publication of the literature was thought to be as new as possible to get new and relevant information for this study. Although, there were some literatures that were older and the oldest literature within this study was from 2002 which the authors considered were relevant within this study.

3.2 Methodological approach

When conducting a study, there are three different approaches that are commonly used. These are: deductive approach, inductive approach and abductive approach. According to Dubois and Gadde (2002) the usage of deductive approaches are connected to developing one or several hypotheses from existing theory and then testing them in “the real world”. Inductive approaches are the other way around, where you depend on “grounded theory” where the theory is grounded in the systematically gathered data. When it comes to the abductive approach, it is a combination of deductive and inductive approach according to Dubois and Gadde (2002). The framework that you have from the start is not necessarily the same when the report is finished since it is successively modified. This is due to the results of unexpected empirical findings and insights that the authors gain in the meantime. It is a perfect match of mixed theoretical models that already exist together with new concepts that are found when looking at reality (Dubois & Gadde, 2002). The use of a deductive approach, however, would have posed a risk of limiting the study to a predetermined theory. This would have meant that the study needed to question these theories and how they solved the problem or not. So, if the deductive theory would be an unsuccessful approach in the sense of not applying on the results, it would have affected the analysis of the study negatively. By using an inductive approach instead, the study would only have needed to search for theories that would have been suitable with the generated results of the study. However, based on the research questions and purpose within this study, it was clear that some theories were essential regardless of the results generated.

If a combination of inductive and deductive approach would be used, it should have made it possible for this study to come up with continuously new theories that would be appropriate within this field of research. This is according to Kovács and Spens (2005) an abductive approach and that the difference is the way of starting and ending the research and what type of outcome it would have. An abductive approach would question the possibly erroneous theory from the deductive approach as it might not give the same results as the theory from the inductive approach would. Therefore, it was interesting to see why the inductive theories might have generated better results than the deductive and put these two approaches against each other, and eventually look for a combination of theories. A combination of the theories could result in a "new" theory in this area of research. It may also be found that only one of the theories, e.g., the inductive theories, fits into this type of problem area and that the other may not.

Based on the above mentioned, the abductive approach fitted better for this type of study. The abductive approach is common to use within qualitative studies when neither deductive or inductive are well fitted according to Awuzie and McDermott (2017). It is also, according to Kovács and Spens (2005), a common approach when it comes to the implementation of case studies and action research within logistics, which strengthens the choice of an abductive approach in this study.

The distribution between the deductive and inductive literature in this study has been leaning a little more to the inductive parts. The deductive parts have had more descriptive characteristics, and the inductive parts have been more focused on what the results have looked like.

3.3 Data collection method

To be able to answer the research questions and fulfil the purpose of this study, collecting primary data was needed as a foundation. This was mainly done through a qualitative method, since the data needed to describe how the general HIL test environment process worked and explain how the stages were connected. Furthermore, the data needed to define the importance of the different KPIs that exist in the general HIL test environment process. The reason for this was to define and clarify what values the general HIL test environment process prioritises to ensure that the suggestions for improvement were focusing on the right place.

A qualitative method of data collection created an understanding of the general HIL test environment process. This is due to the fact that a qualitative method is intended to collect data that is descriptive, e.g., texts, words, feelings and thoughts according to Bell, Bryman and Harley (2019). Through this type of data collection, the general HIL test environment process could be described and mapped. Comparing using a quantitative method instead of a qualitative would in this case partly give similar data as a qualitative method would. Data like that could have been, for example, what values were important in the process by looking at KPIs. Also what different ideas of improvement proposals that people in the process had or parts in the process that they were dissatisfied with. According to Collis and Hussey (2014), a quantitative method is suited for looking at numerical data by using statistical tools. This method could for example have examined what the dissatisfaction of the process looked like, by having conducted a survey. This could have provided facts, statistics and other types of information about what people thought was good or bad in the process but with a more numerical result. However, this would not have given a deeper understanding of what the general HIL test environment process looked like, which was necessary to develop as there was no clear general mapping of the process. Therefore, the qualitative method was considered most suitable for data collection. Thus, the study mainly used qualitative data collection, but some quantitative methods were needed to be used to obtain numerical data about the general HIL test environment process that was not possible with the qualitative one. This was in the form of historical data, which is described in detail further down in the section about case study.

Research design

During the qualitative data collection that was made at Volvo Cars, where descriptive data about the general HIL test environment process were wanted, a research design was needed that matched this. Among the research designs that are common in qualitative data collection, that focus on examining a type of organisation and its departments and groups, there were mainly three designs that were most appropriate for this study. These three were ethnography, action research and case study.

Ethnography is a research design that according to Bell, Bryman and Harley, (2019) describes and looks at groups of people within organisations with focus on things as ethics and cultures, trying to understand the world of the person or group of persons. This would have been interesting to look at further in this study to see if there are cultural clashes within the organisation that affect the general HIL test environment process. However, this would have been difficult in our case since the studied process can take an exceptionally long time. Collis and Hussey, (2014) describes that as a researcher in ethnography design you must participate fully to really understand it. In addition, it is a process that was interesting to explore in this study and not the cultural part.

Since the idea was to look at a specific process at Volvo Cars, the study could have used either action research or case study as research design. According to Collis and Hussey, (2014) action research is a design where the researcher makes a change in for example a process and then measures or examines the impact of that change and later analyses the result against previous research. However, this would not have been possible in this study since it tried to answer "how" and "why" questions such as how and why the process works as it does. This was to be able to create and define a general HIL test environment process mapping which did not exist. Hence, the study carried out a case study as a research design since the authors only looked at a specific unique case to map the general HIL test environment process. However, action research would be relevant in a follow-up study when a definition of the process is made and hence be able to make corrections that can then be checked and compared to see what results they would give.

Based on the chosen research questions, the data that was needed were decided to be collected using several different methods, which Bell, Bryman and Harley, (2019) describes as common in a case study.

Case study

Several employees are involved in the general HIL test environment process, and it was important to get everyone's perspective. This was to bring out the general HIL test environment process but also an accurate perception of it and not just one person's perspective. Therefore interviews, observations and historical data were applied. By using interviews with different people from different departments, the credibility of the process mapping increased. The observations in the study were made in order to collect other data that was important for the authors own understanding. This meant, among other things, employees showing the authors around in the facilities, looking at parts of the general HIL test environment process to get a better idea and also getting concepts and definitions clarified.

The observations resulted in a simplified way to give and get feedback with the respondents and ask questions as well as show and explain our perception of their description of the general HIL test environment process. This constituted a so-called feedback-loop as described by Chirumalla, Jackson, Bruch, Andersson and Löv (2018), where a constant check that the authors understood the general HIL test environment process correctly could be done. The authors used feedback-loops frequently within the investigation to ensure that the data would be correct. This led to several of the interviews being made twice to further dig into and gain more and deeper data about the general HIL test environment process. All the respondents agreed during the first interview that they were able to do a complementary interview if needed. The authors were also using feedback-loops by sending out the figure of the descriptions and over the process to confirm that they agreed on the explanation.

The interviews were designed at the beginning of the study as semi-structured where the same questions could be asked to several different people in different parts of the process and analyse the difference between them. Collis and Hussey (2014) describe semi-structured interviews as having the ability to use more open questions even if it is pre-prepared questions. Further Collis and Hussey (2014) mentioned that within a semi-structured interview, the interviewer can add further questions to obtain more information about the answers. However, the authors first interviews were made to get a broad picture over how the general HIL test environment process worked. Later in the study, the interviews became increasingly unstructured to get answers to questions that only concerned specific departments and to get the respondents to describe more freely on the subject why things worked as they did. This led to interesting dialogues and the planned time of 45 to 60 minutes was starting to get too short. Therefore, the authors tried to increase the interview time and instead have 90 minutes. Though, it was not possible to schedule such long meetings with the respondents since they were often busy. Furthermore, early in the investigation the authors made a flowchart and a figure of definitions to show the respondents and to get feedback on these, which developed figure 2 and 3 in the result of this study. However, in all the interviews the authors explained for the respondents that they are going to be anonymous to make the respondent feel comfortable within the situation and also generate that they could speak freely without jeopardising them to be judged. Further the authors chose not to transcribe the interviews due to the fact that the recordings were giving the authors capability to listen to the interviews as many times as they wanted and therefore not waste time on writing everything down. Instead, the authors focused on listening to the recorded material and trying to come up with further questions or information to fill gaps within the general HIL test environment process.

The respondents were chosen by using the snowball sampling method which is a commonly used method according to Bell, Bryman and Harley (2019) and Collis and Hussey (2014). According to Bell, Bryman and Harley (2019) snowball sampling is about having contact with relevant groups of people and using them to establish contacts with others. The snowball sampling method was used in two ways. First off, the authors' supervisor together with the people responsible in the general HIL test environment process were asked who, in the start of the process flow, would be suitable to interview. The other way of using the snowball selection was indirectly made during the interviews by asking question 4 (appendix 1) to be able to follow the product in the production that was studied. In the end, a total number of twelve different employees in the process were interviewed once, and six of these employees were interviewed a second time (feedback-loop). The reason for the number of respondents ending up in twelve was because when the authors asked question 10 (appendix 1), the people already interviewed was mentioned. Furthermore, twelve persons was enough to get sufficient information about the process, together with the feedback-loops. The feedback-loops ended up in six respondents because further information regarding that specific department was needed and these departments were HIL Solutions and Testing Technology & Metrology. Regarding the different departments involved in the process, the snowball sampling worked as planned. Although, there were a few times where the respondents did not follow the process flow perfectly since that specific person was for example working at the end of the process. Nevertheless, this did not disturb the gathering of information.

As previously mentioned, the quantitative data was also collected in the form of historical data that was in Volvo Cars' own systems. This was to obtain additional information such as numerical data, in the form of lead times, in the process. Although, the historical data that were found and thought would be valuable for this study was not that clear as wanted. This meant that the historical data was in the end not used the way it was thought to be used. Nevertheless, the historical data gathered was still valuable for the study and ended up in a good result.

3.4 Quality

When it comes to quality criteria in qualitative research, Collis and Hussey (2014) and Bell, Bryman and Harley (2019) mentions that the criteria are different from in quantitative research. In quantitative research, validity and reliability are used to check the quality of the research but in qualitative research, these criteria do not apply well. Instead of using validity and reliability, credibility, transferability, dependability and confirmability are used as criteria. Nevertheless, these four criteria are not replacing reliability and validity, they are parallels to them according to Bell, Bryman and Harley (2019).

Credibility (parallels internal validity)

According to both Collis and Hussey (2014) and Bell, Bryman and Harley (2019) credibility is used within research and describes how secure or correct the results within research are and how the authors have worked to reach a proficient level of credibility. In this study the credibility has been gained when the authors have interviewed twelve different respondents from the general HIL test environment process. During these interviews, the authors asked if it was okay to record in order to listen to the interviews again to secure and control that everything was understood correctly. The authors also asked if it were okay to return with further questions which has led to that the authors had been able to ask further questions to secure more information and that the authors understood the general HIL test environment process. Furthermore, the authors decided that the respondents would be anonymous. This was made due to the fact that the authors believed anonymity would increase the respondents honesty and also let them feel free to speak about problems within the general HIL test environment process without jeopardising them to being judged or pointed out afterwards this thesis was released. Furthermore, another thing that adds to the credibility of this study is that the number of respondents has been divided into all the different departments that are involved within this general HIL test environment process. Furthermore, the quantitative method of looking at historical data has been complementary information to confirm that the authors understood this process correctly.

Transferability (parallels external validity)

Collis and Hussey (2014) and Bell, Bryman and Harley (2019) describes the transferability as how this study contributes to other contexts. This study relates to a process that develops new products for customer demands which is useful within many different contexts or industries. Customisation and its importance within the processes is not only usable within this process, but it could also be used for example within the construction industry as well.

Dependability (parallels reliability)

According to Bell, Bryman and Harley (2019) dependability is about adopting and ensuring that different documentations from the study are preserved. During the collection of all data in the study, the authors have used methods such as recordings and notes during interviews and meetings. This has meant that the data has been available throughout the thesis' work. However, the recordings were deleted after the work was finished since it was promised to the respondents during the recordings. The recordings were promised to be used only by the authors and no one else. Notes, on the other hand, have been saved to always be able to access this data. On the other hand, a logbook was not carried out because the authors both considered themselves to work equally and if they were to start to differ in how much one had done to the other, a logbook might have been used. What has been done, however, are to-do lists and reconciliations around these to be able to follow what has been done or not.

Confirmability (parallels objectivity)

Bell, Bryman and Harley (2019) mention that confirmability is in a way how honest the conduct of the research is, meaning that personal values and theoretical inclinations have not affected the outcome. In this study, the authors have used the literature honestly and have not allowed the study to be affected by any personal values. It has not been in the author's interest to put personal values into this research, nor making theoretical inclinations.

4. Inductive Theoretical framework

This section presents the inductive literature that was collected after the empirical data was gathered. It deals with literature that the authors of this study considered was important in order to get a deeper analysis of the problems that were found in the empirical data.

4.1 Information and communication

Within leadership and management, a crucial part is to describe, discuss and argue to create understandings. Bergman and Klefsjö (2012) describes that leadership is communication and that information usually is communicated through different media such as email or intranet at companies. This leads to that information could be unread which creates misunderstandings and therefore has increased the demand of direct communication within companies (Bergman & Klefsjö, 2012). Due to the fact that the results have indicated a lack of information and knowledge in the process at Volvo Cars, information and communication was seen as an important aspect to study deeper within logistics and its correlation to it.

Material flow is traditionally seen as the primary flow within logistics. However, it is not the only flow that is central for logistics. This is because material flow needs effective information flows according to Jonsson and Mattsson (2017). To meet customer demands, information about available capacity, customers requirements and supplier reliability in both short and long terms are needed. Therefore, logistics systems and its information are crucial to have effective material flows (Jonsson & Mattsson, 2017). Enterprise Resource Planning (ERP) and other IT-systems are used to support and plan logistics flows. However, in manufacturing environments Torkul, Yilmaz, Selvi and Cesur (2016) mention that uncertainty is an inevitable problem, due to the fact of studies of variance of orders, variance of lead time and backorders. In order to avoid bullwhip effects and decrease the costs, applications of order batching and considering order trends together with sharing information is important (Torkul et al., 2016). Further, information sharing should also lower costs and manufacturing lead time since it decreases the uncertainties within its environment.

Liker (2013) mentioned that engineers transform information into designs and that if you study engineers' work, you will find out that they mostly work to collect information for developing products. Further, in a process the engineers report new solutions or developments. The report that the engineer has made, later turns into a queue of waiting in an information warehouse, until it is someone that receive or starts looking at this report of solution. Decisions can therefore sometimes miss this information, or it takes months for the data to go through several departments, processes and people according to Liker (2013). This is because the information goes through several inefficiencies, since the process is structured by batch and queue manufacturing (Liker, 2013). However, by organising the flow of communication from the start to the end of the design process, no one would do anything before it is needed further away in the process. This is something the authors think is important for all processes to have better communication.

Internal integration

In an agile environment, cross-functional teams play a vital role. These teams consist of people who can contribute with skills necessary to produce what is needed (Project Management Institute, 2017). Parker (2003) describes that a standard cross-functional team consists of people from different departments in a company whose "*competencies are essential in achieving an optimal evaluation. Successful individuals combine skill sets which no single individual possesses*". This is the most important part of a cross-functional team according to Parker (2003), to use expertise from many different people from different departments in the organisation. Because of fast changes and the importance of competitiveness in today's business environment, the use of cross-functional teams is commonly used to get more responsive (Daspit, Tillman, Boyd & Mckee, 2013). Daspit et al. (2013) also describes that the cross-functional teams consist of people from different functional areas in a company who are working together to reach a specific goal and is used for example when new products are developed.

Furthermore, Daspit et al. (2013) mentions that the diversity of knowledge can be both good and bad. It has positive influences on performance because of the different perspectives that every member can bring to the team. Although, it can be negative since the members have specialised expertise, and the variation in knowledge and perspectives from member to member can result in communication barriers and conflicts (Daspit et al., 2013). If this is the case, that the members cannot collaborate properly, the diversity of the group is not put to use. This means that if the dynamics of the group does not support the collaboration and collaborative interactions between the people in the team, then the team's full potential is not reached. Furthermore, Daspit et al. (2013) mentions three internal elements that influence the outcomes from a cross-functional team. These are *stage-setting elements* which are connected to the climate in the team, *enabling elements* that are connected to efforts of the team related to projects, and lastly *behavioural elements* which are connected to trust and cooperation.

The usage of cross-functional teams and the development of them helps organisations with adapting to process oriented structures which is essential to get a smooth resource flow in the supply chain according to Gunasekaran, Patel and McGaughey (2004). Cross-functional teams contribute to an improved effectiveness in the supply chain and minimise, or even eliminate, boundaries between departments and functions in the organisation and gather specialised knowledge into one group. This leads to that no one can alone have complete control over the process, but instead this team has a joint responsibility and control with the mixed specialised members instead. Gunasekaran, Patel and McGaughey (2004) further mentions that cross-functional teams have been of huge importance in the forming of modern supply chains, where they have promoted a clearer and more accurate integration between organisations and suppliers.

Cross-functional teams have been involved in this study since there are a lot of different departments and functions involved in the studied process at Volvo Cars. The literature suggests that these cross-functional teams are great to have and in order for them to work, the collaboration in the team must work well. Literature about cross-functional teams could, according to the authors of this study, give the analysis more depth on how these sorts of processes with teams involved can work together to get a better result.

External integration

It is common that organisations work closely with their supplier to break down barriers and reduce uncertainty to get more control of the organisation's supply and distribution channels (Gunasekaran, Patel & McGaughey, 2004). This closer relation to suppliers shall also increase the information sharing and operational performances and further would reduce inventories and total costs. Furthermore, a closer relationship to suppliers improves service, technology innovation and product design (Gunasekaran, Patel & McGaughey, 2004). Integration through the supply chain is needed to achieve control to manage the flows in the operating systems. According to Gunasekaran, Patel and McGaughey (2004), well defined and controlled processes are essential for better supply chain management. However, there are many companies that do not succeed perfectly with their supply chain since they usually do not have developed their measures of performance, which is needed to maximise efficiency and effectiveness (Gunasekaran, Patel & McGaughey, 2004). Though, according to Petersen, Handfield and Ragatz (2004) all information shared and collected from this close collaboration within the integration of suppliers does not mean that it would be relevant within the decisions making. However, they mention that the major reason for integrating suppliers is to gain more, better and earlier information in developing processes by using the suppliers expertise. Furthermore, it is the manager's role to choose information and what is relevant and vital information in order to achieve effectiveness in the project groups or teams within projects (Petersen, Handfield & Ragatz, 2004). Furthermore, the earlier a supplier gets involved it should result in faster development processes, since it is in these stages the important decisions are made. If the suppliers are included too late in the process, they have almost no possibilities to make an impact to change the decisions. An earlier supplier integration is a coordinating mechanism for the decision over designs regarding the product, the process and the formation of the supply chain (Petersen, Handfield & Ragatz, 2004).

4.2 Process management

Understanding the process

Regarding the problems within this process, there was a lack of knowledge and deficient communications through the process and therefore further theoretical framework was made about the importance of understanding the process.

The understanding of a process is crucial within the work of improvements. This is due to the fact that it requires collaboration through different actors in the process (Bergman & Klefsjö, 2012). It is important to understand how changes in the process could affect other actors both positively and negatively. However, as Bergman and Klefsjö (2012) describe it, many processes have immense potential for improvements and therefore it is good to be consistent within a description of a process to reach all the possibilities of improvements. This is something they suggest doing by mapping the process in a flowchart, since it creates a joint picture over the process and what is happening or not within it. Facts about the process and how it has performed or been executed is crucial to make improvements (Bergman & Klefsjö, 2012).

Ownership and measurements

According to Bergman and Klefsjö (2012) process results should be measured in many ways, for example customer satisfaction, resource consumptions and time to be able to choose appropriate areas of improvements. Based on what Kohlbacher and Gruenwald (2011) describes in their journal that a process needs to have a process owner who takes care of all necessary measurements to coordinate and improve the process. The reason is that it is the process owners task to optimise and try to continuously improve the process. The author thought this was relevant to add more about in the theoretical framework, since the result from the respondents indicates that there is no clear process owner over this process. A process owner has the responsibility to set rules and limitations within the operative operations, according to Bergman and Klefsjö (2012). Further, functions as purchasing should not affect a process owner's demands. This is due to the fact that purchasing functions should support their competencies and knowledge to the process owner (Bergman & Klefsjö, 2012). However, a crucial factor is that if the process ownership is not clearly specified, there can be internal power-struggles consequently.

The results about the KPIs within the process have indicated that measurement does not exist in the process to the extent needed. Harvey et al., (2016) states that *"You can't manage what you can't measure"* and also that performance indicators are attempting to meet this challenge. The authors did not expect that no measurement existed in the studied process. Therefore, this new theoretical framework about process owners and their significant role of measurements has been added. Furthermore, the theoretical framework about how to start working with KPIs within the process was then interesting to find out more about and which performance indicators to use or ignore. This is due to the fact that implementing measurements that have too few or wrong performance indicators is costly, since it is then generating inadequate results (Harvey et al., 2016). Organisation is therefore needed to consider the cost against the result and if it is worthy. Harvey et al., (2016) describes a seven-step process, shown below in figure 1, which is used to find out what indicators that would generate quality assurance.

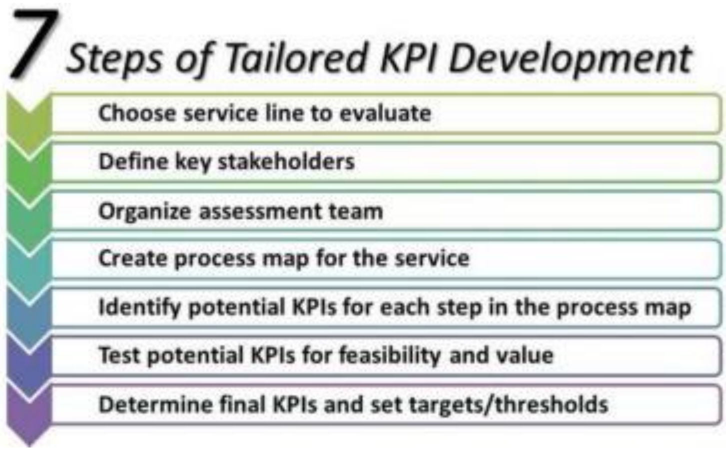

Figure 1: *Seven-step process of Tailored KPI Development* (Harvey et al., 2016)

This seven-step process was also based on a method called *Plan Do Check Act* (Harvey et al., 2016) and is a method from lean management that Liker (2013) describes as a process of continuous improvement. To start with, the goal in this seven-step process is to find a service line to the process that needs KPIs (Harvey et al., 2016). Further, defining the stakeholders and organising the assessment teams are the two next steps in this process to be able to create a process map for the service. In a process, KPIs are most efficient when focusing on measuring more specific and clinical tasks according to Harvey et al. (2016), compared to indicating more general performance indicators. A more general KPI could start to block the process from achieving the expected results from the KPIs (Harvey et al., 2016). A common mistake when developing KPIs is that fundamental process maps are not made over the service tasks from the beginning of the demand until the demand is fulfilled. A well described process map should be able to analyse which KPIs in each step of the process that would be good to measure and indicate. Based on these mappings, KPIs should be able to be chosen. However, a key factor is the prioritisation of which KPIs that the organisation commits to start tracking (Harvey et al., 2016). Feasibility, cost and comprehensive coverage are some factors to take into consideration when selecting KPIs and finally deciding targets to reach.'

4.3 Material and production management

In manufacturing companies, material and production management aims at contributing to an improved efficiency and resource utilisation and by this get a positive impact on results and improved competitiveness according to Mattsson and Jonsson (2013). By measuring and following up different efficiency measurements, a company can get an idea of how well the business works and to what extent the set goals are reached. The company can also influence different behaviours so that the business is running in conformity with the company's general strategy (Mattsson & Jonsson, 2013).

Inventory management

Inventory was something that some of the respondents mentioned during the interviews conducted in this study. Out of that reason, the authors considered it to be useful to have some literature about inventory management and further analyse whether Volvo Cars should or should not use more inventory to solve their problems with long supplier lead times. The same goes with material requirement planning further down, since it is a tool to use when having more inventory in the company.

Yao, Lee, Jaruphongsa, Tan and Hui (2010) mention that the fast development during the last decades in logistics and supply chain management has resulted in inventory management becoming more important. It has gotten increased attention both in research and practice, and the effort on inventory management has increased. This is something that Torkul, Yilmaz, Selvi and Cesur (2016) also put emphasis on. Torkul et al. (2016) talks about the increase in variance of demand in different businesses and that it has caused more inventory to be held. Re-order point models are used that give a safety stock to meet the variance in the demand, which ends up in even more inventory holding costs. The competition on the market forces companies to lower costs and work faster and companies increase product variety to cope with the rapid changes on the market. Torkul et al. (2016) further states that having a lot of inventory to reach fast response times is not efficient, and that shortening lead times is instead the most effective thing to do.

In many cases the material flow comes from some sort of warehouse or inventory. It can range in size from a smaller storage room to a big distribution warehouse. When designing a physical warehouse of some sort, the goal is to minimise the warehousing costs (e.g., storage shelves and insurance) and handling costs by achieving high filling rates and low operating costs (Jonsson & Mattsson, 2017).

The subjective definition of a warehouse can be described as a "*structural unit with all resources and organisational provisions necessary for the execution of processes connected to inventory and warehouse management, including the organisational units involved with goods receipt and shipping*" (Kappauf, Lauterbach & Koch, 2012, p.99). On the other hand, Kappauf, Lauterbach and Koch (2012) mentions a more proverbial saying that is "*the best warehouse is no warehouse*". The proverbial saying implies that warehousing is a negative thing to have, which has a bit of truth in it (Kappauf, Lauterbach & Koch, 2012, p.99). The reason for this is that having inventory results in costs, and the statement then implies that because of the different costs it is better to not have any inventory at all since it is more cost effective. Furthermore, Kappauf, Lauterbach and Koch (2012) describes that warehouse and the equipment that comes with it are both taking up space and ties up fixed assets, and the inventories that are stored in the warehouse ties up liquid asset capital.

Material requirement planning

Material requirement planning (MRP) is a material planning system which is principally based on the planning of new deliveries and when they should be made (Mattsson & Jonsson, 2013). This is done by calculating when the net need of material occurs, i.e., when the estimated inventory supply becomes negative. The decision rule for MRP is: Plan a new order for delivery at the first net need. Thereafter calculate the order time as the delivery time minus the product lead time (Mattsson & Jonsson, 2013).

MRP is used in production planning in order to set the order dates and the quantity that is needed (Putri & Rosydi, 2020). MRP gives the company the right information needed regarding inventory and production. The idea with MRP is to get a good picture of "*raw materials, components, and sub-assemblies quantified in the correct quantity and ready at the right time*" (Putri & Rosydi, 2020, p.94). MRP has been, and is still, the most frequently used production planning system in the world according to Díaz-Madroñero, Mula, Jiménez and Peidro (2016). MRP is often used in combination with different production techniques such as lean and agile manufacturing, just-in-time production etc.

Design and manufacturing against customer order (engineer to order)

The authors of this study thought it would be good to have literature about engineer to order (ETO), since this process is a form of ETO project. The literature helped the authors to discuss how this process copes with working with ETO.

According to Mattsson and Jonsson (2013), designing and manufacturing to customer order is the most complicated customer order process that exists in manufacturing companies. When this is applied it is not only the final products that are not specified before the customer makes the order, but also all the semi-manufactures and components that need to be purchased are unknown. Furthermore, there is a lot of development work, work with design and preparing the products for production during these processes. All these inputs are related to individual customer orders and therefore must be performed before moving on to production (Mattson & Jonsson, 2013). These efforts affect the customer order process in the sense that there will always be a delivery time whose duration depends on the scope and complexity of the customer order.

Vaagen, Kaut and Wallace (2017) describes it the same way as Mattson and Jonsson (2013). ETO is a fully tailored way for customers when creating their products. One thing that is typically when working with ETO projects is that the manufacturer has a dialogue with the customer through the entire process. This can often result in changes after the design phase and even after the production has started. From the customers perspective the flexibility is a good thing, but for the manufacturer it gives a high degree of uncertainty through the process. Since the customer during the process is able to change their mind, Vaagen, Kaut and Wallace (2017) describes that it can result in that different adjustments have to be made by the manufacturer, both in procurement, engineering and execution. This results in that the completion time for the project is uncertain, and that the design for the project is also uncertain. The design uncertainty makes the planning in ETO projects extremely complex, since the designs and engineering continues to happen at the same time as the production (Vaagen, Kaut & Wallace, 2017). Mattsson and Jonsson (2013) describes the planning process in ETO in four different steps. The first step is to *forecast future demand*. After this, *generating a preliminary delivery schedule* is important to make. The third step is to *generate a preliminary production plan* and the fourth and last step is to *reconcile and settle the produced plans*.

5. Results & Analysis

This section will go through what kind of parts that are needed in a HIL test environment for HIL testing, what different actors that are involved in this process at Volvo Cars and the authors mapping of the general HIL test environment process. Finally, experienced problems from respondents together with suggestions of improvements in the process from the respondents will be presented. All of this will follow with an analysis.

5.1 Definitions

First, when the study of this case started, the authors understood that there were a few words and definitions that needed to be defined. The authors, during interviews and observation at Volvo Cars, understood that employees in the process could use the same words as others but with a different meaning. This made it hard for the authors to understand the respondents and their explanations. This problem of misunderstandings was also described by the employees to be happening between people within this process. Therefore, the authors decided to make figure 2 below to clarify the definitions of different words in this process. It was also helpful further on regarding the mapping of the process, that the definitions were clearly stated.

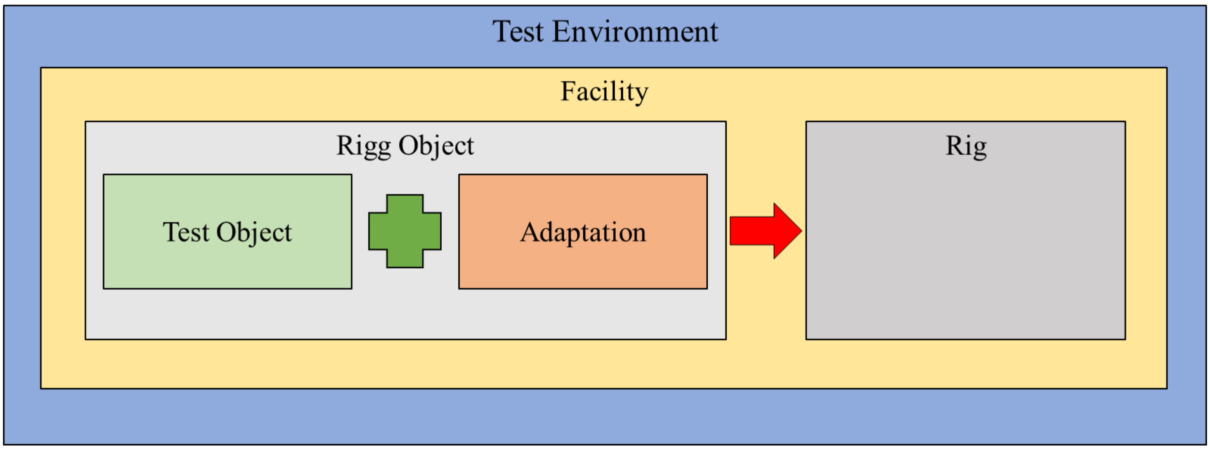

Figure 2: *HIL test environment (Own illustration)*

The first thing that is needed is an ECU to make the test on and in the process, this is called a *test object* (figure 2). The test object is further on in need of *adaptations* which could be an interface with different cablings to be able to adapt the ECU into the rig. When the test object has its adaptations, it is by the authors called a *rig object*. The word rig object is used in other processes and sectors at Volvo Cars but is not used within the general HIL test environment process. The authors of this study thought that it would fit here as well, and the people in the process that have been interviewed have also agreed on this. The word rig object fits well since it is parts that are connected into the *rig*. A “rig” is where the rig object can be tested by having equipment that can measure or simulate different environments and/or situations. Therefore, a rig can be the physical room with walls in some situations and in other situations just a simulation box. Usually within HIL tests, the rig is a simulation box that has the capability to simulate a whole car without having the physical car and create situations to see how the ECU reacts and then measure the results. Depending on the complexity of the test and how “much” the simulation box must simulate, the size of the simulation box can differ. Furthermore, the rig must be somewhere in a physical room, which is called *facility* (figure 2). As described earlier the rig and facility can be the same thing depending on the test, but commonly within HIL tests it is a simulation box within a facility. Finally, all these terms and parts together, which are needed for a test, becomes a HIL test environment.

Looking at what Aguilar-Savén (2004) mentioned, that a successful process always starts with understanding the company’s business processes, this process needed a clarification of the different definitions. By visualising the parts in a general HIL test environment through a map (Figure 2), the definitions were clarified and resulted in an understanding and mutual picture for everyone, as Aguilar-Savén, (2004); Heher and Chen, (2017); Rybicka et al., (2015) mention is important in a process.

5.2 Departments

During this investigation, specifically from the interviews and the usage of snowball selection, the authors got some knowledge about which different departments that are involved in the general HIL test environment process for HIL testing.

Customer

First off, there is a customer or a colleague. The reason it says colleague and not only customer is because Volvo Cars has decided to use the word "colleagues" when it is an internal customer, which it is in most cases, and just "customer" when it is external. In this study, the authors have decided to only use the word customer when describing the process to make sure to avoid any confusions. The customer is someone from another department at Volvo Cars that wants to make tests on a test object, or needs a new HIL test environment for their department to make tests in. In other words, it is not necessarily the actual tester that comes with the request for a new HIL test environment. This means that the customer comes with developed software that needs to be tested in an ECU to see how it performs. It can vary a lot in which department the person comes from, but some departments at Volvo Cars are more frequently represented.

HIL Solutions

This is sort of the main player in this process, which has developed quickly over the last two years and has more than doubled their number of employees. HIL Solutions role in the process involves construction, design, guidance and support. HIL solutions work with guiding and supporting other departments with developing HIL systems with a specific focus on the hardware in the HIL test environment and testing. They are working with the development, maintenance and communication of strategies and structures in the HIL test environment. The scope that they have is to make inhouse development of HIL hardware solutions together with benchmarking of HIL suppliers in order to find the right HIL tools for the different solutions. Furthermore, they make specifications and commissioning of all HIL solutions. Lastly, they support HIL simulators (rigs) of all sizes together with maintenance of these during the time that the rigs are up and running. They also take care of documentation with the HIL simulators. HIL Solutions supports and guides the customers through the entire process and helps them to reach out to whoever they need to contact and gives them overall support with their needs. In connection with Figure 2, HIL Solutions work with the rig and adaptation. Connected to the mapping in this study, it will be more thoroughly explained in 5.3 how HIL solutions are connected to the general HIL test environment process, in what parts they come in and what they do in these specific parts.

Testing Technology & Metrology

The next department that is involved in the HIL test environment process is Testing Technology and Metrology. Testing Technology and Metrology offers different support services and resources connected to measurement and metrology. They have the ownership of all the measurement tools that Volvo Cars has internally which is around 40 000 different tools, reaching from simple voltmeters to bigger complex measurement systems. They consist of two different teams; *Measurement & Development Solutions* who work with providing solutions when departments have problems with their metrology, and *Measurement Tools Acquisition & Support* who are in control over the administration of all the measurement equipment and take care of acquisitions, lending and support of this equipment. Connected to the HIL test environment process, Testing Technology and Metrology have earlier been involved by lending out measurement equipment to customers (employees from other departments) that want to test something. This has changed lately, now they do not lend out equipment to the same extent as they did before. Testing Technology and Metrology is involved in the HIL test environment process when there is an update needed in a rig, which could be capability for example, and never involved when a new HIL test environment is needed. They take care of the procurement of the measurement equipment needed regarding the updates. They also work with helping the users to calibrate simulators and measurement equipment, and they are the technical experts when it comes to *Vector* equipment, which is commonly used in the simulators.

Digital

The next department is IT, or Digital as they are named at Volvo Cars. They are divided into different teams in Digital, and one of the teams is called *Diamond team*, which is one of the teams that works with the HIL test environment process. They are involved when there is a question about licences for the HIL test environment, and this is mostly connected to the rigs. Digital is the only department who has the responsibility and rights to handle the licences. These licences are quite expensive, so it is important that the right licence is put at the right place. They are also involved sometimes when updates are needed in the software in these HIL test environments.

Test Facility Development (TFD)

TFD is a part of the Research and development (R&D) at Volvo Cars, and this department is working with transforming ideas into innovations to be ahead in the industry by meeting new and high standards of future cars. TFD are working specifically with development and procurement of testing equipment and facilities connected to testing within R&D. TFD provides customers advanced engineering, which can range from an early pilot study to a complete facility. When looking at the HIL test environment process, TFD joins the process when a completely new HIL test environment is needed and becomes the project leader of that process, where they help with the planning and construction of these environments whether it is just a room or a new facility. They are also involved when it comes to facility updates in the HIL test environments.

HIL Solutions, *Testing Technology & Metrology* and *TFD* runs the overall process together and combines their different expertise in the different parts to get the test environment working as wanted.

5.3 The process

Everything starts with a program or a project at Volvo Cars when a new car with new functions is planned. These functions are specified with descriptions of what they should do and what kind of hardware (ECU) and software that is needed to be capable of performing these new functions. However, in the initial stages of developing these functions that an ECU should control, several tests are needed to ensure the performance and functionality of the ECU. The structure of the tests is to gradually increase the complexity and include other parts of the car and also other ECUs that could be old, updated or new ECUs. This means that first, there are tests on only one ECU where Volvo Cars simulates it so that it thinks that it is in a car. The next step is to test a couple of ECUs together to see how they work with each other. The goal is to finally test all the ECUs at the same time except for a few which then are simulated together with the connected ECUs.

Shown in Figure 3 bellow is the mapping of the general HIL test environment process. It describes the general steps in the process from where the test is needed to when the test is feasible. The steps in the process will be more thoroughly explained below and is divided into three different parts, where the first part is the beginning of the process, and the second and third part is referred to as scenario one (*update*) and scenario two (*new HIL test environment*).

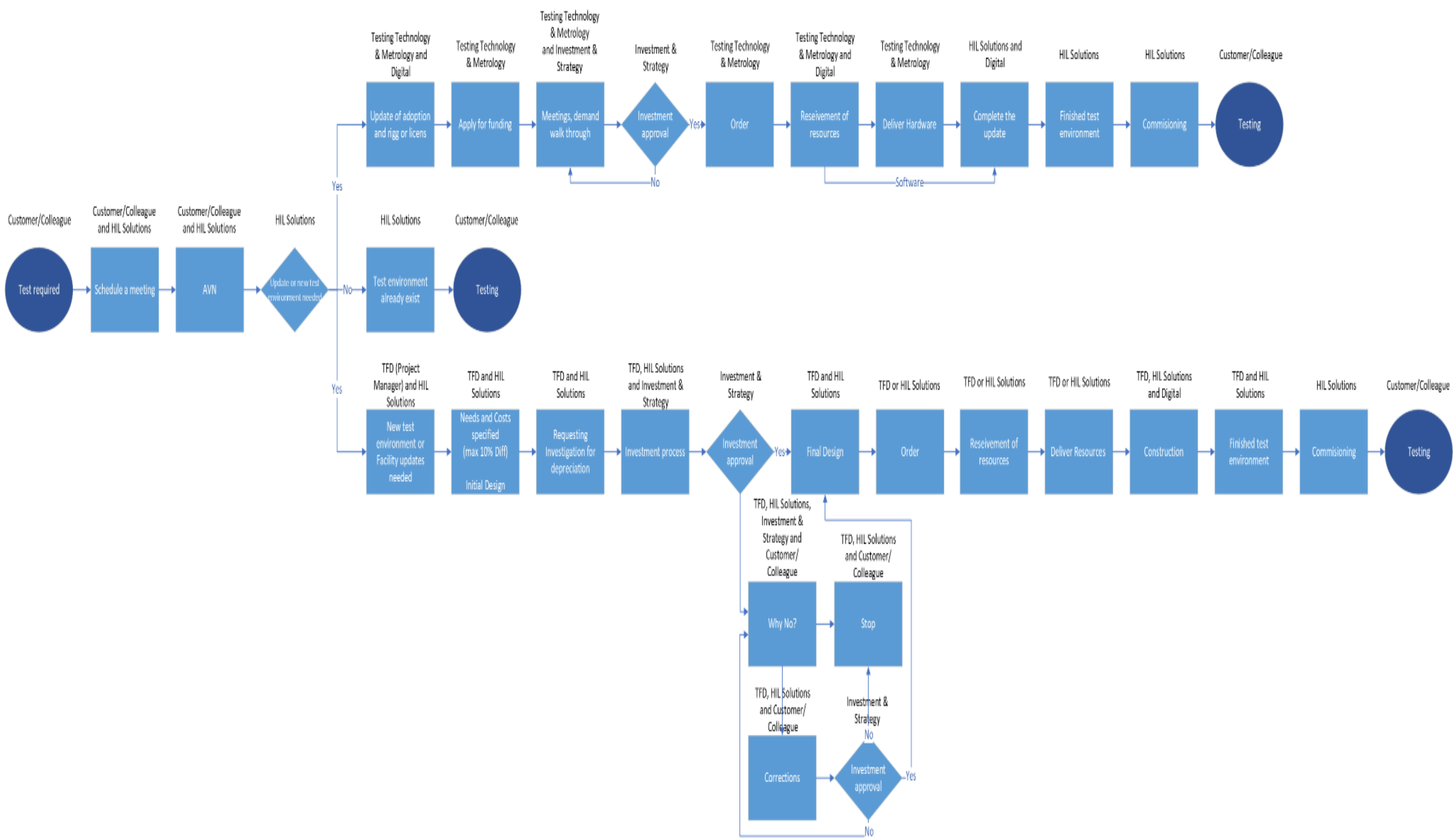
Customer/Colleague
Test required
Customer/Colleague and HIL Solutions
Schedule a meeting
Customer/Colleague and HIL Solutions
AVN
HIL Solutions
Update or new test environment needed
Yes
No
Yes
Testing Technology & Metrology and Digital
Update of adoption and rigg or licens
Testing Technology & Metrology
Apply for funding
Testing Technology & Metrology and Investment & Strategy
Meetings, demand walk through
Investment & Strategy
Investment approval
Yes
No
Testing Technology & Metrology
Order
Testing Technology & Metrology and Digital
Reseivement of resources
Software
Testing Technology & Metrology
Deliver Hardware
HIL Solutions and Digital
Complete the update
HIL Solutions
Finished test environment
HIL Solutions
Commisioning
Customer/Colleague
Testing
HIL Solutions
Test environment already exist
Customer/Colleague
Testing
TFD (Project Manager) and HIL Solutions
New test environment or Facility updates needed
TFD and HIL Solutions
Needs and Costs specified (max 10% Diff)
Initial Design
TFD and HIL Solutions
Requesting Investigation for depreciation
TFD, HIL Solutions and Investment & Strategy
Investment process
Investment & Strategy
Investment approval
Yes
TFD and HIL Solutions
Final Design
TFD or HIL Solutions
Order
TFD or HIL Solutions
Reseivement of resources
TFD or HIL Solutions
Deliver Resources
TFD, HIL Solutions and Digital
Construction
TFD and HIL Solutions
Finished test environment
HIL Solutions
Commisioning
Customer/Colleague
Testing
TFD, HIL Solutions, Investment & Strategy and Customer/ Colleague
Why No?
TFD, HIL Solutions and Customer/ Colleague
Stop
TFD, HIL Solutions and Customer/ Colleague
Corrections
Investment & Strategy
Investment approval
No
Yes
No

Figure 3: *General HIL test environment process (Own illustration)*. See clearer picture in Appendix 2.

In the beginning of the process in figure 3 there is a customer that requires to do a HIL test (*test required*). These tests can vary depending on the complexity of the requirements which usually follows a structure of how far the test object (ECU) has come in its development to its final state. Further, the planned way for the customer to get help with their requirements is to contact HIL Solutions at Volvo Cars. Although this is the decided way, the customer often ends up at the wrong place when a test is needed. A lot of customers have contacted Testing Technology & Metrology, for example, and then that department has supported them from there. But the planned way is as mentioned that the customer should always contact HIL Solutions when they need help with HIL test environments. Therefore, they have started with directing the customer to the start of the HIL test environment process, which is to HIL Solutions, instead of trying to help them in other departments that takes place later in the process.

The next stage in the process when the customer has contacted HIL Solutions is to *schedule a meeting* between the two. This meeting is where the *AVN* is made, where the customer and HIL Solutions together specify the requirements that this HIL test environment needs to fulfil to make the test. Based on the AVN, HIL Solutions can analyse and check if they already have resources in an existing HIL test environment that can fulfil the customers needs or if they need to *update the existing test environment* (scenario one) or *create a new test environment* (scenario two). When a *test environment already exists*, the customer can start with their test almost immediately. In the other two scenarios, HIL Solutions decides based on the resources on whether to go for an update or a new HIL test environment as seen in figure 3.

The choice between the first and second scenario is when there is an existing HIL test environment that needs to be updated or if there is a need for a brand-new HIL test environment. How the choice is made between these two scenarios, based on some of the interviews, has been differently described. In some of the interviews, the description was that the expected cost of the project decided if it should go through the TFD department or the Testing Technology & Metrology department. The authors have although heard from other respondents that the decision is based on if it is an update or a new environment. However, sometimes when there are updates that need to be made it could also be facility updates. It is HIL Solutions that takes care of facility updates when it comes to smaller updates. In bigger updates of facilities, TFD gets involved and these updates are often more complicated and costly. Therefore, the cost and complexity also can be seen as deciding the choice between the two scenarios.

Scenario one

When HIL Solutions' decision is to *update* an environment, they help the customer by guiding them to fill in a request for updates to the department Testing Technology & Metrology, which is the main department involved regarding *updates of adoption, rigs and licences*. Based on this request, Testing Technology & Metrology go through the needs and contact the customer if they have any questions. If there are software updates, Testing Technology & Metrology contacts Digital that is in charge of these matters. In this case Digital informs what kind of software resources that exist and can be used or what another update would cost to obtain. When Testing Technology & Metrology has all the details that they demand, and the costs for all these parts suggest that they need to *apply for fundings*, they bring a document with needed updates to a *meeting (demand walk through)* with the department "Investment & Strategy". In these meetings they go through all requested parts for the updates and discuss why this is needed. The Testing Technology & Metrology department applies for fundings, which Investment & Strategy needs to approve. Since the two departments have had these meetings before the *investment approval* and have already sorted everything out, Testing Technology & Metrology usually do not get a denial from Investment & Strategy since they already know the reasons for the request of fundings. If it for some reason would be denied, they will go back and have another meeting and sort everything out. However, when the fundings are approved Testing Technology & Metrology *order* the hardware from the suppliers and Digital order the software.

Further when the ordered resources are delivered from the suppliers, Testing Technology & Metrology or Digital gets the *receivement of resources*. This is due to the fact that it is the department that has ordered the material that receives it. Therefore, the received hardware resources need to be moved from Testing Technology & Metrology and delivered to HIL Solutions at Volvo Cars *(Deliver Hardware)*. The reason for this is that HIL Solutions is the department that constructs and *completes the updates* with the hardware. When it comes to the software on the other hand, it is Digital that receives it and instals the updates. When all updates are done and there is a *finished test environment*, HIL Solutions makes *commissioning* to ensure that everything works as it should. Finally, it is time for the customer to use the HIL test environment and make the required tests.

Scenario two

The second and last scenario is when the existing HIL test environments and resources do not fulfil the customers needs and a *new test environment* is needed or complex and expensive *facility updates*. In this case HIL Solutions hands over the project to TFD. From this moment, TFD is the project manager and HIL Solutions is a supportive department that helps with design and also takes responsibility to document the simulators. These two departments collaborate with planning and constructing this HIL test environment to fulfil the requirements. TFD and HIL Solutions start the project by *specifying all the resources needed* to construct an environment that is capable of doing the required test. This specified document is a BOM (Bill of Material) list that also contains the cost of everything, which summarises to a total cost of the resources to build this HIL test environment. The total cost is in the next step of figure 3, meant to start a request of *investigation for depreciation*. The total cost of these resources can differ a maximum of ten percent, against its finished state. This request of investigation for depreciation goes further into an *investment process* where the department Investment & Strategy is looking into this request of getting the financing to further give an *approval* or denial of the request. If the request gets approved, TFD and HIL Solutions get the fundings to buy the resources for the new HIL test environment and go directly to the *final design* step in figure 3. However, if Investment & Strategy denied the request for fundings, TFD and HIL Solutions investigate *why* they got the denial. Depending on the answer, TFD and HIL Solutions together with the customer must either *stop* the project or make *corrections* in the request. The Investment & Strategy department then gets the updated request, which still can be either approved or denied. If the decision of the request gets a denial, it will continue to go back and forth until it gets approved or stopped.

When the request finally has been approved, the next step in the process is the *final design*. TFD and HIL Solutions now create the final design of the HIL test environment. Why this was not made earlier is due to the fact that there can be changes in the initial design depending on if corrections were needed to get the fundings for the project. When the financing is approved, TFD and HIL Solutions make the final design and *order* the hardware. They also contact Digital with an order request for the required software. This works the same way as the "update" process, it is the department which orders the parts that gets the *receivement of resources*. However, the material needs to be transported to the place where it will be constructed *(delivered resources)*. Finally, after *construction* and the *test environment is finished*, HIL

Solutions makes *commissioning* as they did in the first scenario to see that everything works. After that the customer can start using the HIL test environment and fulfil the needs.

5.4 Key Performance Indicators

Although KPIs were important for this study and finding them were vital to answer research question 2, it was hard to get clear answers in the interviews about this. This is due to the fact that the respondents mostly answered that they did not have any clear KPIs within this general HIL test environment process. However, the result of the answers from the respondents differed depending on which department the respondent worked at. Comparing the answers of the question about KPIs there were six out of twelve persons who came up with KPIs. Five of them mentioned utilisation as a KPI and also mentioned that it is something they need to increase within the process. These five respondents came from the Testing Technology & Metrology, Digital and HIL Solutions departments.

Furthermore, the respondents explained how they work with utilisation. The respondents from HIL Solutions described that they were trying to check if material and resources already existed before deciding to make updates or new environments. However, Testing Technology & Metrology said that they do not measure anything yet but are trying to come up with solutions to be capable of measuring the utilisation of their resources and materials. Testing Technology & Metrology was aiming to have the same solutions as the Digital department already had. Digital mentioned during the interview that they have utilisation as a KPI to increase the utility of the licences within the organisation. The aim with it was to be able to optimise the level of utilisation and minimise the cost of obtaining new unnecessary licences. Looking into the different answers from these three departments, Digital is the only department that measures utilisation. The two other departments are trying to increase the utilisation, but only Testing Technology & Metrology are looking for a solution to start measuring the performance.

Furthermore, in an interview with a customer to this process the respondent talked about the costs of producing these new HIL test environments when the authors asked about KPIs within the process. The respondent described that it is too expensive to build a new HIL test environment for every new test request, and hence now looking into what parts that already exist and what supplements that are needed to meet the demand. The respondent from Digital had the same approach when this question was brought up. Digital is getting directives from the finance department to minimise the cost of licences since this resource is expensive. Therefore, Digital strives to increase the utilisation of the licences to also minimise the number of licences and instead use the licences that they already have.

Many of the respondents have complained and explained that the general HIL test environment is taking too much time. This was something that two respondents mentioned connected to this question about KPIs. One of the respondents was from HIL Solutions, who mentioned that they strive to have a more standardised solution and ways to be more efficient within this process and that standardisation was sort of a KPI.

The authors believed in the beginning of this study that KPIs would not be a problem to identify within this process and that it was thought to be obvious that KPI and measurements existed. Although, when analysing the result from the study there is only one department that measures their performance within utilisation. Utilisation is a great value to measure within this process but needs to be measured throughout the entire process. The fact that Testing Technology & Metrology is trying to develop measurements of utilisation is great, since it is important to have control over the capacity cost and production cost as Mattson and Jonsson (2013) mentions. However, it is interesting that HIL Solutions do not measure their utilisations, since they mention that they are striving to increase the utilisation of the parts that already exist. The question is, how do they know their performance, without measuring it? The difficulties with utilisation may not lie in measuring it although, but in the actions that are taken after the measurement. Measuring is good to get an idea of whether you use your things or not, but if you then must take actions to possibly increase utilisation, it could be problematic. If you then start to remove resources to increase your utilisation, it may affect the quality and efficiency negatively and could result in losing the ability to meet the requirements from the customers. Nevertheless, the biggest and most remarkable result in this study is that there is no one who measures lead time continuously or measures customer satisfaction.

According to Harvey et al., (2016) implementing measurements is costly if there are too many, but could also be costly if there are too few since it does not generate the results as expected. Liker (2013) described that shortening lead times within a process gives the best quality and lower cost. Without measuring lead times within the process, how do they know if improvements really are giving the results as expected? Both with trying to achieve high customer satisfaction but as well increase the speed and smoothness of the process flow by decreasing the lead time. Harvey et al. (2016) stated that *"You can't manage what you can't measure"* so how do they know the outcome of the changes or improvements in this process if measurements are not made?

5.5 Opportunities of improvements

In this section, descriptions from the respondents answers to question 6 in Appendix 1 are presented.

Customer perspective

One respondent, who is an internal customer to this process at Volvo Cars, mentioned that it can be complicated for new customers when getting involved in this general HIL test environment process when a new HIL test environment is needed. Sometimes they are guided to TFD, and in some cases these customers feel like they get a sort of "project leader" role in this process. In the same interview, it turned out that knowledge about who you as a customer should make first contact with when you want to do a test is limited. This respondent said that it always depends on several factors, e.g., costs and resources needed, that decides who to contact and that these several factors make it unclear. According to the respondent, this is due to insufficient information about this, which is not good since the process is complex according to the customer. The same applies to one of the interviews with a person from HIL Solutions, where the respondent said that a lot of customers do not have knowledge about the process. Furthermore, the respondent describes that it is not clear on how it is communicated to the customers on how this process works and where to go if the customers need help. It was also mentioned in the same interview that the respondent does not know how the customers find HIL Solutions, that is also a part that is not well communicated.

The internal customer further mentioned that as a customer, you get more involved in the process than necessary. The investment part is one of the parts in the process that this customer gets involved in, which according to the respondent is not reasonable. The respondent thinks that the structure of the process, where the customer gets involved and sort of gets a “project leader” role as mentioned, is not optimal because of the lack of experience and knowledge about these things. The customer should only need to express a need for a HIL test environment, and then just wait for it to be done.

A general mapping of the HIL test environment process did not exist when this study started. From the interviews it was obvious that customers to the process think that it is not the easiest to understand and that it is hard to know who to turn to. The authors of this study decided to make a general mapping to give a better understanding of the process, and according to Aguilar-Savén (2004) a process always starts with understanding it. Furthermore, Aguilar-Savén (2004); Heher and Chen (2017); Rybicka et al. (2015) describes that a visualisation of a process generates an understanding of a process for those who are involved in it and Heher and Chen (2017) further mentions that through illustrations, people can quicker understand instead of only using text for example. Since this process is a production and the purpose with the mapping was to show what it looks like to give the people involved in the process a better understanding, it was well fitted to use a flowchart for the mapping since it is one of the most used mapping tools in a production according to Rybicka et al. (2015). The same goes with Bergman and Klefsjö’s (2012) description of using a flowchart, where they mention that it is a great tool for generating a joint picture over the process and what is happening within it. The mapping would generate that the customers in this process would then know who to turn to, and later know what steps that are coming and what they mean.

When Mattsson and Jonsson (2013); Vaagen, Kaut and Wallace (2017) describe the ETO process, the customer is always involved during the whole time since the process of ETO is fully tailored for the customer. This is well connected to the HIL test environment process, since the product (the test environment) is fully tailored from the customers requirements and the customers are, as one of the respondents has mentioned, highly involved in this process. Mattsson and Jonsson (2013); Vaagen, Kaut and Wallace (2017) describes that customers gain flexibility as a positive outcome by being involved during the process. Although, the customer in this study does not like the degree of involvement that is in this process which is a little contradictory with what Mattsson and Jonsson (2013); Vaagen, Kaut and Wallace (2017) mentions.

Outside the boundaries

Another thing that has been brought up during some of the interviews is that some customers are making adjustments by themselves on their rigs, and some have even made their own HIL rigs with borrowed equipment from Testing Technology & Metrology. This has led to that HIL Solutions, together with the other departments, does not know how many HIL rigs that exist or where they are located since the customers does not communicate this, which the respondents have stated is problematic. All HIL rigs should be registered in HIL Solutions systems, which cannot be done with these “home-made” rigs. There is also a connection to the problem that some of the customers might not have enough knowledge about HIL rigs, and when they start to make adjustments on their HIL rigs, some grave consequences might happen since it could be connected to safety issues with the rigs for example. This gets problematic with the structure for HIL Solutions, since all the HIL rigs are very spread out in the facilities, and there are a lot of departments that have their own HIL rigs which makes them hard to keep track of.

Another respondent from HIL Solutions mentioned that they are in a transition phase of some sort at the moment and that they do not have the time or the knowledge to cope with all their projects. The respondent further mentioned that these customers that build their own rigs actually are good in a way with their great knowledge about HIL rigs because of the capacity shortage that HIL Solutions have, but that it still must be solved.

Almost every respondent that were interviewed has talked about the complexity of the process, either by implying it or explicitly stating it, and that the planning is difficult because of the complexity. The internal customer at Volvo Cars that was interviewed said that when you get forwarded to TFD, it is one of the hardest and most complicated steps to go through. The problem with the complexity of the process, according to the customer, results in all the shortcuts that people take and make their own rigs to avoid contacting TFD.

As described above, some customers are building their own rigs and that they are also making some adjustments on their own which could be related to what Bergman and Klefsjö (2012) mentioned about direct communication. It is common within organisations that information is not reaching out to involved people through media such as intranet and email, which Volvo Cars is using. This leads to misunderstandings easily occurring and therefore direct communication has been increased to reach out and decrease these failures (Bergman & Klefsjö, 2012). When it comes to this study and that customers do not know that these actions of making their own rig is not allowed, it might be grounded in that the customer did not have the knowledge or understanding of the process and how it works. According to Bergman and Klefsjö (2012) leadership is communication about arguing, discussing and describing to get an understanding within groups. Further, Jonsson and Mattsson (2017) describes the needs of effective information flows to meet customers demand and that information flow is crucial to have effective material flows. The respondents express the unawareness of all the materials of HIL test environments that exist, which can be derived from not getting the information out properly.

The mapping of the process would give a clearer picture of the process and what applies in every step as Bergman and Klefsjö (2012) mentioned in their report. This would mean that people who want to make a new HIL test environment, or just an update, would know where to go and who to contact instead of trying to make their own changes. This would result in a structural improvement in the process, if this problem with customers making their own HIL rigs would be eliminated. Bergman and Klefsjö (2012) mentions that this is great with making a flowchart, that improvement possibilities can easily be found.

On the other hand, it was mentioned in one of the interviews that it was not only negative with these customers' adjustments because of the capacity shortage that HIL Solutions have. It is also good in the sense that some of these customers have the skills to make these changes in the HIL rigs. This could be connected to internal integration, where it is good that HIL Solutions takes care of the knowledge and skills that these customers have. Volvo Cars works with an agile environment, and the cross-functional teams are one of the things that plays a vital role here according to Parker (2003) and Daspit et al. (2013). These cross-functional teams are although meant to include different departments that works within a process, but in this case, it could be good to involve the skilful customers even more so that the customers really get what they want which connects well to what Mattson and Jonsson (2013); Vaagen, Kaut and Wallace (2017) mentions about ETO processes.

Ambiguities

In the beginning of this study, the authors had difficulties just to understand all the different definitions and abbreviations that are used in this process. It took a while to get into that way of thinking as they do at Volvo Cars with all these abbreviations, and when conducting all the interviews in the beginning this was asked for to get explained in order to understand. A result from this was that the different respondents talked about different abbreviations and definitions in different ways, which just made it even more difficult to understand. This suggests that the people involved do not communicate on how they should talk about these definitions and abbreviations. One example is that the respondents used the word “HIL” and “rig” differently. In one of the interviews with a person from HIL Solutions it was mentioned that there have been some misunderstandings in the process because of this, which has led to delays for example. One example that the respondent mentioned is that when the test object has been ordered, and when HIL Solutions receive the test object it is just a circuit board, and those test objects need adaptation built around it to be able to do the test. This specific example ended up in that they had to order the material needed for the adaptation after they received the test object, instead of ordering earlier so that the test object and the material for the adaptation arrived at the same time.

It is once again important that everyone in a process has the same picture of it. In order to make improvements in a process there must be a mutual understanding of it which applies both for the steps in the process, but also for how the process is communicated according to Bergman and Klefsjö (2012). The mapping of the process (figure 2) together with figure 3 with the definitions that were generated from the conducted interviews would together create a clear picture of the process and also what words to communicate it with, which is exactly what Aguilar-Savén (2004); Heher and Chen (2017); Rybicka et al. (2015) mentions a map of a process should do. It would also get much clearer for the customers since there are customers who do not have a good knowledge of this process and would have an easier time to understand it if the definitions are clearly defined like in figure 2.

Investment process

The long waiting times is something that every respondent has mentioned in one way or another. One of the parts that has been a lot of comments on is that the investment part in this general HIL test environment process takes too much time, and that some of the respondents think that it should be possible to shorten it somehow since they consider it as the part that slows down the process. Although, in some of the interviews it has been stated that the investment part probably cannot be forced or shortened since it has to do with depreciations and that it is governed by Swedish law and must be handled in a specific way. This suggests that people do not have the knowledge about this, which makes it obvious in a way that there are complaints about that part.

When it comes to the investment part in this general HIL test environment process, there has been some comments from one respondent from HIL Solutions that the amount of times that you can apply for these investments needs to be increased. As it is for the moment, there are only four times per year (one time per quarter), and the respondent thinks that this is a structural problem and that it would be good to have more occasions for this in order to get the investment process going faster. If you as a customer miss this occasion to apply for the fundings, you then must wait for three months until next time. There have been a lot of complaints about the investment process and that it takes too much time, much because of the few occasions that you are able to do this. On the other hand, one respondent from Testing Technology & Metrology mentioned that the limitation of four times per year to apply for the investments has been changed sometime during 2021. These occasions are no longer limited, but instead you can apply whenever you have the need for it, which suggests that not everyone knows this.

All the respondents agreed that the investment part takes a lot of time but when it comes to the opinions that it takes much time for the investment process, the respondents are a little bit divided in their opinions. Some of the respondents think that the investment part should be shortened somehow, and others have mentioned that it might not be possible to shorten it down and that it is not that bad for the process that it takes time. This suggests that some people in the process have a better insight in the investment part and some people do not. Bergman and Klefsjö (2012) mentions that it is vital to understand a process in order to improve it, which suggests that information about the investment process has to be communicated thoroughly to everyone in the process. By doing this, the focus might change to other parts in the process instead and by starting to measure the other parts in the process, they will get an idea on what needs to be done which Mattson and Jonsson (2013), Harvey et al. (2016) and Bergman and Klefsjö (2012) mentions.

Regarding the number of occasions it is possible to get approval from the Investment & Strategy per year, the authors compare these against having batches within a production or manufacturing process. This is due to the fact that all decisions for approvals or denials are happening once per quarter of a year and not constantly over the year. As Liker (2013) and Torkul et al., (2016) mentioned, batches are something to avoid. Especially according to Liker (2013), stating that the que of information that is not being received in the right time to be used within making a decision. Similar to this process, they need to wait up to three months to get an answer and until they have fundings to order the components that are needed to build or update the HIL test environment. Furthermore, it is interesting that one respondent mentioned that this has been changed already during 2021, and that other persons who work closely to this process tell the opposite. Here as mentioned above, communication through different media is a problem once again. Added to this, it is especially notable that people do not have the knowledge about when these dates are during the year and cannot schedule and plan to be done with the request of fundings at that time. This leads once again to the importance of information sharing through this process. Furthermore, according to Torkul et al., (2016) manufacturing lead time would be reduced by information sharing, due to that uncertainty is reduced.

Involvement

Looking at the planning in the process between the different departments, there has been some comments from both Testing Technology & Metrology and Digital. The respondents from these two departments have mentioned that they are not planned for involvement until later in the process, which ends up in unnecessary and time-consuming steps that could be avoided if they had been planned to join the process in an earlier stage. Regarding Digital, they are barely included in the thoughts until a licence is needed which either could be in the investment process if it is an expensive licence, or later in the construction part where they realise that they need a licence. Both departments have mentioned that they want to get involved as early as directly after the AVN is set with the customer. Digital can contribute here by telling what licences that would fit well and also if they already have these licences in their possession. Testing Technology & Metrology can help with telling what different measurement tools and systems that already exist in house, and also discuss how the customer could modify their requirements just a little bit to be able to skip the investment on some parts for the HIL test environment. Nevertheless, the problem remains that these two departments do not get involved here, but instead later in the process and must take these unnecessary steps as mentioned. The respondent from Testing Technology & Metrology also mentioned that this is somewhat of a problem from TFD:s view also, since they do not get involved early enough either to the extent needed. For TFD it would also be good to get involved more clearly here, especially since they take the project leader role when there is a new HIL test environment needed.

It is clear from the interviews that people in the process have a lack of knowledge when it comes to the Digital department. In an interview with a person from Digital, it was mentioned that people do not think about the IT parts in the process until later when they need help with it at once. One thing that came up is that Digital is not even involved in a value stream mapping that has been made. Licences, which is the main reason Digital is involved in the process, is something that is thought of very late. This is because of the lack of knowledge about the importance of them and that Digital needs time to see what is needed for the HIL rigs so that they do not have to make unnecessary steps or buy unnecessary licences. Furthermore, the respondent from Digital mentioned that people do not have the knowledge about the excessive costs of the licences and do not think about that when they order an expensive licence late in the process. Also, the connection between the costs of these licences and Digital is something that, as the respondent put it, the "management people" do not understand. This is due to the fact that digital gets directives about cutting their costs every year but what the "management people" do not think of is that it is the overall business that affects how high the IT costs get, Digital just follows the overall business and purchases what they are asked to. At the moment, Volvo Cars are developing a lot of new HIL simulators, which makes it hard for Digital to cut their costs since these simulators need new licensees.

Just as mentioned earlier, it is once again important that everyone involved in the process knows how it works, and in this case, who is involved and where they are involved. Just as Bergman and Klefsjö (2012) put it, it is vital that everyone knows how the process looks like and what is happening within it, this by doing a flowchart, to be able to see what sort of possibilities of improvements that exists.

Regarding this process, the different departments within it have started a workshop. This could be seen as a cross-functional team when looking at Parkers (2003) and Project Management Institutes (2017) description that a cross-functional team consists of people from different departments in a company that can contribute with skills and knowledge necessary to get the desired results. When the departments in this process have meetings in this constellation, it is important that everyone that is involved in the process should be included here to get the most out of these meetings. Gunasekaran, Patel and McGaughey (2004) mentions that cross-functional teams contribute to an improved effectiveness in the supply chain and minimise, or even eliminate, boundaries between departments and functions in the organisation and gather specialised knowledge into one group. This implies that these workshops might eliminate the boundaries that are described by the respondent from Digital. Although, it is important that the departments really take care of this and involve everyone and really make use of the diversity of knowledge that everyone has. Otherwise, it could have a negative outcome as Daspit et al. (2013) describes the variation in knowledge and perspectives from member to member can result in communication barriers and conflicts, meaning that if the dynamics of the group does not support the collaboration and collaborative interactions between the people in the team, then the team's full potential is not reached.

Suppliers and Deliveries

The complexity of the orders of different tools and material for the HIL test environment can also be problematic according to one respondent from Testing Technology & Metrology. When they get orders for some smaller cables or voltmeters it only takes a couple of days until the products are delivered, but when there are orders on more complex measurement systems that require application for fundings, the delivery time together with the investment process can in worst case take up to ten weeks. There have also been some comments on the overall delivery times from the suppliers in the general HIL test environment process, and that it takes much time which is problematic, but no one thinks that this can be dealt with and changed.

Another respondent from Testing Technology & Metrology mentioned that their structure with the supplier contracts is something that is a bit problematic, at least with the Vector supplier who supplies them material for many of the HIL rigs. The respondent said that if they have the parts "on the shelf" it is not a problem, but usually they do not have it on the shelf since it is often Vector parts that are asked for. Regarding Vector parts, they always have to purchase the parts when needed because of licences. Vector parts are commonly used by Volvo Cars, but Volvo Cars is not a huge customer to Vector and because of that it gets expensive with Vector parts since there are many smaller purchases that they do, and the contracts are not optimal.

It is not only a closer collaboration within the organisation that would give this process a better efficiency. Petersen, Handfield and Ragatz (2004) mentions that a closer collaboration with the supplier as well would speed up the development process if the suppliers would have been included earlier, getting the possibilities of influencing the decision to the solutions. This would give the general HIL test environment at Volvo Cars a faster and easier process with the suppliers and also might end up in better contracts with them. According to Gunasekaran, Patel and McGaughey (2004), including the suppliers would not only improve the service from the supplier, but also generate technology innovation and product designs, since the supplier expertise would be used within the supply chain. This would result in that the general HIL test environment process would get a better insight on what to order and how to put it together, and it would be clearer for the supplier at an earlier stage what they would send and help Volvo Cars with.

Lack of knowledge and consequences

Regarding the customers when it comes to knowledge about the general HIL test environment process itself there is, according to some of the respondents, a lack of it. There are some of them that do not know how this process works. In one of the interviews where the respondent was from HIL Solutions, it was stated that some customers and especially new customers have limited knowledge about HIL simulators regardless of if it is internal or external customers. These customers do not know how the HIL test environment is made and what is involved in it. The problem with not having enough knowledge is not only a problem for the customers. In one interview with a person from HIL Solutions, it was mentioned that people do not have the knowledge about the time that this process takes, which can be problematic when a customer wants a HIL test environment in twelve weeks but what they do not know is that the requirements for that HIL test environment might take 24 weeks to get it done.

Something that almost every respondent has mentioned is that the requirements come too late, both from the customers but also between the departments involved. Although, some respondents have said that some customers can come to HIL Solutions and say that they want to have a HIL test environment in two years, since they know that it could take a long time for it to be made. From the interviews with people from HIL Solutions, they have mentioned that when the needs from the customers are received, i.e., how many days before the customers wants to do a test, can vary from a couple of days up to two years as mentioned above. The respondents have mentioned that neither of these (coming late or extremely early) is good. Coming too late is not good since the tester wants to make a test in a couple of weeks or even days, since they have their test object done at that point, but then might have to wait for six months or even longer sometimes. On the other way around, with the customers that plan way ahead as mentioned, it might change in the development of their test object according to one respondent. When that time comes, the test object and the requirements on the HIL test environment might have changed a lot so that the HIL test environment that is now ready is no longer needed, and instead a new one is required. It is also hard to estimate the costs when planning this far ahead, since the costs are not allowed to differ more than ten percent when making the investment process for the parts needed in the HIL test environment according to the respondents from HIL Solutions. Regarding late communication between the departments in the process, one of the respondents from HIL Solutions mentioned that needs could suddenly just pop up, where they need material that they do not have inhouse and must order which can also take a lot of time, especially if it is expensive things that need to go through the investment process. That can take up to three or four months before the investment is approved and the supplier delivers the products to Volvo Cars. A respondent from Testing Technology & Metrology said almost the same. It is too often that people come to Testing Technology & Metrology and want them to order something at once, it is most often panic as the respondent put it.

During the second interview (feedback-loop) with the different respondents at Volvo Cars, one question that came up was if there is any process owner or process leader that has some sort of responsibility for the HIL test environment process. The answers from the different respondents were either that they did not know, or that there was no process owner or process leader in this process. According to Kohlbacher and Gruenwald (2011), a process needs a process owner that has responsibility for necessary measurements to coordinate and improve the process, which is the task for a process owner. Further on, Bergman and Klefsjö (2012) mentions that if the process ownership is not clearly specified, there could be internal power-struggles as a consequence. The literature suggests that the general HIL test environment process needs a process owner that can take care of measurements and improvement work. Looking at what the different departments are doing now to improve the process, the work with that is a bit spread out. Assigning a process owner to this process would make the improvement work a lot easier to control, and the departments in the process can instead be focused on their work.

When HIL Solutions get the test object, they might need to do an adaptation as mentioned earlier, and when they get the test object and get information from the tester that they want to do the test in say three days, it is almost impossible to complete it according to one of the respondents from HIL Solutions. To make the adaptation, they need a specification on all the parts that are needed to be able to build it and they need this in time to avoid delays for the tester. According to the respondent, the problem is that the sharing of information and communication between the departments is not good enough.

ETO projects are one of the most complicated customer order processes when it comes to manufacturing companies according to Mattsson and Jonsson (2013). Vaagen, Kaut and Wallace (2017) mentions that in these ETO projects, the manufacturer has a constant dialogue with the customer through the entire process. In the case of Volvo Cars in this study, HIL Solutions is the supportive department that has constant contact with the customer to fulfil their needs. It is mentioned as a problem that some of the customers does not have much knowledge about the process, but since it is an ETO project and HIL Solutions together with the other departments is taking care of the HIL test environment, then the question is if the customer really needs to understand the process that well since they are not the experts anyway. Although, when it comes to the lack of knowledge regarding the time that the process takes it is a bit different. As mentioned in the interviews, it is problematic when the customers come very late with their requirements and want a HIL test environment in a couple of weeks or even days, since they do not have knowledge about the time that this HIL test environment process can take. On the other hand, some results suggest that the people that work within this process do not have a perfect knowledge of the time in the process either. Several respondents have been asked if they know how much time the different steps in the process take and have not been able to give a clear answer. Further on, a value stream mapping (VSM) has been made in the process as mentioned earlier. This VSM did not have a worst-case scenario, and some of the lead times that were written in it were hard to interpret and when the authors asked one of the persons that were involved in this VSM about these lead times, the employee could not answer on why it was like that and could not interpret it either. Further, besides this VSM that includes three different processes that have been measured, they do not make continuous measurements of lead times in the process. Harvey et al. (2016) mentions that "*you can't manage what you can't measure*", which suggests that they should start to measure their lead times so that they can communicate this clearly to customers.

Furthermore, the mapping could be a valuable tool to develop and expand even more after the lead times have been measured. The mapping would as mentioned give a better understanding of the process steps as Aguilar-Savén (2004); Heher and Chen (2017); Rybicka et al. (2015); Bergman and Klefsjö (2012) implies. If the lead times would be measured, then they could be integrated into the mapping of the process and then it would be easier to get the knowledge about how much time the process can take.

Test Object Process

In the interview with the internal customer at Volvo Cars, it was mentioned that the process with planning this HIL test environment process is not timed at all with the test object (TO) process in most cases. The respondent said that the general HIL test environment often takes much longer time than the test object process, and that they need to be better timed so that the customer does not have to wait for a long time to make their test.

The TO process as mentioned in the limitations section 1.5 is not the main process that this thesis studies. Nevertheless, there has been a lot of comments on the timing between the test object together with testers having to wait for a long time for the HIL test environment to be finished because of short notice. The authors of this study thought that one thing that might solve this problem, or at least give a hint on what needs to be done, is to time these two processes. Since the TO process was already mapped, the authors took advantage of this to show it with the authors own general HIL test environment process in order to show how they could be timed. The TO mapping is shown below in figure 4, with a brief description of the steps further below. These descriptions are from Volvo Cars intranet and with some help from one employee at Volvo Cars, and these descriptions are just briefly explained to get a quick picture of how it works. As mentioned, this is not the process that is studied and therefore it is not described too thoroughly.

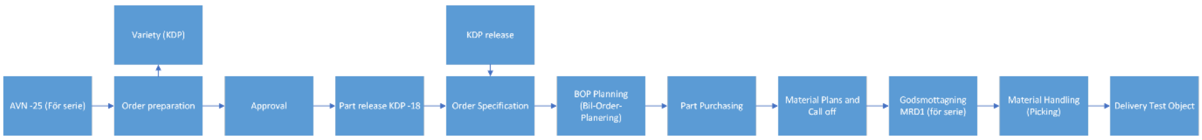

Figure 4: *Test object process (Own illustration)*. See clearer picture in Appendix 3.

The TO process starts with the same step as the general HIL test environment process which is *analyse and verification of needs*. Next up an *order preparation* of the test object is made and checked against *varieties in KDP* (Konstruktions Data Personvagnar). After this an *approval* is made and then *parts are released in KDP* by an engineer which means that when releasing a change order with new parts, it is made in KDP. This must be made minimum 18 weeks before the material requirement date (MRD). The next step is the *order specification* where the test object is specified in either a BOM list, KPD or manually. They are specified in the structure, which means that the parts are visible in KDP, and you can see in what cars these parts are used. After this is done the BOP planning (Bil-Order-Planering) starts, which describes in what order they are going to assemble parts when they build the cars in the pre-series. A build plan is created for the ordered test objects. Now it is time for the *part purchasing*, where it is essential that all part folders need to be released in order for the purchasing department to be able to purchase all the required parts. *Material plans*, which is the next step, requires that procurement has been made. Only once the purchase order for a part is in place, it will show up in the material planning system and a *call off* will be sent out to the supplier. Further on, *MRD (Material Requirement Date)* is when the material is scheduled to be in stock at Volvo, available to be picked for a specific test object. After this the *material handling (picking)* is made. Later when the test object is done (*delivery test object*), the need for a facility with a rig is needed in order to make the test.

Respondents have described during the interviews that the test object sometimes is finished before reaching out for help in getting the rest of the HIL test environment (adaptation, rig and facility). This means, when looking at the TO process, that after the *Deliver test object* the customer is reaching out to HIL Solutions as shown in figure 3. Furthermore, the respondents have mentioned during the interviews that sometimes they contact the customers when they have an *order specification* on all the parts that should belong to the test object. Therefore, the customer sometimes comes with the need of a HIL test environment in the stage *order specification* into the HIL test environment process. Lastly respondents also have described that the customer sometimes contacts HIL Solutions two years in advance before a test is needed. This means that the customer that comes to the general HIL test environment process has not started the test object process yet.

5.6 Improvement proposal

During the interviews, the authors asked the respondent if they had any solutions or ideas to improve the general HIL test environment process. The answers connected to be more efficient in the process or create a better structure within the process. All the improvement proposals are explained below connected to efficiency and structure.

Efficiency

First, as already mentioned in 5.5 the investment process described by the respondents is taking too much time. Two respondents from HIL Solutions came up with the suggestion to find new solutions to develop the entire process before and after the investment process. This is due to the fact that they described the investment process to be difficult to change and therefore one suggestion from HIL Solutions would be to come up with a new way of purchasing resources on their own budget and afterwards trying to receive an approved depreciation and get finance through the investment process.

Furthermore, all four respondents from HIL Solutions mentioned that increasing the inventory could be a solution to improve the process. Two of the respondents came up with the ideas of trying to find a standardised assortment of a limited number of choices of HIL simulators for example. The chosen concepts would be commonly used parts within the process. This would, according to the respondents, give the possibility to have standard resources as inventory and have a more modular way of thinking in the process. It would also be aligned with the aim to decrease customer solutions that were an old way of how they have worked before. One of the respondents also added that there are long lead times on the deliveries from the suppliers and that obtaining inventories could be a solution to that problem.

However, the innovation of software as Koch and Blind (2020) has mentioned has put the standardisation on challenges. A standardisation as the respondents mentioned might give the process a chance of being more effective, since EL-Khalil, Leffakis and Hong (2020) and Liker (2013) describes that standardisation and effectiveness has a close correlation. Therefore, the idea that this respondent has mentioned could be a solution to minimise the flexibility and increase the speed of the process.

Torkul et al. (2016) mentioned the increase in variance of demand that causes more inventory to be held and that the competition on the markets forces companies to lower costs and work faster. According to the suggestion from the respondents to have an increased inventory within this process, Torkul et al. (2016) described that it is not efficient with having a lot of inventory to reach fast response times. This is due to the fact that warehousing and the equipment that comes with it are both taking up space and ties up fixed assets, and the inventories that are stored in the warehouse ties up liquid asset capital (Kappauf, Lauterbach & Koch, 2012). According to Torkul et al. (2016), shortening lead times is instead the most effective thing to do, which is similar to Kappauf, Lauterbach and Koch (2012) statement that a more proverbial saying is "*the best warehouse is no warehouse*". This leads to the earlier problem of no measurements within this process and the importance of this to be able to manage the process.

Structure

A suggestion that was brought up from one of the HIL Solutions respondents was to clarify words so that everyone uses the same words for the same reasons and having the same definition in the entire process. As another HIL Solutions respondent stated, the communication needed to be improved since there is a lot of information that disappears between people within the process. Although, the respondent had no ideas on how it could be improved. However, this respondent came up with a suggestion to use the Swedish word "simulatorskåp" (simulator) instead of rig to make that clearer.

Furthermore, one respondent from HIL Solutions wanted clarifications on the structure within this process connected to the different departments involved. The respondent explained that this could be done by clarifying the department's role and what their responsibilities are in the process. The respondent felt that information sometimes disappeared during the process. Another respondent from the same department described a comparable situation that had happened a few times and was not really a huge problem, but that it still was a disruption. This was regarding a misunderstanding between two departments, where they thought that the other department was going to order or construct the same part to the test object or adaptations and later realised that none of them had fixed those parts.

The same respondent mentioned that a suggestion to structure this process even more and also increase the efficiency of the process would be to create a better collaboration between the customers and HIL Solutions. This is due to the fact that the customer often gets a specification of how their test object should be built and thereafter constructs the test object. Further when the test object is done, the customer turns to HIL Solutions for help with adaptations to be able to connect the test object into the rig. The respondent argued in this case that it would be better that the customer sent the specification on the test object to HIL Solutions at the same time as they receive it. This is to be able to prepare resources and eventually other constructions to the adaptation and the rig beforehand, and therefore increase the efficiency of the process time. During the interview, the respondent mentioned that it goes much faster and easier in cases when they receive the specification in time. However, the respondent also described that even if they get the specification, the test might not always work directly since there could be problems even if the test object is finished for being connected to the rig. This happens also on the occasions where they do not get the specifications of the test object. Therefore, it would be better if the collaboration between the customer and HIL Solutions increased to be able to be more efficient in the process to meet the demands of test requirements.

Every respondent from Testing Technology & Metrology, Digital and TFD also suggested better collaborations and to get information earlier in the process. In both interviews made with Testing Technology & Metrology, the respondents described that if they get involved earlier in the process, there would be less unnecessary loops that could occur, and the process would be smoother.

During the interview with Digital, the respondent mentioned that when a customer comes and describes their demand at HIL Solutions, they should directly contact Digital. The reason is that they should also be included in the discussion about the rig and how it should be utilised. As mentioned in section 5.5, this is not the case at the moment, but it should work like this. Nevertheless, when the customer has the first meeting with HIL Solutions and the customer need a new licence, the respondent from Digital described that HIL Solutions cannot give a clear answer on whether it is needed or not since they do not have the knowledge about this. This is due to the fact that they do not know which licences that already exist at Digital and therefore HIL Solutions do not know if they need to buy new ones or not. There might be licences that already exist at Volvo Cars, which is Digitals role to know and handle. Therefore, Digital is needed in the beginning to be able to get an understanding of how the rig is meant to be used and based on that come up with the most efficient way to move, update or buy licences for that case. This goes in line with Digitals ambition to reach higher utilisation and minimise the cost of the expensive licences, but this is not possible when they get involved later in the process.

One respondent from HIL Solutions talked about the problem that material requirements can suddenly just pop up. The respondent mentioned that one reason for the problem is the way people and departments operate within the process. This is due to the fact people within the process wait until they have knowledge of all parts that is needed for the whole HIL test environment. The suggestion from the respondent was therefore to structure and develop the way of operating so that people share the things they had decided and already know, even if it is only 20% of the final product or HIL test environment. This would improve further down in processes at Volvo Cars when people get information earlier and can prepare for that in advance and therefore create a smooth flow through the process.

6. Conclusion

In this section, the research questions of this study are discussed and concluded through the data from the results and analysis section.

6.1 Which stages are included in the general HIL test environment process and how are they connected?

Looking at the description of the process and the mapping of it in section 5.3, it is an extraordinarily complex process. As it is described in the picture, it shows the “thought” process of how this process “should” work. Although, as seen from the interviews, the process does not work exactly like the mapping that has been made in this study. This is due to the fact that information about the process in a simpler way has not existed before.

Regarding the process and its steps, it is not that complicated when looking at the mapping, but when information in the form of this mapping does not exist it is understandable that neither customers nor those who work within the process know every step and how it works. Since all the stages have not been clearly defined like this before, it is not surprising that problems have occurred, and a lot of these problems are in one way or another connected to a lack of knowledge about how the process works.

Regarding the number of different departments that are involved in the process, the complexity increases much because of this. Here it gets complicated, since there are many departments involved and it changes in the process steps on who is responsible for that specific step. As mentioned by the customers who are involved in the process, they have described that they do not always know where to address their demands. Sometimes the customer should contact HIL Solutions and another time to Testing Technology & Metrology and further to TFD and in the end do not understand why they are being handed over to different departments all the time. Although there are many departments involved in the process, it might be hard to just change that. What can be changed is instead the communications between the departments and with the customers. As also mentioned in section 5.3 there have been different explanations on the decision between the two scenarios in the process. It depends on the cost as some people describe it and others mention that it is the difference between updates or new HIL test environments that separate which department that should be involved. Both explanations are right in a way, since the costs get a lot higher when a new HIL test environment is being made or when there are facility updates. Although, the clearest explanation is that it depends on whether it is an update or a new environment.

Concluding remarks

To summarise and conclude, the mapping of the general HIL test environment was made (figure 3) which shows what steps that are included and how they are connected. The general mapping of the HIL test environment process would generate an understanding of the process and how it works for the moment. It is a picture that indicates that there are many departments involved in this process and therefore the information and communication are crucial factors to make this process work smoothly.

6.2 What are the most important KPIs in the general HIL test environment process?

Considering the KPIs in this process, the authors were a little surprised by the results that came out from the interviews regarding the question about this. The only department that mentioned a KPI that they also measured was Digital. The other departments mentioned some KPIs that they thought might be important, but they did not measure these or did not know if they were measuring these. This is something that might reflect on the process and the problems that the respondents have mentioned.

If they do not measure the KPIs in the process, they will have a tough time to manage it. This becomes clear when looking at what kind of problems that exist in the process. One KPI that could solve a lot of problems is lead times and a constant measurement of these. The problem with customers that do not know how much time the process takes might not even be a problem with the customers, but instead a problem with the people and departments that work within the process. If they do not measure the lead times, they cannot know how long the process will take and therefore cannot communicate this to the customers, which leads to the problem that the customers come very late or early with their requirements. Furthermore, by starting to measure lead times, other improvements would be easier to make in the process when knowing the time that it takes. Since a process does not perform better than its weakest link, it would also show what different parts in the process take more time than others and would give the opportunity to focus on these parts when streamlining the process.

Furthermore, measuring the lead times could give a clearer picture of the time spans that they have in the process, since this process is varying a lot in how long it takes to finish a HIL test environment. Even if the process could vary between a couple of months to two years in time, it is still important to know the time span for every step in the process to be able to communicate this to the customers but also that the other people involved in the process know approximately when the steps in the process should be done.

Based on the fact that lead time is not a KPI that is measured in the process, there is no clear indication when the customer should come to have their needs met on time. It is easiest to start by measuring the entire process continuously from start to finish. This would generate measurement data in the process that indicates how long it takes. Based on this data, analysis and other calculations can then be made to be able to meet the customer's needs within a certain time frame that is decided. The measurement could be performed by documenting when the customer comes to HIL Solutions with their needs and conduct further documenting when the requirements are fulfilled and the customer can start testing. The time in between is the lead time for the entire process and is an easy measurement to start with. HIL Solutions is the first and last department that is involved in the process and can execute these documents.

One aspect that might be connected to why they do not measure the lead times or other KPIs in this process is that there is no process owner or process leader assigned to this process. A process owner would in this case have the responsibility to control the process and implement measurements to be able to make continuous improvements in the process. This might also give the other people in the departments involved in this process more time to focus on their tasks instead of figuring out how to improve the process.

Furthermore, the utilisation within the process as the respondents mentioned in the study is an important KPI to measure. This is due to the fact that it can increase the use of resources and reduce costs within the process. Especially when the material and resources in this process are expensive, it is important to measure utilisation. Further, utilisation measures would also indicate which resources are not valuable within the process anymore. Things that are not being used could be sold or disassembled to spare parts for example, which would generate a higher grade of utilisation. This refers also to places where the HIL test environment takes up space, which could be used for something else as other new developed test environments. Although utilisation might be a reasonable measure in this process, the measurements need to be taken care of in the right way. If the utilisation is low, it would not be a solution to just making adjustments by taking away resources to increase the utilisation on the resources that are left. In that case, it could jeopardise the customer satisfaction since the ability to meet customer demands might not be fully possible.

Customer satisfaction is another KPI that might be a good thing to measure in this process. By having a process owner, and since it is an ETO process, there would be a continuous contact with the customer. The process owner can check with the customer through the entire process on whether the customer is satisfied or not. This would result in a better knowledge of what needs to be improved in the process and would also give a higher customer satisfaction. This is a crucial factor, since it is a need from a customer that triggers this process to start, and therefore it is for the customer that they make these HIL test environments.

Concluding remarks

This process is in need of measurements on the identified KPIs. In order to start with these measurements, a process owner would be beneficial to assign this process in order to control the measurements and communicate these. The most important KPI is the lead times which would give the development and the improvement work a great boost since it would be easier to identify where to focus. Combining this with measuring customer satisfaction would take this process to a whole new level of efficiency, knowing even clearer what improvements that need to be made. Lastly, measuring the utilisation needs to be made in order to know what is used and what is not used.

6.3 Based on the mapping, what changes and tools can be used to streamline the general HIL test environment process?

As already mentioned in section 6.2, the KPIs in this process need to be measured. In order to streamline the process, knowledge about the lead times for example can be helpful and give hints on what parts in the process that need improvements. The measurement of different KPIs might not be a form of tool that would have a direct impact on the efficiency of the process, but it would help pointing out what parts that need to be improved, and from there it can be easier to implement tools that are well fitted for that specific part.

Regarding problems that have been stated within the results of this study, there is a frequent problem about information and what information people or departments get during the ongoing process. However, the problem was sometimes that information was not shared internally between the different departments or from the customer to HIL Solutions. Therefore, the authors suggest more direct contact as Bergman and Klefsjö (2012) described is important to increase in order to gain better communication and information sharing. A way to have direct communication is through cross-functional teams, which Volvo Cars already has with their workshop mentioned earlier. Although, it could be increased if all the departments were more included in the beginning of the process when the customer expresses the demands and needs. This would allow all expertise to be gathered and every department can come up with their knowledge and bring solutions. Furthermore, this is similar to the section about external integration where Gunasekaran, Patel and McGaughey, (2004) and Petersen, Handfield and Ragatz, (2004) describe the pros of including suppliers early in a process. This is due to the fact that their knowledge and expertise can help the process to quickly come up with solutions and that no changes must be made later in the process. Although, since this process is an ETO process, it should include the customer and therefore also cross-functional teams together with all departments and the customer plus eventually the supplier would help the process to be smoother.

Regarding the tools of standardised parts within the process, some respondents have mentioned this as a suggestion to improve the process. The tool standardisation is common when trying to increase the effectiveness of the time within a process. Though, since there are no existing measurements of how this process performs, it is hard to know what tools would really increase the efficiency of this process and streamline it. Therefore, the authors believe that standardisation would be a useful tool to use if the measurement of the customer's satisfaction is implemented, and that the customer demands a greater time efficiency.

One improvement proposal that came up from some of the respondents was the usage of more inventories at Volvo Cars in order to be quicker with meeting the demands from the customers. Interpreting these proposals, there could be a lack of knowledge regarding what more inventory actually means. The respondents are right in that they would have a faster response to the demands if they have a lot of material in house, but what they might not think about is that it is a lot of tied up capital that lies in inventory. If the use of more modular thinking and standardised rigs would be used, it could be a smart move with more inventory. Although, MRP is something that they would need to work with which ends up in more work. Torkul et al. (2016) suggests that having a lot of inventory to reach fast response times is not efficient, and that shortening lead times is instead the most effective thing to do. Once again, it is important that lead times are measured in the process, and in turn make the process more efficient by shortening the lead times instead of using more inventory. Furthermore, a closer relationship with the suppliers would be beneficial and could give a quicker delivery which would mean that inventory is not needed in the end.

Concluding remarks

Finally, concluding what changes and tools that can be used for streamlining this general HIL test environment process is primarily to start measuring to be able to manage. Further, starting to use more agile tools like cross-functional teams to create a direct contact between all the departments and the customer. This also regards trying to include the supplier even more in the beginning of this process, since they have expertise that could be used within the development of the HIL test environment to get a smoother process flow.

6.4 Future Research and Limitations

In future research in this area as well as at Volvo Cars, the implementation of measurements would be interesting to look further into in order to do this in the most efficient way possible. Furthermore, it would be interesting to see which parts of the investigated process take longer time, review any eventual bottlenecks, and see how these have affected the process and how they could be eliminated. In addition, looking further into the relationship between Volvo Cars and their suppliers in this process would be interesting to see if it would be possible to further improve the process by examining the entire supply chain. It would then have been interesting to take a deeper look at the agile way in which Volvo Cars works, to see if the agile tools would help with the integration within this supply chain.

The authors believe that it would be useful to examine the Test objects process further in order to be able to link it to the general HIL test environment process so that the processes have a better interconnection. By starting from the mapping from this study this would be possible, and to further look more closely at how the Test objects process works and how the people in these different processes can collaborate more clearly to make this integration possible. Furthermore, the conclusions from this study can be applicable everywhere where an ETO process is used. The importance of measuring processes and having owners that takes care of these measurements is important regardless of location or company. The communications are also important regardless of location, but in Volvo Cars' case the tool cross-functional teams might not be the best solution elsewhere if agile work is not applied.

Regarding the limitations of this study, the main limitation was that there were no trustworthy lead times in the process. The authors believed that the lead times would have been important to have in order to find the tools to streamline the process, but instead the focus was on measurements. This can be seen as a kind of tool for the process although, but this was the main limitation for the study.

Reference list

Acar, O.U., Güvenç, L. and Altuğ, E. (2019). Hardware-in-the-Loop Testing of Automatic Lift Dropping System for Heavy Trucks. *Journal of Intelligent & Robotic Systems*, 98(3-4), pp.693–703.

Aguilar-Savén, R.S. (2004). Business process modelling: Review and framework. *International Journal of Production Economics*, 90(2), pp.129–149.

Altinger, H., Wotawa, F. and Schurius, M. (2014). Testing methods used in the automotive industry: results from a survey. *Proceedings of the 2014 Workshop on Joining AcadeMiA and Industry Contributions to Test Automation and Model-Based Testing - JAMAICA 2014*.

Awuzie, B. and McDermott, P. (2017). An abductive approach to qualitative built environment research. *Qualitative Research Journal*, 17(4), pp.356–372. https://www.emerald.com/insight/content/doi/10.1108/QRJ-08-2016-0048/full/html.

Bell, E., Bryman, A. and Harley, B. (2019). *Business Research Methods*. 5th ed. Oxford: Oxford University Press.

Bergman, B. and Klefsjö, B. (2012). *Kvalitet från behov till användning*. Lund: Studentlitteratur.

Biba, D.R., Ancuti, M.C., Ianovici, A., Sorandaru, C. and Musuroi, S. (2020). Power Supply Platform and Functional Safety Concept Proposals for a Powertrain Transmission Electronic Control Unit. *Electronics*, 9(10), p.1580.

Chirumalla, K., Jackson, M., Bruch, J., Andersson, N. and Löv, R. (2018). Exploring feedback loops in the industrialization process: A case study. *Procedia Manufacturing*, 25, pp.169–176. https://www.sciencedirect.com/science/article/pii/S2351978918305900.

Collis, J. and Hussey, R. (2014). *Business Research*. London Macmillan Education Uk.

Damelio, R. (2011). *The Basics of process mapping*. New York: Crc/Productivity Press.

Daspit, J., Tillman, C.J., Boyd, N.G. and Mckee, V. (2013). Cross-functional team effectiveness. *Team Performance Management: An International Journal*, 19(1/2), pp.34–56.

Díaz-Madroñero, M., Mula, J., Jiménez, M. and Peidro, D. (2016). A rolling horizon approach for material requirement planning under fuzzy lead times. *International Journal of Production Research*, 55(8), pp.2197–2211.

Dörnhöfer, M., Schröder, F. and Günthner, W.A. (2016). Logistics performance measurement system for the automotive industry. *Logistics Research*, 9(1).

Dubois, A. and Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research*, 55(7), pp.553–560. https://www.sciencedirect.com/science/article/abs/pii/S0148296300001958.

EL-Khalil, R., Leffakis, Z.M. and Hong, P.C. (2020). Impact of improvement tools on standardization and stability goal practices. *Journal of Manufacturing Technology Management*, 31(4), pp.705–723.

Ferràs-Hernández, X., Tarrats-Pons, E. and Arimany-Serrat, N. (2017). Disruption in the automotive industry: A Cambrian moment. *Business Horizons*, 60(6), pp.855–863.

Gunasekaran, A., Patel, C. and McGaughey, R.E. (2004). A framework for supply chain performance measurement. *International Journal of Production Economics*, 87(3), pp.333–347. https://www.sciencedirect.com/science/article/pii/S0925527303002561.

Harboe, T. (2013). *Grundläggande metod : den samhällsvetenskapliga uppsatsen*. Malmö: Gleerup.

Harvey, H.B., Hassanzadeh, E., Aran, S., Rosenthal, D.I., Thrall, J.H. and Abujudeh, H.H. (2016). Key Performance Indicators in Radiology: You Can’t Manage What You Can’t Measure. *Current Problems in Diagnostic Radiology*, 45(2), pp.115–121.

Heher, Y.K. and Chen, Y. (2017). Process mapping: A cornerstone of quality improvement. *Cancer Cytopathology*, 125(12), pp.887–890. https://acsjournals.onlinelibrary.wiley.com/doi/full/10.1002/cncy.21946.

Jonsson, P. and Mattsson, S.-A. (2017). *Logistik : läran om effektiva materialflöden*. Lund: Studentlitteratur, Estland.

Kang, N., Zhao, C., Li, J. and Horst, J.A. (2016). A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. *International Journal of Production Research*, 54(21), pp.6333–6350.

Kappauf, J., Lauterbach, B. and Koch, M. (2012). *Logistic Core Operations with SAP - Inventory Management, Warehousing, Transportation, and Compliance*. 1st ed. Springer, Berlin, Heidelberg.

Koch, C. and Blind, K. (2020). Towards Agile Standardization: Testbeds in Support of Standardization for the IIoT. *IEEE Transactions on Engineering Management*, pp.1–16.

Kohlbacher, M. and Gruenwald, S. (2011). Process orientation: conceptualization and measurement. *Business Process Management Journal*, 17(2), pp.267–283.

Kovács, G. and Spens, K.M. (2005). Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management*, 35(2), pp.132–144.

Langevin, A. and Riopel, D. (2005). *Logistics Systems: Design and Optimization*. New York Springer-Verlag.

Liker, J.K. (2013). *The Toyota way : 14 management principles from the world's greatest manufacturer*. New York Mcgraw Hill Professional.

Mallik, S., Ekere, N., Best, C. and Bhatti, R. (2011). Investigation of thermal management materials for automotive electronic control units. *Applied Thermal Engineering*, 31(2-3), pp.355–362.

Mattsson, S.-A. and Jonsson, P. (2013). *Material- och produktionsstyrning*. Lund: Studentlitteratur.

Parker, G.M. (2003). *Cross-functional teams : working with allies, enemies, and other strangers*. San Francisco, Calif.: Jossey-Bass.

Petersen, K.J., Handfield, R.B. and Ragatz, G.L. (2004). Supplier integration into new product development: coordinating product, process and supply chain design. *Journal of Operations Management*, 23(3-4), pp.371–388.

Project Management Institute (2017). *Agile practice guide.* Newton Square, Pennsylvania, Usa: Project Management Institute, Inc.

Putri, A.S. and Rosydi, B.I. (2020). Analysis of raw material inventory for insecticide packaging bottle with material requirement planning: a case study. *Jurnal Sistem dan Manajemen Industri*, 4(2), pp.93–98.

Raikwar, S., Jijyabhau Wani, L., Arun Kumar, S. and Sreenivasulu Rao, M. (2019). Hardware-in-the-Loop test automation of embedded systems for agricultural tractors. *Measurement*, 133, pp.271–280.

Rybicka, J., Tiwari, A., Alvarez Del Campo, P. and Howarth, J. (2015). Capturing composites manufacturing waste flows through process mapping. *Journal of Cleaner Production*, 91, pp.251–261.

Torkul, O., Yılmaz, R., Selvi, I.H. and Cesur, M.R. (2016). A real-time inventory model to manage variance of demand for decreasing inventory holding cost. *Computers & Industrial Engineering*, 102, pp.435–439.

Vaagen, H., Kaut, M. and Wallace, S.W. (2017). The impact of design uncertainty in engineer-to-order project planning. *European Journal of Operational Research*, 261(3), pp.1098–1109.

Vuli, P., Badalament, M. and Jaikamal, V. (2010). Maximizing Test Asset Re-Use across MiL, SiL, and HiL Development Platforms. *SAE Technical Paper Series*.

Yao, Z., Lee, L.H., Jaruphongsa, W., Tan, V. and Hui, C.F. (2010). Multi-source facility location–allocation and inventory problem. *European Journal of Operational Research*, 207(2), pp.750–762.

Appendix

Appendix 1:

Interview guide

Place: Volvo Cars Torslanda/Teams

Date: XX

Time: 45-60 minutes

Respondent: Department

Interviewer: Filip Arousell and Simon Hellgren

Recording: Yes/No

We are two students from Handelshögskolan (University of Gothenburg) where we do a Master's within logistics and transport management and we are doing our final thesis here at Volvo Cars Torslanda. We are investigating the hardware-in-the-loop (HIL) process and will map it together with finding eventual improvement measures.

The purpose of this thesis is to study how Volvo Cars general HIL test environment process works and map it in order to see if there are any possibilities of improvements in the streamlining of the general HIL test environment process. By identifying the important KPIs, the right improvements can be made in the right steps of the general HIL test environment process. Furthermore, by looking at the general HIL test environment process with a production perspective, the study will further investigat what kind of tools that can be used to streamline this production. Depending on who you are asking, the answers might be different about how the process works/looks like. The outcome of this investigation will be to find the stages that are included in the general HIL test environment process and how they are connected to each other. Furthermore, different tools to streamline the process will be investigated.

Further on in this interview we would like you to know that we are new and not familiar with Volvo terms and this process. This means that we do not know much regarding this process yet and want you to describe your view of the process as clearly as possible.

Because of GDPR and Swedish law, we will ask you if it is okay to record this interview. This material will only be documented and used within our work and used in our result and analysis of the research study. You will be anonymous and therefore no names or identity will be shown. Furthermore, all eventual recorded material will be destroyed and deleted after we have analysed and made our research.

Is it okay for us to record this interview?

Tell us more about yourself

- How long have you worked at Volvo?
- And how long within this department?

1. Can you describe your perception of the HIL process (from the start where a test is needed to the point where the test is executed)?
    - Do you think there are any differences in how the people involved perceive the process?
2. In what part(s) are you involved in? What is/are your task(s)?
3. Who hands over to you in the process and where in the process does that come from?
4. Who do you hand over to in the process?
5. Do you have any time frames/limits to keep, how do they look?
6. Do you feel like any parts of the process do not work like it should/could be improved?
7. Do you have any thoughts and ideas of improvements in the process?
8. Is there anything more that you want to add? Or any questions that we might have missed asking?
9. Would it be ok if we come back to you if we have more questions?
10. Is there anyone else within this process that we could contact to gather more information?

Appendix 2:

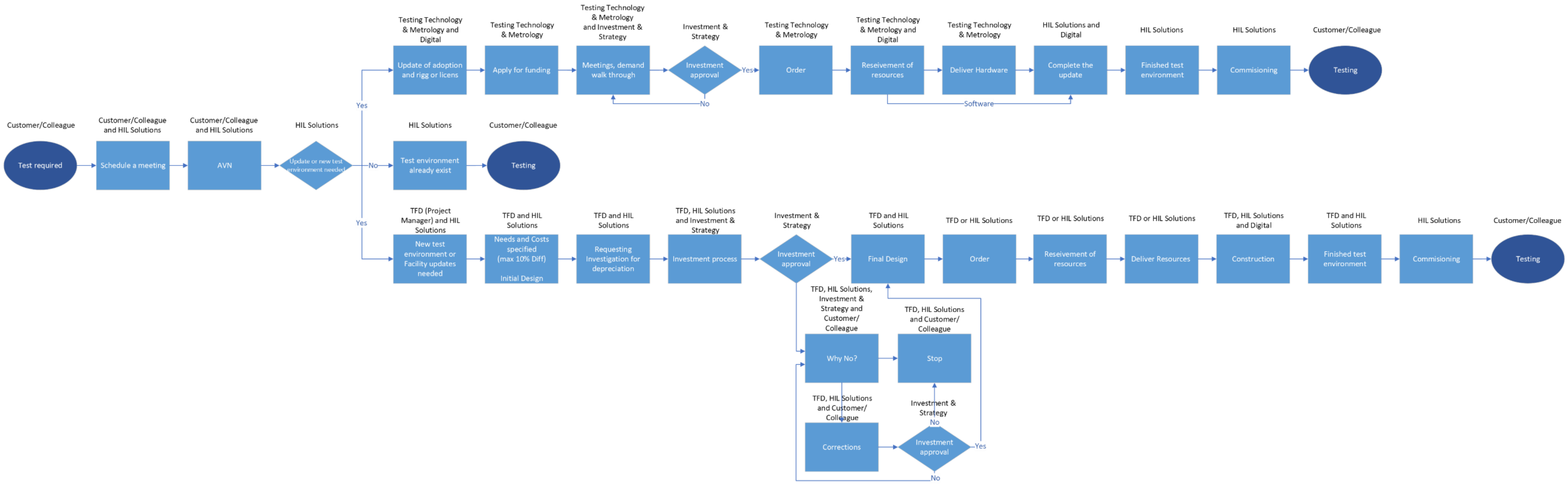

Figure 3: *General HIL test environment process (Own illustration)*

Appendix 3:

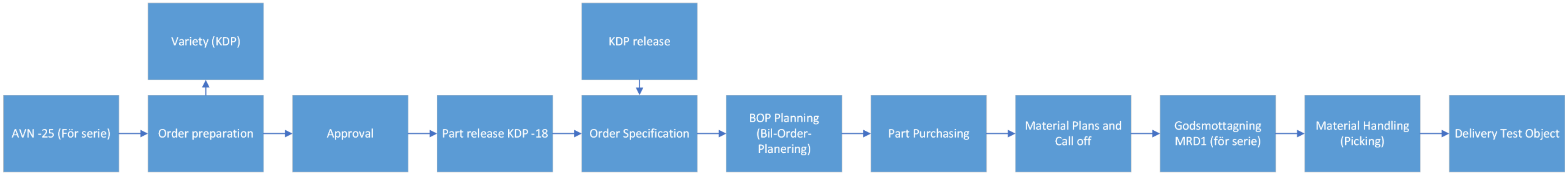

Figure 4: *Test object process (Own illustration)*