Alternative Test Methods for Mine Trucks and Loaders to Reduce Environmental Impact, Improve Lead Time and Productivity

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Underground Rock Excavation

"Alternative Test Methods for Mine Trucks and Loaders to Reduce Environmental Impact, Improve Lead Time and Productivity"

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Acknowledgement

Master Thesis. Final Project. A proof for the gathered knowledge from the past five years. When I started my university studies back in 2014 the thesis project felt far away. I remember how tough the first courses in mathematics and physics felt like and how much I fought to pass them. The years went by with new courses and the last two years with a specialization within Production. Now I see the end of this episode. Five years after I moved to Luleå I have now fulfilled my dream of becoming an Engineer.

I am very grateful for my time at LTU and I will always look back with happiness and gratitude. In Luleå I found amazing friends and you have all helped me during these years. I will always be thankful for your help, your happiness and our memories we will have for the rest of our lives. Thank you for these years! I would like to thank my family as well. Your support and belief in me has been important during these years. Thank you all!

In order to perform this thesis project, corresponding to 30 credits, I moved south for the first time in my life. I moved away from the winter in Luleå and unpacked my luggage in Örebro to conduct this project at Epiroc Underground Rock Excavation. For me this thesis was an insight in a new industry, the mining industry with an interesting and exciting future. I would therefore like to thank everyone at Epiroc for these months and all your help from the very beginning until the end now in May.

During these months I have had two supervisors; Jesper Sundqvist (LTU) and Johan Ståby (Epiroc). Jesper has answered my questions and supported me through this thesis project and I would like to thank you for all your help. Johan, you have helped since day one with all my questions about Epiroc’s abbreviations, who to contact and how to move on. Thank you for a good collaboration. Lastly, I would like to thank everyone I met during my study visits. Thank you for your time, effort and inspiration!

To summarize it all, these years have been amazing and I am very pleased I chose LTU and Epiroc. I am now ready for the next episode, work life.

Örebro, June 15, 2019
Petter Aksnes
Abstract

Epiroc manufactures and develops equipment for the mining and infrastructure industry. This thesis has been performed at Epiroc Underground Rock Excavation (URE) in Örebro, the company’s largest production unit for underground machines. In this project MH machines (material handling) have been investigated, i.e loaders and trucks. These machines are currently being built at the factory area in central Örebro and subsequently quality controlled in the Kvarntorp mine before they are finally delivered to the customer.

The project aims to evaluate how current test methods in the mine could be minimized and, in the future, removed for certain machine types. Today the machines passes six steps between final assembly and delivery, which results in an extended lead time. The machines are started up at the pressurizing station before they are ready for the quality control, i.e testing. The machines are then transported to Kvarntorp, about 20 kilometers from the factory, before the test operators from Epiroc conducts the testing. Each machine type has machine-specific checklists which means that the test operator performs both visual inspection as well as test drive in order to verify the machine’s overall quality and performance. The current test procedure causes machine damages and the mining environment makes it necessary to perform both re-painting and washing. Summarized, the current test procedure leads to increased costs, increased amount of rework and extended lead times. In addition, the machine handling between the factory area and Kvarntorp involves logistical challenges.

The work began with a literature study where the focus was on change management, flow efficiency and total quality management. Subsequently, a current state analysis was carried out in order to map the current structure and it’s problem areas. Identified problems included extended lead time, machine damages (paint, tires, bucket, snow) and work environment. All together, these areas lead to increased costs for the afterflow. These problems were categorized into three main problems; test procedure, environment and economy. To seek for improvements, three study visits were carried out; Volvo CE Arvika, Komatsu Forest Umeå and Epiroc SED Örebro. The inspiration was used to create an optimized test facility at the factory area.

The work resulted in a solution where all areas are improved, i.e lead time, machine damages and work environment. A new test procedure based on an improved visual inspection, new bucket test and a succeeding test drive on a chassis dynamometer has eliminated the need for the Kvarntorp mine. With the new test facility the machine damages have been eliminated and the working environment for the affected people has improved considerably. Furthermore, the lead time is also heavily reduced. All together, the improvements results in large annual savings, which in turn gives relatively short pay back time. Epiroc is recommended to invest in both short and long term solutions where the short term can be implemented before the new test facility is finalized. In a short term perspective it is important to create a good dialogue between test operators and assemblers, switch to digital checklists and to remove the currently mandatory drag test. In longer term, Epiroc should implement a quality team, invest to increase data access and finally invest in the test facility.

Keywords: operations development, deviations, wastes, production flow, machine testing
Sammanfattning


Nyckelord: verksamhetsutveckling, avvikelser, slöserier, produktionsflöde, maskinprovning
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<th>Definition</th>
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<tbody>
<tr>
<td>CCM</td>
<td>Cultural Change Management</td>
</tr>
<tr>
<td>CM</td>
<td>Change Management</td>
</tr>
<tr>
<td>ERD</td>
<td>Epiroc Rock Drills AB</td>
</tr>
<tr>
<td>HMLV</td>
<td>High Mix Low Volume</td>
</tr>
<tr>
<td>HVLV</td>
<td>High Volume Low Variety</td>
</tr>
<tr>
<td>JIT</td>
<td>Just In Time</td>
</tr>
<tr>
<td>KBD</td>
<td>Key Business Drivers</td>
</tr>
<tr>
<td>LTU</td>
<td>Luleå University of Technology</td>
</tr>
<tr>
<td>MH</td>
<td>Material Handling</td>
</tr>
<tr>
<td>MT</td>
<td>Minetruck</td>
</tr>
<tr>
<td>OM</td>
<td>Operations Management</td>
</tr>
<tr>
<td>PDCA</td>
<td>Plan Do Control Act</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>ST</td>
<td>Scooptram</td>
</tr>
<tr>
<td>TC</td>
<td>Test center</td>
</tr>
<tr>
<td>TPS</td>
<td>Toyota Production System</td>
</tr>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
</tr>
<tr>
<td>TSA</td>
<td>Test System Architecture</td>
</tr>
<tr>
<td>URE</td>
<td>Underground Rock Excavation</td>
</tr>
<tr>
<td>VSM</td>
<td>Value Stream Map</td>
</tr>
<tr>
<td>WIP</td>
<td>Work In Progress</td>
</tr>
<tr>
<td>3C</td>
<td>Three Circles</td>
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</table>
# List of Variables

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Average lead time</td>
<td>[days]</td>
</tr>
<tr>
<td>B</td>
<td>Extension through after flow</td>
<td>[days]</td>
</tr>
<tr>
<td>C</td>
<td>Extension through after flow, ST</td>
<td>[days]</td>
</tr>
<tr>
<td>D</td>
<td>Extension through after flow, MT</td>
<td>[days]</td>
</tr>
<tr>
<td>E</td>
<td>Average cost: pressurizing, test drive, readjustments</td>
<td>[SEK]</td>
</tr>
<tr>
<td>F</td>
<td>Standard cost: transportation, repaint, wash</td>
<td>[SEK]</td>
</tr>
<tr>
<td>G</td>
<td>Driven distance test operators</td>
<td>[km]</td>
</tr>
<tr>
<td>H</td>
<td>Amount value adding time, pressurizing</td>
<td>[%]</td>
</tr>
<tr>
<td>I</td>
<td>Amount value adding time, rust protection</td>
<td>[%]</td>
</tr>
<tr>
<td>J</td>
<td>Amount test drive</td>
<td>[%]</td>
</tr>
<tr>
<td>K</td>
<td>Number of machines, 2018</td>
<td>[nr]</td>
</tr>
<tr>
<td>L</td>
<td>Number of machines, production plan 2019</td>
<td>[nr]</td>
</tr>
<tr>
<td>M</td>
<td>Time pressurizing</td>
<td>[hour]</td>
</tr>
<tr>
<td>N</td>
<td>Time test drive</td>
<td>[hour]</td>
</tr>
<tr>
<td>O</td>
<td>Time readjustments</td>
<td>[hour]</td>
</tr>
<tr>
<td>P</td>
<td>Cost from operation cards (ST14)</td>
<td>[SEK]</td>
</tr>
<tr>
<td>Q</td>
<td>Deviations drag test, 2013</td>
<td>[nr]</td>
</tr>
<tr>
<td>R</td>
<td>Deviations drag test, 2014</td>
<td>[nr]</td>
</tr>
<tr>
<td>S</td>
<td>Deviations drag test, 2015</td>
<td>[nr]</td>
</tr>
<tr>
<td>T</td>
<td>Deviations drag test, 2016</td>
<td>[nr]</td>
</tr>
<tr>
<td>U</td>
<td>Deviations drag test, 2017</td>
<td>[nr]</td>
</tr>
<tr>
<td>V</td>
<td>Deviations drag test, 2018</td>
<td>[nr]</td>
</tr>
<tr>
<td>X</td>
<td>Cost after flow</td>
<td>[SEK]</td>
</tr>
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1 Introduction

The work has been conducted in cooperation with Epiroc Rock Drills AB in Örebro at the department for Production Engineering and Operations Development. This Section will introduce Epiroc as a company and further discuss the background, objectives and scope for the project. Lastly, the project’s stakeholders and the thesis outline will be explained.

1.1 Company Introduction

Epiroc was born in 2017 when Atlas Copco announced the split between Atlas Copco and the previous division Mining and Rock Excavation Technique. The company Epiroc was introduced as an independent company in the summer 2018 and has approximately 14 000 employees with sales in 150 countries (Epiroc 2019a).

Epiroc is a leading productivity partner for the mining, infrastructure and natural resources industries. With innovative technology, the company develops and produces drill rigs, rock excavation and construction equipment, and provides services and consumables worldwide (ibid.).

1.1.1 Underground Rock Excavation

The division Underground Rock Excavation (URE) develops and manufactures tunneling and mining equipment for underground activities. Their rock drilling equipment are used to excavate rock in infrastructure or mining operations worldwide. The loaders and trucks are used to transport rock and ores in an effective and powerful way. Lastly, rock reinforcement equipment are used to secure the underground environments during mining and infrastructure projects (Epiroc 2019b).

Epiroc Rock Drills (ERD) AB in Örebro is URE’s main production facility and has 1800 employees. Figure 1 shows the organizational structure for ERD. The department of

![Figure 1: Organization structure for URE Örebro. Source: Epiroc (2019c).](image)

Production Engineering and Operations Development lays under the production manager’s overall responsibility. Figure 2 shows the structure for the production department and it’s different sub departments. The figure further shows the department of Operations Development.
1.2 Background For the Project

ERD develops and manufactures a wide range of machines for the mining and infrastructure industry. Today, all manufactured machines are tested before being delivered to customer, a time-consuming and costly operation. The tests varies between machine types, but have a common ground. The material handling (MH) machines, i.e trucks and loaders, are all tested in the mine Kvarntorp outside Örebro. In addition, the tests also involves logistical challenges, extends lead times and requires the machines to be re-painted, washed and readjusted after the tests. Epiroc believes it is possible to minimize some of the tests for the MH machines and replace a large part of the mining tests with test methods at the factory area in Örebro. Figure 3(a) shows a Minetruck (MT) 42 and Figure 3(b) a Scooptram (ST) 14, both manufactured in Örebro and part of the MH series.

1.3 Objectives

The thesis project aims to, through a feasibility study, evaluate how tests for trucks and loaders in the mine can be minimized and in the future also be removed for certain types of machines. The thesis therefore aims to investigate how the test methods can be adapted in order to shorten the lead times and make the handling of finished mining machines more efficient after manufacturing, i.e analyze the after flow. Furthermore, the project aim is to conduct an analysis over the current situation and suggest improvements to
reduce lead times. The purpose is thus to analyze the handling of the machines after the manufacturing process and to investigate the time between production line and shipment. To fulfill the objectives the following research questions will be answered:

1. How are tests regarding trucks and loaders conducted today and are they all necessary?
2. How can the tests be adapted and developed for the future?
3. What methods are available for these types of machines?
4. How can new methods be implemented at Epiroc Rock Drills AB?
5. How will the improvements affect Epiroc?

1.4 Project Scope
To ensure that the project stayed within the actual scope, the following delimitations were made:

- The project will only analyze material handling machines (MH) such as trucks and loaders.
- The real (detailed) implementation phase at Epiroc will not be analyzed.
- Lack of free space at the factory area will not be taken into consideration.
- Test procedure for autonomous vehicles will not be analyzed.

The master thesis concludes 30 credits on full time, which corresponds to 20 full work weeks, during spring 2019.

1.5 Stakeholders
The master thesis is made for the department of Production Engineering, which thereby acts as the main stakeholder for the project. Johan Ståby, Operations Development Manager and project employer together with the department will hopefully be able to use the project results for further developments within the company. Hopefully the thesis project will help to reduce lead times, reduce costs and make the handling more efficient. Examiner at LTU together with involved personnel are classified as secondary stakeholders. The testing personnel are this projects user stakeholders.

1.6 Outline
The following text explains the outline of this master thesis. Chapter one, this section, presents the introduction such as company information, background, objectives and scope. Chapter two clarifies the theoretical framework used in this master thesis. The presented theories have been used in the improvements, analysis and discussions. The methodology will be explained in chapter three. The chapter will clarify every phase of the thesis project and will explain how the work was done, when certain decisions were taken and how the work ended up with a complete solution. Chapter four explains the current situation and highlights problem areas. An analysis over the current state is followed,
which highlights what areas to prioritize. Next chapter, result and analysis, begins with four interviews and their combined analysis. The interviews are followed by a description of four conducted study visits and their combined analysis. The empirical work is summarized in a requirement specification before the chapter ends with a description over the final solution and it’s result. The result and the whole outcome from the thesis project is then discussed in Chapter six before everything is summarized in the last chapter, Conclusions.
2 Theoretical Framework

This chapter contains the theoretical framework used in this thesis project. The sources for the literature review have been books and scientific articles. The used books have previously been used in other courses at LTU and otherwise borrowed at Örebro University Library. The scientific articles have been gathered at Scopus, Emerald Insight and Google Scholar.

Production is defined as a network of processes and operations. Connected operations forms the processes in which the products are produced (Shingo 1989). According to Karlsson (2003) there are numerous forces driving the production development towards more networks than it has been before. Production development is a wide term and refers to both development of new systems, as well as improvements of already existing systems. The largest potential to achieve high quality systems, is according to Bellgran (2009) during the development phase of new production systems. The author states that production development is more important than ever due globalization and the overall competitiveness and that it requires a long term perspective to ensure the potential. This is also stated by Bartezzaghi (2013) who explains that companies have experienced considerable changes regarding their overall activities, and specific production.

This project aims to analyze and improve the end of an already existing production system. The end in this case symbolizes the testing phase before the machines are delivered to the customers.

2.1 Operations Management and Development

Operations development is how to develop and improve the efficiency, quality and technology to achieve better business according to Salvendy (2001) who further states that so called full potential organizations have achieved the following four aspects during their journey:

- Sensitivity to the environment
  An organizations ability to adapt and learn.

- Cohesion and identity
  An organizations ability to build an own and powerful identity.

- Tolerance and decentralization
  The ability to build long lasting relationships within and outside the own organization.

- Conservative financing
  Strong finances with long perspective.

Due operations development often can lead to changes, the ability to adapt is crucial. To implement improvements, the concept of change management (CM) can be used. According to Harrington and Voehl (2015) culture change management (CCM) is a more complex, but also more efficient, way to enable the desired culture and increase the capability for changes within an organization. The authors states that the culture has considerable impact on how an organization is prepared and willing to adapt and implement improvements and changes. The aim should be to create a culture where changes are accepted as well as expected. Further, Harrington and Voehl (ibid.) states that it is estimated that an average employee is directly affected by a projects output approximately once every five years but
argues that poor culture can affect the outcome nevertheless. According to the authors, 75% of all projects fail due lack of support from the employees. The resistance to change is also stated as a problem by Hiatt and Creasey (2003). The approach for CCM is described below:

1. Current State Assessment
   Define the key business drivers (KBD).

2. Vision Statements
   Develop a vision statement for every KBD.

3. Performance Goals
   Compare the vision statements to the strategic plan for the company. Set 5 year performance goals for every KBD.

4. Desired Behavior
   Make sure the KBDs and the organization’s values are matching.

5. Year Plans
   Develop individual 3 year plans for every KBD.

6. Combined 3-year Plan
   Combine the individual plans to one overall plan.

7. 90-day Action Plan
   Breakdown of the first 90 days to single weeks with assigned tasks.

8. Implementation
   Establish a group responsible for the tasks in the 90-days action plan.

In addition, follow up is crucial to remain desired level regarding the implementation. This is also stated by Paramanathan et al. (2004) who argues that support from management is an important factor to ensure motivation and expectation for changes and improvements. Stanleigh (2008) argues that changes will occur, despite people like it or not and that everyone have to be prepared and ready to adapt to remain successful. Changes can be radical, incremental or endemic (Counsell, Tennant, and Neailey 2005). Common reasons for change initiatives to fail are according to Stanleigh (2008) the following: not engaging all employees, managing change at management level, sending employees to short change programs and not giving time for the employees to adapt. To overcome the barriers, it is important to understand that change is a process, to move forward step by step and to create and communicate a clear vision (Stanleigh 2008; Hiatt and Creasey 2003).

Operations management (OM) has, until recently, been an internal business function with focus on the management aspect of operations development. Nowadays the focus for OM has entered another path towards a more external role where focus is on how to develop closer relationships with every part in the supply chain (Johnston and Staughton 2009). The need to build strong relationships have grown bigger due globalization, which according to Johnston and Staughton (ibid.) have affected the role for OM. The importance of strong alliances and long term perspective is also supported by Liker (2009), Bergman and Klefsjö (2012) as well as Petersson et al. (2015). Although a more external role, OM is still much about internal changes and improvements with a large focus on continuously improvements (Johnston and Staughton 2009). Hicks (2007) argues that OM has large impact on the overall management system.
2.1.1 ADKAR

ADKAR is a model for change and is divided into five steps. These steps will act as a guide throughout the change (from the beginning until the end) and is illustrated in Figure 4. The model illustrates what phases a person goes through during change. The culture regarding change will affect how employees experience the five phases (Harrington and Voehl 2015; Hiatt and Creasey 2003). Management has to be aware of the different phases to implement changes and improvements step by step in an adapted way for the employees to ensure efficiency (Paramanathan et al. 2004; Stanleigh 2008; Hiatt and Creasey 2003). The ADKAR model can be used by management to focus on the right thing in the right moment.

![Figure 4: ADKAR model for change.](image)

2.1.2 Kotter’s 8 steps

ADKAR and Kotter’s 8 steps have similarities. Both are based on the different phases employees and people go through during change. Kotter’s model consists of eight steps and is like ADKAR dependent on that right type of culture is available at the company. As Figure 5 illustrates the first three steps are linked to culture to ensure the right conditions for change exist. The following steps can be merged to engage the organization. The last two steps is in the end of a project or change and are connected to the implementation phase (Appelbaum et al. 2012).
2.2 Lean Production

Lean is a concept and production philosophy that derives from the automobile manufacturer Toyota. The concept of Toyota Production System (TPS) was first described in the west in 1990 by Womack, Jones, and Roos (1990) and the concept of Lean was introduced. Lean redefined the previous production system, mass production, which was introduced in the beginning of the 20th century. Lean is focused on the customer demand and to reduce costs through elimination of waste (Liker 2009).

According to Pardi (2007) the main benefit with TPS is its constant focus on continuous improvements and waste elimination. This is done through the focus on Just-In-Time (JIT) and Jidoka (autonomation), two fundamental parts for TPS according to Liker (2009). He further states that TPS is built upon 14 principles which in turn is organized through the 4P-model (Philosophy, Processes, Partners and Problem solving). The procedure for Lean according to Liker (ibid.) is:

1. Identify value
2. Map the value stream
3. Create flow
4. Establish pull
5. Seek perfection

Petersson et al. (2015) states that TPS cannot be directly copied to other organizations without adaption. Instead, it is crucial to adapt the principles and the methods in TPS to the current situation at the company to reach the potential of Lean. Lean is dependent on a specific culture to ensure that principles and methods are followed as desired. That is why a long term perspective is highlighted as the most important factor for Lean (Liker 2009; Petersson et al. 2015; Modig and Åhlström 2017). Further Hines, Holweg, and Rich (2004) highlights the identification of customer value as crucial.

According to Modig and Åhlström (2017) Lean is based on values, then principles which in turn is followed by methods. Lastly there are tools and activities that together form
Lean. The values defines how an organization should be, principles how it should think, methods how it should do and the tools defines what it should use. Lean should be seen as an operations strategy. Figure 6 illustrates Lean as a management system and how the content is linked to each other.

![Figure 6: Lean as a management system. Source: Modig and Åhlström (2017).](image)

2.2.1 Kaizen

The Japanese term Kaizen stands for continuous improvements, an important idea within Lean. Continuous improvements is supposed to eliminate waste and improve the company continuously. The Deming wheel PDCA (Plan, Do, Control, Act) is an important method for continuous improvements (Liker 2009; Bergman and Klefsjö 2012). Petersson et al. (2015) states that standardization of successful implementations are crucial to maintain the result in long term. To succeed with continuous improvements, it is crucial to not get pleased with the current situation. According to Liker (2009), Bergman and Klefsjö (2012) and Petersson et al. (2015) the strive for perfection and continuous improvements is a journey with no end.

2.2.2 Waste Elimination

According to Hicks (2007) there are two fundamental parts of Lean: waste elimination and ensuring value flows. Those in turn consists of identification of value, understanding of flow and characterisation of waste. Shah and Ward (2007) states that the values, principles, methods and tools that are associated with Lean exist in order to eliminate waste and to increase the customer value. In Lean there are seven wastes, i.e non-adding value, which have been developed to 7+1 (Hicks 2007):

- Overproduction
- Inventories
- Transport
- Waiting
- Motion
- Extra processing
• Defects
• Underutilisation of employees

To minimize waste it is crucial to produce according to customer demand which in turn can be ensured by pull production. The idea is to deliver what the customer wants and when the customer wants it, which according to Hicks (2007) and Shah and Ward (2007) can be done through JIT. Liker (2009) states that pull production in small quantities reduces lead time and is far more efficient than push production. Pull system also reduces the work in progress (WIP) due production takes place with small lot sizes, which in turn increases the flexibility (Karlsson and Åhlström 2013). The WIP level is a measurable variable and can be used to analyze the current situation in a production facility. Little’s law is used to calculate the WIP level where the throughput rate and lead time is multiplied as followed

\[ WIP = \text{Throughput rate} \times \text{Leadtime} \]  

and the product of them becomes the WIP level (Segerstedt 2008).

### 2.2.3 Resource and Flow Efficiency

The efficiency in a system can be defined in two ways, either flow or resource efficiency. The most common efficiency type is resource efficiency according to Liker (2009). Modig and Åhlström (2017) refers resource efficiency to a single resource (i.e machines, employees) and the amount of time it is used in a system during a specific time unit. This focus increases the lead times, WIP and makes it harder to produce according to customer demand. Regarding resource efficiency the aim is to use the resources as much as possible to achieve high efficiency and reduce the alternative cost (the loss for not using a resource maximal). The opposite, flow efficiency, refers to a single flow unit and how the unit flows through the system. Efficiency in this case is measured through the flow units perspective and the time it’s value increases. Table 1 illustrates the differences between resource and flow efficiency.

<table>
<thead>
<tr>
<th>Resource Efficiency</th>
<th>Flow Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Goal</td>
</tr>
<tr>
<td>Resources</td>
<td>High capacity utilization</td>
</tr>
<tr>
<td>Goal</td>
<td>Perspective</td>
</tr>
<tr>
<td>Flow unit</td>
<td>System</td>
</tr>
<tr>
<td>Perspective</td>
<td>Throughput time</td>
</tr>
<tr>
<td>Single resources</td>
<td>Long</td>
</tr>
<tr>
<td>WIP</td>
<td>Many</td>
</tr>
<tr>
<td>Many</td>
<td>Few</td>
</tr>
</tbody>
</table>

Hines, Holweg, and Rich (2004) states that efficiency is a fundamental variable to measure for companies to be able to analyze the current situation. Prioritizing flow efficiency is necessary if focus is JIT and pull production systems. With flow efficiency the flow unit (i.e produced products) will be prioritized above the available resources which thereby will decrease the lead times (Liker 2009; Petersson et al. 2015; Modig and Åhlström 2017). Although flow is the best alternative between flow and resource efficiency, the optimal
alternative is a combination of both high flow as well as high resource efficiency. Modig and Åhlström (2017) states that the combination with both high flow and resource efficiency is impossible to achieve due variation in the system. Figure 7 illustrates the interlinkages between flow and resource efficiency. The star is the optimal state, i.e high flow and resource efficiency. As the figure illustrates the best way to reach the optimum is through flow efficiency. Modig and Åhlström (ibid.) states flow efficiency should be prioritized in order to reach the optimum point. Continuous improvements should therefore, in the first place, aim to move the current state to the right and then move it up in the matrix when wastes have been eliminated. The star is not possible to reach, but according to Modig and Åhlström (ibid.) a company should always aim towards the star in their strive for increased efficiency.

The impact of variation can be analyzed through Kingman’s equation where the relationship between throughput time and resource efficiency is directly affected by variation. The relationship can be seen in Figure 8 where high respectively low variation impacts the two parameters differently. With high variation the throughput time increases rapidly with increased resource efficiency. With low variation, the resource efficiency can be increased without jeopardizing the throughput time (Segerstedt 2008). According to Bergman and Klefsjö (2012) it is crucial to reduce the variation in a system, at least if the variation is a result of deviations. Although variation can reduce throughput time and resource efficiency, it can sometimes be necessary to meet customer requirements. Flexibility and unique customer orders are more important than ever due globalization and it is therefore
necessary to understand how to deal with the variation in an efficient way (Berry, Hill, and Klompmake 2013). Zhanga, Vonderembse, and Jeen-SuLimc (2003) highlights the importance of value chain flexibility. Further, Jina, Bhattacharya, and Walton (1997) argues that product variety and speed of delivery can be advantages for companies working with ”mass customization”.

2.3 High Mix Low Volume

In manufacturing there are two extremes when it comes to volume and variation: High mix/low volume (HMLV) and high volume/low variety (HVLV). Production system has mainly been associated with HVLV. As Kingman’s equation explained, the mix (variation) affects the outcome from a production system heavily. Horbal, Kagan, and Koch (2008) states that production within HMLV has several more requirements than production within HVLV, such as changing demand and more complex processes to maintain efficient. The authors further states that common tools and methods within Lean production may not be directly suitable to fit HMLV, instead it might be necessary to adapt them before implementation. HMLV production systems don’t produce as repetitive as HVLV systems, which makes it harder to ensure pull production.

Although mass customization can be seen as an advantage for companies, Jina, Bhattacharya, and Walton (1997) states that the concept leads to new complications regarding manufacturing. The authors states that typical HMLV volumes are 20 - 500 and 5000 - 20 000 units per year, i.e high variety distribution on few units. Due lower volumes, the unit cost therefore often increases in HMLV systems (Berry, Hill, and Klompmake 2013). Jina, Bhattacharya, and Walton (1997) declares that HMLV suffer from system turbulence and highlights four areas:

- Schedule changes
- Product mix
- Changes in production volumes
- Design changes of products

These four areas affects a HMLV system far more than a traditionally HVLV and it is therefore important to map the challenges in such a system to prevent their impact. Lean tools and methods can through adaption to current circumstances be implemented in many cases to ensure efficient manufacturing with high quality despite HMLV (Jina, Bhattacharya, and Walton 1997; Horbal, Kagan, and Koch 2008). Manufacturing flexibility can be seen as a strategic element in the same way as price, quality and delivery but requires effort to reach the potential (Zhanga, Vonderembse, and Jeen-SuLimc 2003). Further, the authors highlights the importance of logistics flexibility to enhance the overall system.
2.4 Quality Improvement

Total Quality Management (TQM) refers to a management system with focus on continuous improvements and proactive quality work. According to Samsona and Terziovskib (1999) the system is based on the following key content:

- Leadership
- Management of people
- Customer focus
- Use of information and analysis
- Process improvements
- Strategic and quality planning

This is confirmed by Bergman and Klefsjö (2012) who argues that TQM is built upon four cornerstones, illustrated in Figure 9, with the same base as above. The customer is in focus in TQM and therefore in center of the figure above. Bergman and Klefsjö (ibid.) states that it is essential to identify what the customer requires and expects to fulfill the business in an acceptable way. It is impossible to fulfill the customer requirements if they are not identified. As described in chapter 2.2 "Lean Production" it is important to work with processes in order to achieve continuous improvements. Processes are crucial for quality improvement due to the ability to map and improve single processes to a working entirety. Bergman and Klefsjö (ibid.) states that the purpose is to satisfy customer requirements with as few resources as possible. They can be distributed in operational, supportive and management processes. To base decisions on fact is crucial in order to reduce deviations on the journey towards improvements and higher quality (ibid.). To collect, analyze and decide the 7 quality control (QC) tools can be used. Most of the tools uses statistical data to analyze quality, which in turn can be used to interpret data from production. The tools are Pareto diagram, Cause & Effect diagram, Histogram, Control charts, Scatter diagram, Graphs and Chec sheets (Magar and Shinde 2014). Continuous improvements are fundamental within TQM and an important way to maintain competitive. The PDCA cycle as well as DMAIC (Define, Measure, Analyze, Improve and Control) can

Figure 9: The cornerstone model for TQM. Based upon Bergman and Klefsjö (2012).
be used as an iterative tool for continuous improvements (Taylor et al. 2014). The last cornerstone is about participation and it’s importance for the overall quality improvement. According to Bergman and Klefsjö (2012) communication, delegation and education are all important factors to achieve participation throughout the organization. Similar to Lean, TQM is also built upon the idea of a committed and supportive leadership. Regarding TQM it is crucial the leadership encourage change (Samsona and Terziovskib 1999).

Within both TQM and Lean the idea of highest possible quality is fundamental. Bergman and Klefsjö (2012) states that quality is supposed to be built in directly and that quality controls should be minimized if the quality is as high as it can be within TQM. This is supported by Petersson et al. (2015) who states that Lean production should focus on doing right from the beginning, which thereby minimizes the importance of quality controls during production. The quality improvements within TQM and Lean is thereby proactive instead of reactive. Also Liker (2009) argues that proactive quality improvements are more effective than reactive in the journey of continuous improvements.

Bergman and Klefsjö (2012) estimates that among Swedish industry companies the costs of poor quality (CPQ) stands for approximately 10 - 30% of their turnover, which is supported by Roden and Dale (2000) who argues that 25 - 30% of manufacturing companies turnover can be linked to poor quality. These CPQ can be distributed to internal respectively external CPQ. The internal CPQ are directly linked to the work inside the company, i.e the deviations and failures discovered before delivery to customer. The external CPQ are deviations and failures discovered at customer. Normally the external CPQ are more expensive for the company compared to the internal (ibid.).

2.5 Machine tests

According to Black (2011) tests can be divided into structural (white-box) and environmental (black-box) tests. The structural tests seeks to find errors in lines of code and interfaces, i.e low level operations. The environmental tests instead seeks to identify bugs and deviations in high level operations. The tests are functional and based on what the system should manage. These environmental tests involves an understanding of the system, but not on the same detailed level as the structural tests. The test operator relies on the requirement specification together with experience. The tests are best conducted by experienced test operators who understands the design and the systems structure (Engel 2011).

2.5.1 Test System Architecture

Black (2011) states that machine tests requires a test system architecture (TSA), which in turn is based on four elements. The fundamental element is the test team, i.e the group of people who performs the tests. The test team has to be competent and be in agreement with the machines. The test team is in turn dependent on the other elements; testware, test processes and test environment. Testware contains documentation and test tools, i.e tools to conduct the tests. The usage of the test tools leads to result logs, which can be analyzed and interpreted. The test processes are the arrangement of the test steps, from start to end. Those processes can thereby be seen as the cookbook for the test and can be both written and unwritten. The last element, test environment, is the outer circumstances and includes hardware, software and other infrastructure for the tests. The
interlinkages for the test system architecture can be seen in Figure 10. As the Figure shows, the test team is the fundamental part of the architecture. Although the importance of the test team, the other three elements are essential as well and the Figure illustrates their impotence with the corresponding arrows between all four elements. The hardest element to change is the test environment due it’s complex nature. The other elements can be changed and adapted more easily.

2.5.2 Repeatability and Reliability

It is impossible to conduct tests without deviations. Those can be a result of weak standardized processes, human factor or a result of measurement systems. The possibility to conduct several identical test with the same result are called repeatability (Pyzdek 2003). Standardized methods is according to Pyzdek (ibid.) the best way to heavily increase the repeatability.

Tests can be conducted to identify deviations or to analyze the risk for deviations to later appear, i.e the reliability. In that case, the number of deviations discovered during a test are used to estimate deviations to later appear. Engel (2011) states that reliability tests should be performed in environments with similar circumstances as the products natural habitat. Some errors may appear after long time, which makes it hard to test and provoke them in an early test stage. Increased load during tests can be used to trig errors and deviations to appear earlier than expected, which Engel (ibid.) calls accelerated testing. The correlation between load and life-span can then be used to interpret the accelerated testing to a normal perspective.
2.6 Sound

According to Gäderlund et al. (2015) industries within cities and close to housing must adjust their sound level according to regulations. The sound level is measured in Decibel [dB] but often readjusted to dB(A) which is a weighing filter and used to approximate the sound to the human ears capability (Callermo 2015). New planned building can be categorized in three zones, where $L_{eq}$ is a form of time weight which makes it possible to read the values instantaneous;

A houses: External sound level is low and no need for adjustments. $L_{eq\text{,day}} = 50$ dB(A), $L_{eq\text{,evening}} = 45$ dB(A) and $L_{eq\text{,night}} = 45$ dB(A).

B houses: New houses can be accepted with sound protection adjustments. $L_{eq\text{,day}} = 60$ dB(A), $L_{eq\text{,evening}} = 55$ dB(A) and $L_{eq\text{,night}} = 50$ dB(A).

C houses: Due high external sound level, buildings should not be accepted. $L_{eq\text{,day}} > 60$ dB(A), $L_{eq\text{,evening}} > 55$ dB(A) and $L_{eq\text{,night}} > 50$ dB(A).

Nationalencyklopedin (2019) states that a normal human conversation is equivalent to 55 dB and a car 10 meters away is equivalent to 70 dB. A sound level above 120 dB is perceived as painful, but hearing damages can appear already at around 85 dB.

Callermo (2015) states that it is up to the concerned company to make measures and prevent inconvenience. Every company is responsible for noise related to it’s operations and the responsibility thereby lays on the company and not neighbours. Actions should be targeted at the source for best result, which according to Callermo (ibid.) can be new machines, processes or work methods. Actions intended to minimize noise at the receiver (i.e neighbours) should be taken only when measures against the source is considered insufficient or unreasonable costly (Gäderlund et al. 2015).
3 Methodology

Chapter three, Methodology, contains details regarding the method used in the master thesis project. The project circle has been used during the project and six out of eight phases have been passed by. The different phases are described below, first according to theory and then how they have been used in the project.

The methodology for the project is based on Johansson and Renhagen (1995) and their project circle. The eight phases follows a chronological order and consists of the following steps:

1. Plan for changes
2. Analyze the current and future state
3. Formulate goals and the requirement specification
4. Search for alternatives
5. Evaluate and choose alternative
6. Develop and finalize the chosen concept
7. Implement the chosen concept
8. Evaluate the effects. Due time constraints, the thesis project will not reach phase number 8. The evaluation process will therefore not be carried out.

The green external line in Figure 11 illustrates the phases used in this project. This shows that phase number seven (implement) will be started but not finished. In this project the implementation will only be analyzed in general. Phase number eight will not be started at all.

Figure 11: The project circle used in the thesis.
3.1 Plan for Changes

The first phase of the project circle includes the overall project planning combined with a literature review for the theoretical framework used in the project. The phase aims to form the structure for the project, i.e. time distribution and resource planning for the content.

3.1.1 Time Plan

In the beginning of the project the overall time plan (Gantt chart) was formulated. The purpose with the Gantt chart was to illustrate the different phases of the project, their respectively time amount and can further be seen in Appendix 1. A project plan was then conducted in order to form the structure for the project in a more detailed level. The background, objectives, scope, theoretical framework and methodology were explained in a summarized way and was then distributed to the projects two supervisors for approval.

3.1.2 Research Approach

According to Saunders, Lewis, and Thornhill (2009) the research approach can be divided into inductive and deductive, where the deductive approach is common in scientific research. The inductive approach aims to investigate a problem which in the end is turned into a theory. Prince and Felder (2006) also states that engineering and scientific research are mostly conducted in a deductive way. However, inductive perspective regarding the investigation process focuses on observations that can be interpreted, questions that should be answered and problems to be solved in a more quantitative approach. Borrego, Douglas, and Amelink (2009) states that qualitative research often takes an inductive way throughout data analysis, which in turned is confirmed by Tjora (2016) who argues that an inductive approach is strongly linked to empirical investigations. Due this project focuses on an existing case, i.e to map and analyze the current state in order to find improvements, the project thereby aims to interpret observations into solutions. The investigation strategy was thereby concentrated to the case study. That’s why an qualitative and inductive approach was chosen in the projects beginning.

3.1.3 Literature Review

The purpose of the literature review was to gather relevant information for the projects continuing and to ensure the project would be based on reliable theory. The previous written research questions acted as the base for the research and literature with interlinkages to the questions were analyzed. The purpose of the five questions was to contribute to the overall scope of the project, i.e to find alternative test methods for trucks and loaders. The services from Luleå University Library were used, such as available search engines. For the most part Google Scholar, Scopus and Emerald Insight were used to identify relevant literature. Common search phrases were, but not limited to, operations management lean, change management, high mix low volume production, lean production, Toyota production system, waste elimination, resource flow efficiency, flexible production, total quality management. The identified articles throughout the literature review were mostly chosen through relevance of titles and abstract. The chosen books had for most of the time been used in previous courses during the years at the program Mechanical Engineering. Otherwise, they were selected with help of the library staff at Örebro University Library.
3.2 Analyze the Current and Future State

This phase was concentrated to the analysis of the current state in order to find the current problems and thereby the potential improvements. Also, the future state was analyzed in order to identify the demands for the future. Several interviews and study visits to the Kvarntorp mine were conducted during this phase. The objective was to seek improvements within the subject and to identify the biggest problems that exists today.

3.2.1 Observations

Observations is a method to analyze what and how people do certain things (Tjora 2016). In order to gain broad understanding of the current state, the initial part of the project was concentrated to observations at the production lines within ERD. The purpose was to identify critical phases during the manufacturing and to see the assembling of MH machines. The purpose of the current test drive for the machines at Kvarntorp is to identify deviations from the manufacturing line and it was thereby important with a deep understanding of the manufacturing process. Those observations were conducted in what Bell (2000) calls non-participation, i.e objective observations. Tjora (2016) argues that the role for the observer varies during observations and that the interaction both increases and decreases. Furthermore, several observations have been conducted at Kvarntorp. Flow leaders within the after now have been observed and followed several times, which according to Tjora (ibid.) is a good method to see the reality. The current situation were analyzed throughout discussions and observations with test operators. Every test step (i.e visual inspection and test drive) have been investigated through what Tjora (ibid.) calls interactive observation, i.e the observer acts as observer but can interact with the observed people. The current state has been video recorded and photographed in a wide range of series to have documentation throughout the project. Documentation is a crucial part of the analyzing phase after observations (Bell 2000).

3.2.2 Data Collection

To collect and analyze data has been a vital part of the current state analysis. The purpose has been to map the deviations from today’s manufacturing in order to identify where and what deviations that occur. These deviations must be identifiable in the future state as well. All identified deviations for 2018 were analyzed and sorted in different categories depending on type and amount. For this project, the most important category was deviations discovered during test drive. These deviations where analyzed in different stages and sorted by product and machine type. Through the analysis it became clear that deviations discovered during test drive is a clear minority of the total amount. The production economy has been analyzed as well. The costs for the after now have been compiled in order to analyze the costs after production line. The costs for the processes have been collected or calculated and analyzed in order to find the most expensive processes in the after flow. However, due lack of data the analysis could not be conducted in the desired approach.

There are two types of data according to Saunders, Lewis, and Thornhill (2009), quantitative and qualitative. The data regarding deviations has been quantitative and the interviews have been qualitative. In Table 2 the classification of data can be seen. Saunders, Lewis, and Thornhill (ibid.) states that these two methods can be combined, which they also have been in some cases during the project.
3.2.3 Interviews

As mentioned, the project has mostly been focused on qualitative methods. Tjora (2016) states that interviews are the most used method to collect data and is a method to later analyze what people say. Unstructured interviews were held in the projects beginning to get a deeper understanding of the current situation. According to Bohgard et al. (2015), unstructured interviews are best when the interviewer only has a vague idea of the situation. The purpose was only to understand the situation quickly and thereby the answers were not analyzed further. When the knowledge increased, semi-structured interviews were held. Those are a combination of unstructured and structured interviews and the prepared plan can thereby be adjusted due new circumstances during the interview (ibid.). Tjora (2016) argues semi-structured interviews can be used to study attitudes and experiences, two important aspects for this thesis project. The interviews were analyzed in order to find similarities and differences and some of the result was compiled in a tabular which according to Carlström and Hagman (2012) is a method to visualize result from qualitative research. Tjora (2016) states it is important to maintain a subjective perspective during qualitative approaches, which has been a constantly present conclusion during the thesis project.

3.2.4 Value Stream Mapping

Value stream mapping (VSM) is according to Petersson et al. (2015) a method to map the current state in order to find improvements for the whole system. The purpose is to identify the current state, analyze it and then improve it with remained focus at the product. The current state should act as the starting point for the improvements and the authors highlights the importance of an overall perspective to prevent single process perspective. A VSM should be conducted backwards, i.e from the customer to the supplier, according to Rother and Shook (2003). Although the backwards focus, Petersson et al. (2015) states that it is not necessary. Due the HMLV production in this project, the VSM was conducted in chronological order. To follow the products and to map the current state the products should be divided into product families.

This thesis project looked into two product families, ST and MT. The purpose was to investigate if there existed differences and if so, where and why. One ST and one MT was followed and significant data was measured and collected. The future state was based on Petersson et al. (ibid.) improvement rules (eliminate, combine, rearrange and simplify - ECRS) which acted as a help to question the flow and it’s structure and can be seen in Figure 12. The last step was to create an action plan for the improvement activities. In this case, only a small plan was created but normally the plan should include what to be
done, whom is responsible and when it should be done. The purpose of the plan is to assign smaller projects to the involved persons (Petersson et al. 2015).

3.2.5 Study Visit

To get a new perspective on the current situation, a study visit at Volvo Construction Equipment (VCE) in Arvika was conducted on the 20th of February. The purpose was to see and observe other methods and procedures for quality assurance for similar products. Arvika is Volvo’s main production facility for wheel loaders and produces a large number of customized machines every year. The visit was conducted from morning to late afternoon. During the morning the visit was concentrated to the quality assurance department, where a team leader in production was followed. During the afternoon the test drive / afterflow department was followed in order to see how VCE works with quality securing. The study visit was thereby mainly based on observations and interviews.

3.3 Formulate goals

The third phase "Formulate goals" was conducted at the end of phase number two. The third phase was about the future state and the requirements to reach the goals. The goals were specified in a requirement specification and based on the interview analysis regarding the current state. Bellgran (2009) states that the requirement specification should contain demands and goals for the optimized future state in order to improve the production system. The specification was divided into a description and a weight for each requirement.

The weight illustrated the relevance for each requirement and where to put extra effort and acted thereby as a guide during the projects proceeding. The requirement specification acted as a decision maker for ideas and solutions. It was conducted when all data was collected and analyzed in order to base the weight factor on real fact.

3.4 Search for Alternatives

Phase number 4 in the project circle, search for alternatives, was mainly based on benchmark and identification of other ways to conduct quality tests. Although the phase
was number 4 in order, the search for alternatives was part of the project from the beginning until the end, both directly and indirectly. The focus on alternatives was part of the project through every meeting, interview and study visit and the project was thereby mainly focused on improvements and alternatives. Although the continuously focus on improvements and alternatives, some methods and tools have been used in order to work in a structured and efficient way.

3.4.1 Benchmark

Benchmark is according to Bergman and Klefsjö (2012) a method for companies to compare themselves to leading competitors and companies in order to find improvements and keys for successful development. The authors explains the idea of benchmark as a structured way to identify and find possible improvements for the internal processes. Bergman and Klefsjö (ibid.) further states that the ambitions should be high, i.e to become one of the best. Benchmark should not be used to copy other companies, instead the method should be used to identify successful solutions and then reflect why those are better. Bergman and Klefsjö (ibid.) describes the benchmark process in the following steps; Plan, Seek, Study, Analyze, Adapt and Improve.

In this thesis project the purpose of benchmark was to identify other methods that could be used to evaluate and test the MH machines. This was mainly done through a benchmark against companies with other types of machines compared to the MH series. The criteria was heavy machines designed for tough conditions and environments and non of the studied companies were thereby a direct competitor. Bergman and Klefsjö (ibid.) states that it is harder to benchmark competitors due the concern of protecting methods and information and the authors highlights the importance of collaboration for best results. To conduct the benchmark, study visits at the chosen companies was done. Those visits was mainly based on each companies way of working with quality test and quality assurance. The first two steps in the benchmark process described above was common for all companies, but the steps after the study was separate for each and one of them. As mentioned earlier, the first visit was conducted at VCE in Arvika and their wheel loader factory. During the visit semi-structured interviews and observations was used to identify and collect the desired information. The other study visit was conducted at Epiroc Surface and Exploration Drilling (SED) in Örebro and the third study visit was at Komatsu Forest in Umeå and their production facility for forest machines. The last study visit was conducted in order to see and analyze a vehicle inspection facility and was conducted at Opus Örebro-Truckstop.

3.5 Evaluate and Choose Alternatives

During this phase ideas from the previous phases were gathered into alternatives and solutions. These ideas were combined with inputs from the four study visits and later on combined with the result from the interviews. The overall purpose with the phase was to evaluate the alternatives and then choose the final concept, based on all the previous work. When ideas were gathered into solutions, new issues appeared. As a result of continuous dialogue with the thesis stakeholders, two more delimitations were added to the thesis project during this phase;
• Lack of free space at the factory area will not be taken into consideration.
The current lack of free space is a problem. However, if the management agrees to implement the final solution this problem will be solved according to the projects supervisor.

• Test procedure for autonomous vehicles will not be analyzed.
Epiroc has some projects going on with autonomous machines, but the test procedure for these machines won’t be part of this thesis due to it’s complexity. Several vehicle inspection companies in Sweden was contacted in order to analyze their future test procedure. However, none of these companies had a clear vision for the future. Instead they referred to the Swedish Transport Agency, responsible for such questions. They on the other hand referred to both European Union as well as United Nations. With no input about autonomous vehicle inspections, it was chosen to not take these machines in consideration.

The requirement specification was used to verify that the chosen solution actually led to significant improvements for the after flow.

### 3.6 Develop and Finalize Chosen Concept

Phase number six acted as the last full length phase and thereby as the detail development phase in order to finalize an effective and optimized solution. The chosen alternative from the previous phase was developed further into a final solution for the current problems. The final solution have ideas and improvements collected from both the study visits and conducted interviews. The theoretical framework acted as the base for the detailed solution, i.e the chosen solution is based on theories from operational management, Lean, HMLV and quality improvements. Further the solution has taken theories regarding both machine tests and sound in consideration.

Manufacturers of test equipment were contacted during this phase with an inquiry about their possibilities to deliver a system according to the machines requirements. Due to heavy weights and axle loads several manufactures replied they were not able due to lack of knowledge and personnel. Some manufactures replied with an estimation, while some did a serious attempt to calculate the actual costs for such system. 10 manufactures were contacted, however only two were able to deliver a solution. To be able to replace the tests in the Kvarntorp mine, new ideas and solutions were discussed with both colleagues and manufactures/suppliers in order to finalize a complete solution.

### 3.7 Implement

Phase number 7, Implement, is the second last phase in the project circle. The implementation phase will be discussed theoretically, but not analyzed in practice due to the fact that the solution cannot be tested. The implementation discussion were based on change management and theories for how to implement new solutions and ideas successfully. The chosen solution will affect several positions, making it necessary to implement the solution in the right way. Focus has thereby been on how to ensure commitment and understanding.
3.8 Reliability and Validity

Throughout a research project, validity and reliability are two important aspects according to Saunders, Lewis, and Thornhill (2009). Those two can, according to Tjora (2016), act as a quality indicator. For a research project quality is important and the goal is to reach high levels of both validity and reliability. Bell (2000) states high reliability does not guarantee high validity, but high validity presumes high reliability.

3.8.1 Validity

Saunders, Lewis, and Thornhill (2009) states that validity in a research project is whether the findings actually are what they seem to be and that data analysis measure what they intend to measure. Saunders, Lewis, and Thornhill (ibid.) further states that validity classifies how well the result has been analyzed and how the result can be generalized. Regarding validity there are several risk factors that can affect the output: History may affect the validity due the influence of historical tendencies. Other risks regarding the validity are testing, instrumentation, morality and maturation.

Triangulation is a method to increase a research projects validity. The idea is to analyze a problem through different point of views, i.e collect data from different sources. During this thesis project several interviews have been conducted and the focus has been to reach a diversity regarding the respondents, i.e triangulation. In order to reach a high level of validity from the beginning, several observations have been conducted where different persons and situations have been analyzed and studied. Those observations played a key role in the beginning of the project when the current state was analyzed and mapped. The outcome from the interviews have been analyzed to see if they suffer from morality bias. All studied situations were discussed with the personnel to verify they were common and relevant for the project. These discussions led to great relations and a good dialogue with the personnel at Epiroc. During the current state analysis a lot of data were studied. The data was collected from many different persons and files, which sometimes made it complex to find the most relevant type. It was important that used data didn’t suffer from historical tendencies, which made it necessary to evaluate every data source. In some cases the desired data didn’t exist, which made it necessary to rethink and take another path. Some historical data could not be used due low validity and it has thereby been important during the thesis project to evaluate the validity level in order to reach a high level. However, the collected and used data have been analyzed several times in order to reach high validity.

3.8.2 Reliability

The reliability seeks to answer how well the collected data really will lead to reliable data. Bell (2000) states that reliability is a way to measure how well a method or result can be repeated once again with the same output. Regarding the reliability Saunders, Lewis, and Thornhill (2009) highlights four risk factors. The first one is participant error, second participant bias, thirdly observer error and lastly observer bias. Both the participant and the observer may affect the reliability conscious or unconscious.

The risk factors explained above have been present in consciousness during this thesis project to be able to compensate for them. To compensate for them every interview
were planned before it took place. The purpose of a certain interview as well as desired findings were written down before which enable a straight communication. Every answer has been treated anonymously (and explained in the beginning of each interview and observation) to minimize the risk for participant bias. Several respondents have been interviewed, which minimizes the risk for participant error. To increase the reliability the empirical study has been conducted during several weeks, i.e. to minimize the risk for observer errors and bias. Furthermore, the conducted interview were always recorded which enabled good analysis opportunities later on. Every crucial decision or observation from study visits, interviews or meetings were written down and motivated in order to reach high reliability.

According to Tjora (2016) transparency can increase the reliability. The chosen methods, asked interview questions, data sources and field trips are all explained deeply in order to reach a high level of transparency. Continuous meetings with the projects supervisors have been conducted; once a week with the supervisor at Epiroc and every second week with the supervisor from LTU. This increased the transparency and guided the project in the right direction.
4 Result, Current State

This chapter contains the details regarding the current state at URE, i.e. a description of production deviations and the current test procedures for the MH machines, from production line until the machine is ready for delivery to customer. Throughout this section, several interviews and field trips have been conducted in order to get a deep understanding of the situation, the problem and the improvement potential.

4.1 Production Quality

The production of MH machines at URE is a typical HMLV where every machine is customized, which in turn leads to long lead times and low numbers of annual manufactured machines. Today’s production suffer from different kinds of deviations. As a result, the current tests in the mine are seen as a necessity. The purpose of today’s tests is to identify every deviation before the machine is delivered to customer. For year 2018 the deviations of tested machines can be seen in Figure 13 where the distribution is showed in a Pareto chart. The orange line symbolizes the cumulative percentage and the corresponding value can be seen on the right axle. As the figure shows, mechanical deviations stood for almost

![Deviation distribution, tested machines 2018](image)

Figure 13: Pareto chart with deviation distribution of tested MH machines for year 2018.

40% of the total amount. Thereafter came hydraulics, electricity, media and deviations discovered during test drive, important within this project. The current situation was divided into the two sub categories MH and ST for a deeper understanding of the current deviation situation regarding machine type. In Figure 14 the deviation distribution for MT can be seen. As the figure shows, the distribution is similar to the general Pareto chart illustrated above, which is indicated by the orange line, i.e. cumulative percentage.
The deviations for ST can be seen in Figure 15 which illustrates a similar result to the MT chart and thereby to the general Pareto chart.

Regarding deviations discovered during the test drive, crucial for this thesis project, both MT and ST had a total of approximately 10% of the total amount. Deviations discovered during test drive was number four for both ST and MT. The biggest differences between ST and MT were related to electricity followed by hydraulic and media. All discovered deviations during test drive are given a point due their relevance for the products function and quality. Depending on the relevance, the consequences are different. Most of the discovered deviations are fixed at the work shop at Kvarntorp, but some, 200 point errors, requires meetings and investigations. Table 3 illustrates the points for the 5 categories of errors and the consequence of each.
Table 3: Error points due their relevance for the quality.

<table>
<thead>
<tr>
<th>Point</th>
<th>Error Consistency</th>
<th>Complementary info</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Less inconvenience</td>
<td>Noted by the customer but no feedback to the AC</td>
</tr>
<tr>
<td>20</td>
<td>Major problems</td>
<td>Noted by the customer with feedback to the AC</td>
</tr>
<tr>
<td>50</td>
<td>Risk of downtime</td>
<td>If no change is made, it will lead to downtime</td>
</tr>
<tr>
<td>100</td>
<td>Downtime</td>
<td>Downtime during the audit</td>
</tr>
<tr>
<td>200</td>
<td>Risk of injury/legal action</td>
<td>200 points meeting shall be initiated by the auditor</td>
</tr>
</tbody>
</table>

The points are summarized into a total score, which is used to classify the machine. Deviations discovered during the test drive are not characterized of type, instead they are given a point according to Table 3. The distribution of the deviations for 2018 are seen in the Pareto chart in Figure 16 where "Risk of downtime" is classified as the most common category for a discovered deviation, followed by "Major problems" and "Less inconveniences". As the Figure clearly shows the "Risk of injury" is very unusual compared to the others.

![Classification of deviations from test drive](image)

Figure 16: Pareto chart with classification points.

To get an understanding of the test drive category, all deviations related to test drive for year 2018 were analyzed throughout deviations per product. Every deviation related to test drive were filtered to each product, with the aim to identify a correlation between number of deviations and number of tested units. Figure 17 shows the correlation between deviations and number of tested machines for year 2018. The figure illustrates number of tested machines in blue and number of deviations as black dots. As can be seen, the number of deviations increases with number of tested machines for every product except ST1030 where the number of tested machines are significant higher than others, but where the deviations are similar to the others.
For a deeper analysis, all the deviations for a product were divided with the number of tested machines, i.e. the average number of deviations per machine. The result can be seen in Figure 18 where the deviations are seen in blue and the number of deviations per machine are seen as black dots. The number of deviations (in average) varied between one and three deviations per machine. As Figure 18 showed, ST1030 was tested in the highest quantity, but remained its quantity of deviations on a low level per machine which is confirmed by Figure 17.

Figure 18 illustrates that ST and MT series acts differently regarding the interlinkage between deviations per tested machine and number of tested machines. The MT machines have a larger diffusion when it comes to the relationship between tested machines and deviations compared to the ST and it is not possible to identify an interlinkage between deviations and number of machines. When the number of tested machines (MT) increases, deviations per machine increases for some machines and decreases for others in a not
controlled pattern. Regarding the ST machines, it is only ST1030 that brakes the pattern. For the other machines, the relationship between number of tested machines and reported deviations varies in an identifiable pattern. When the number of tested machines increases, the deviations per machine increases as well. Figure 17 and 18 shows that ST1030 passes the current test procedure well compared to other machines. The ideal case has a large quantity of passed machines (and thereby a low amount of deviations), which is similar to the case with ST1030. MT42 suffer from a high level of deviations per machine according to Figure 18, which is illustrated with a large gap between the blue bar and the black dot. This is also the case for ST18.

Leakages are classified in an own category and are often discovered during the test drive. They often appear during the functional tests when the machine is exposed for the rough environment in the mine. These leakages are classified in sub categories depending on their origin. According to the test operators, most leakages are discovered during the test drive which in turn explains why they are not discovered earlier. Figure 19 illustrates the degraded deviations related to media.

![Figure 19: Comparison between different leakages.](image)

The Figure above clearly illustrates that ”Leakage” is the most common category of medium related deviations. Although leakage has several sub categories, the most common deviation is not sorted under the sub categories. This is due the complexity to identify the origin for a leakage. Although deviations from the test drives have been analyzed above, they act as part of the total amount of identified deviations for every machine. As explained earlier, deviations discovered during test drive stands for approximately 10% of the total amount. In Figure 20 the deviations related to test drives for every product are seen as part of the total amount. The figure clearly shows that deviations discovered during test drives are a minority of the total amount for every product.
As Figure 13 showed, mechanical deviations stood for approximately 40% of reported deviations for both ST and MT during 2018. Test related deviations on the other hand stood for a small amount as Figure 20 shows. In Figure 21 the total deviations reported for each machine type have been divided with the number of tested machines, i.e the average total deviation amount for every machine type. The Figure clearly shows that the total amount of deviations varies between machine type. The pattern is similar to Figure 18 which also showed a big diffusion between machine type and number of deviations.

4.2 Process Mapping

The tests today are conducted in the Kvarntorp mine, approximately 20 kilometres from the factory in Örebro, which is called AVOS. Most of these processes exists due current test methods and test procedures. The current state is illustrated in Figure 22 where the steps before and after the quality tests in the mine are presented. Red boxes symbolises external companies. As the figure illustrates the process starts at the end of the production line. Today, a pre acceptance (PA) is conducted when a MH machine is fully assembled at the end of the production line. The purpose is to determine whether the quality is high
enough for test or if corrections are needed. The inspector carries out the PA together with assembly personnel and analyze both quality and documentation. If the quality is as desired, pressurizing is next up where the machine is fully started. If the machine does not fulfill pre-acceptance the tester creates an action list with points to be addressed by assembly personnel before the tester reviews the machine again and the machine is accepted. The pressurizing is performed in accordance with developed specific methods and instructions for each machine. The following steps includes an external company, haulage contractor, to transport the machine to Kvarntorp. The test operators from Epiroc conducts the machine test in two steps; visual inspection and functional test in mine (which also includes visual inspection). If the machine is tested during spring, summer or fall the machine can be tested at the test track next to the mine. However, one test (drag test) is always conducted in the mine. If the test has been conducted in desired way, the operators leave the machine at an external paint shop where the marks from the tests ameliorates. If not as desired, the machine is retested once again. All identified deviations that have been identified during pressurizing and testing is readjusted at the work shop at Kvarntorp. When all points are solved the tester is contacted to verify and acknowledge that all items are completed. The haulage contractor then transport the machine to an external washing company before rust protection back at AVOS. A flow leader then controls the documentation and approves it before a planner later adds the machine to stock. In the end the documentation are archived and the machine is ready for shipment.

4.2.1 Value Stream Mapping

Two value stream maps was conducted, one for ST14 and one for MT42, see Appendix 2 and 3. The times for ST and MT varied a bit. The waiting time for MT was approximately 20% longer than for ST. Regarding the process times MT had around 17% longer process times compared to ST. However, process time is in this case not the same as value adding time due to the fact that several processes is waste for both machine and customer. Test drive stood for 1% for MT and 1.9% for ST. In total MT required 20% longer time through the after flow than what ST did.
4.3 Test Procedure

In this section some of the content above will be highlighted and a deeper explanation of the current test drive procedure will be conducted as well.

4.3.1 Before Kvarntorp

The machines are transported from the production line to the waiting field before pressurizing. The machines are later transported back to the field before the haulage contractor transport them to Kvarntorp. Figure 23 shows trucks waiting to be transported to Kvarntorp. The transport procedure is extensive and requires, as mentioned earlier, external interference from a haulage contractor to transport the machines between AVOS and Kvarntorp. The queue for the MH machines are based on their remaining time before the delivery to customer. Figure 24 shows a delivered MT, the smallest one, in Kvarntorp. The contractor transports the machines to Kvarntorp where they unload them on the enclosure. In some cases the contractor transport tested machines back to AVOS and otherwise they return to Örebro without load.

![Figure 23: The waiting field for the MH machines.](image1)

![Figure 24: Minetruck delivered in Kvarntorp.](image2)
4.3.2 Kvarntorp

The machines remain at the enclosure before the test operators from Epiroc (two persons per machine) picks them up, one at the time, and drive them to the workshop. In the workshop the first test, visual inspection, takes place. The purpose of the visual inspection is to inspect the outer condition of every machine, i.e aesthetic aspects. Furthermore, the test operator inspect every machine according to an inspection protocol, where everything from lights to hydraulic tubes are investigated, i.e everything except the driving experience. Figure 25 shows the visual inspection conducted by a test operator. After the visual inspection, which takes about one hour, the next step is the test procedure in the mine. One test operator drives the machine to the mine and conducts the tests. According to current regulations regarding working temperature, every MH machine is supposed to be tested for at least two hours in the mine so that every machine reaches their working temperature. There are several different tests conducted in the mine. The attempt is to drive the machine as rough as possible so that the machines work environment is tested, i.e to visualize deviations. For the ST machines, the bucket and it’s properties are tested in a pile with the purpose to test the weighing system and bucket function. The operator fills the bucket with gravel and drives back and forth to trig the system. The test is seen in Figure 26 where the bucket is loaded and measured.

Figure 25: Visual inspection of a truck.

Figure 26: Bucket test.
Both ST and MT machines conduct the drag test where the machine is connected to a wall with chains, Figure 27(a), and conducted throughout the attempt to drive the machine away from the wall, see Figure 27(b). The purpose is to measure the performance of the engine and to map the forces. After the field tests in the mine, the machines need to be re-painted as a result of the tests at the external paint shop at Kvarntorp. After readjustment the machines are transported back to AVOS via the washing company for the final stages before shipment.

4.3.3 Test Track

As mentioned earlier, the machines are tested outside at the test track in Kvarntorp during spring, summer and fall. The track, gravel based, consists of several up- and downhills and sharp corners which enables a more rough test procedure compared to the mine. Due to the gravel ground the machines vibrate heavily during the test drive, which enables more deviations related to leakages to appear. For the ST machines it is possible to conduct the bucket test outside due to available gravel piles.

4.4 Lead Time

For year 2018 the lead times for the MH machines have been analyzed. In Figure 28 the average lead times, including weekends and holidays, for the ST and MT machines are shown. The lead time in this case is from the very beginning (pick start) to the end (stock add). The lead time includes every phase during manufacturing, i.e. everything at the factory at AVOS and every step at Kvarntorp. The time distribution for each machine is a result of registered time amount, which is done by the operators. Due manual time registration some machines may have wrong time distribution, i.e. measurement bias. In Figure 28 three times are highlighted for each machine; module, final assembly and TC. The lead time "LT TC" concerns this thesis project’s scope, because the content is the steps after manufacturing, i.e. pressurizing, test drive, re-paint, wash and rust protection. It was not possible to analyze the lead time "LT TC" deeper due to bad statistical data. The other time fields in the Figure stood for a small amount of the total lead time and was thereby not highlighted with specific times.
As the Figure illustrates the lead times are relatively equal between machine types. One machine type, MT2200, has far longer lead time compared to the others. However, during 2018 MT2200 was produced in a low quantity which affects its average lead time. ST1030 has in turn the shortest lead time. The average lead time for all the different machines was calculated to $A$ calendar days. The Figure clearly shows that the lead time for TC extends the overall lead time. The extension was calculated to $B$ calendar days (average for all machines). For ST the extension was calculated to $C$ days and for MT $D$ days.

The distribution between module, final assembly and TC was analyzed further with Table 4 which shows that TC stands for approximately 20% of the total lead time. However, it is important to highlight that the distribution is a result of manual registration, which makes it important to analyze the result in a bigger picture. The category "Total" is the sum of module, final assembly and TC, and does thereby not contain the smaller time amounts from Figure 28.

Table 4: Lead time distribution for MH machines (2018).

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Module</th>
<th>Final assembly</th>
<th>TC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT2010</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>MT2200</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>MT42</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>MT5020</td>
<td>0.1</td>
<td>0.5</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>MT54</td>
<td>0.1</td>
<td>0.5</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>MT65</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>ST1030</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>ST7</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>ST14 MK2</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>ST18</td>
<td>0.3</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
</tr>
</tbody>
</table>
As the Table shows, the time amount for each category varies for both module and final assembly, but not for TC. The time amount for TC (20%) is identical for all machine types except ST14 MK2. The current test procedure and the extensive machine handling is effecting and increasing the lead time for TC.

4.5 Economy

As previously explained, it was not possible to analyze the lead time for TC further with data from Figure 28. In order to analyze the economical aspects of the after flow the operation cards for the machines have been investigated. The cards acts as a guidance for the production planner during manufacturing, i.e time plan, and every operation has a corresponding time and cost. However, the times in the cards have not been optimized or analyzed for a long time and are thereby a bit misleading. Regarding the after flow three internal processes were investigated; pressurizing, test drive (visual inspection and test drive in Kvarntorp) and readjustments after the test drive. Other processes in the after flow are transportation, re-paint, wash and rust protection, where every process except rust protection includes an external company. The times from the operation cards have been compared to the actual outcome for 2018 and the result can be seen in Figure 29 where the differences between planned and real time can be seen. As the Figure illustrates most of the machines requires a longer time in the after flow than planned. Two machines, ST14 and ST18, needs less time in the after flow than planned. The difference between planned and real time makes it hard to optimize the flow and the system becomes reactive instead of proactive.

![Figure 29: Comparison between planned and real time in the after flow.](image)

Every working hour in TC corresponds to a cost of 800 SEK per hour. The Figure above makes it possible to interpret time to economy by multiplying the planned and real time amount by 800. Figure 30 illustrates the cost for pressurizing, test drive and readjustments in the after flow. As a result of the longer real time (compared to planned), the real cost is thereby higher for every machine except ST14 and ST18, who had shorter real time than planned. The average real cost for the three processes (pressurizing, test drive and readjustments) is nearly $E$ SEK per machine in average. The cost for transportation, re-painting and washing increases the cost for every machine. Those costs are estimated for
4.6 Analysis of Current State

Today’s test procedure suffer from several problems. Here the identified problems will be highlighted and analyzed further.

4.6.1 Lead Times

In average the time through the after flow is $B$ days ($C$ days for ST and $D$ for MT). The time is a result of the current test procedure and how the tests affects the machines. As Figure 28 showed, the average lead time was $A$ days and the extension through the after flow therefore corresponds to 20% of the total lead time in average.

4.6.2 Vehicle Damages

Identified problems related to vehicle damages will below be explained and highlighted by figures.

Paint

The machines are transported from AVOS to Kvarntorp and then back again. This requires the machines to be loaded and unloaded on trucks, which in turn leads to paint damages at the machines. Further, the drag test in the mine requires a shackle to be mounted on the machine, which can be seen in Figure 31(a). The shackle affects the paint during the test, which can be seen in Figure 31(b). This requires the damages to be repainted, which
Figure 31: Paint damages on the machine.

in turn costs money and extends the lead time.

**Tyres**
The tyres are affected of the tests as well. The environment is wet and dirty which affects the tyres after two hours of test drive in the mine. The difference between new tyres and tyres on a tested machine is seen in Figure 32 where the impact of the mining environment is clearly showed.

Figure 32: Tyres affected of the tests.

**Bucket**
As explained earlier the bucket and it’s properties are tested for the ST machines in a pile with the purpose to test the weighing system and bucket function. This damages the paint heavily on the buckets. Figure 33(a) shows a new bucket on a ST machine and Figure 33(b) shows the bucket after the dig test. The paint is heavily damaged and requires to be repainted as well.
Snow
The machines are located outside between the processes in the after flow. At Kvarntorp they are located outside as well, which for some machines are a problem. The machines can be ordered without windows, which can be a problem during the winter period. Figure 34 illustrates how snow has fallen into the machine cab. For the test operators the snow also affects the visual inspection, which cannot be conducted if the machine is covered in snow and ice.

4.6.3 Work Environment
The work related to the after flow is mostly conducted in the work shop at Kvarntorp, a rental work shop. This building is not optimized for neither visual inspection or readjustments, which affects the work environment badly. The visual inspection is conducted with bad light conditions and requires the test operators to crawl on the ground in order to inspect the machine beneath. This increases the risk for missing deviations. The current situation can be seen in Figure 35(a) where two operators inspects a machine with both bad light- and ergonomic conditions. Furthermore the visual inspection is conducted beside the machines that are readjusted, which sometimes affects the sound level in the
work shop. The machines are sometimes started in order to verify readjustments and thus requires the exhaust to be extracted. However, this equipment has be mounted and dismounted by the readjustment operators every time, see Figure 35(b). Summarized, the work environment is exacting in Kvarntorp and lack of good equipment extends the lead time during the readjustments.

(a) (b)

Figure 35: Inadequate work environment in Kvarntorp.

4.6.4 Economy

In 2018 $K$ MH machines were tested. Every trip back and forth Kvarntorp corresponds to a distance of approximately 20 kilometers each way. The total driven distance can be calculated through

$$K \times 2 \times 20 = Gkm \quad (3)$$

which gives a total driven distance of approximately $G$ kilometres. The transportation for the test operators between AVOS and Kvarntorp thereby corresponds to approximately 23 000 SEK. The transportation time to Kvarntorp is approximately 20 minutes each way, i.e 40 minutes in total. For year 2018 the total transportation time for each test operator was hence calculated by the following expression,

$$\frac{40 \times 250}{60} = 167h, \quad (4)$$

where 250 corresponds to the number of work days for year 2018. The test operators for the MH machines hence spent approximately 167 hours in the car between AVOS and Kvarntorp, i.e non value adding time. As previous mentioned, the cost for pressurizing, test drive and readjustments have been calculated to $E$ SEK per machine in average. Further the cost for transportation, re-painting and washing have been calculated to $F$ SEK which in total becomes $X$ SEK per machine in general. Of the processes in the after flow only pressurizing and rust protection are classified as value-adding processes. Regarding the two value-adding processes their value adding time was calculated by using the following data; $B$ days lead time through TC and a standard pressurizing time of 5 hours. For pressurizing the time was calculated by,

$$\frac{5}{B \times 24} = H\%, \quad (5)$$
which gave a value-adding time of $H\%$. For the other value-adding process, rust protection, the calculation can be seen below,

$$\frac{6}{B \times 24} = I\%,$$

where the rust-protection time was set to 6 hours. For test drive and visual inspection, crucial for this thesis project, the time amount was calculated in the same way as above. Two hours for test drive and one hour for visual inspection, with the result below;

$$\frac{2 + 1}{B \times 24} = J\%.$$  

This shows that the current test procedure stands for approximately $J\%$ of the lead time through TC. Although the numbers are hidden, they symbolise the improvement potential when it comes to flow efficiency in the after flow.

### 4.6.5 Environmental Impact

The current test procedures affects the environment due transportation of both people and machines between AVOS and Kvarntorp. The economical aspect of this has been presented, but the transportation also affects the surrounding environment. Heavy trucks transports the machines between Kvarntorp and AVOS, which affects the traffic. The big trucks causes noise and emissions, which affects the environment for the surrounding houses. Regarding the trucks, they are driven on diesel fuel with a significant higher consumption than ordinary cars. Those engines directly corresponds to a high level of emissions, i.e carbon dioxide and nitric oxide. Furthermore, the trucks are limited to shorter work days on Fridays due their noise and heavy load. This in turn affects the logistics between AVOS and Kvarntorp.

### 4.6.6 Wastes

Test drive is a method for quality assurance, but in the same time it is an identified waste due bad quality and can thereby be associated with the category defects from the 7+1 wastes presented earlier. Readjustments is also a result of defects due lack of desired quality in the first place. Transportation is directly associated with the waste transport and re-painting and washing is a result of extra processing. Further, between these processes waiting is directly increasing the lead time in the after flow. All together, all steps in TC except pressurizing and rust protection are hence classified as wastes.

### 4.6.7 Summary

The discussed problems above are summarized in the Venn diagram in Figure 36 where the reasons for the current problems are seen as three intersected circles (henceforth called 3C). It can be seen that the overall problem is extended lead time due the time between production line and shipment. The increased lead time is a result of the current test procedure (blue), economical aspects (red) and environmental aspects (yellow). The interlinkages between the subjects are seen in the area between the circles. For each category specific problems are highlighted. Some content is similar between them, while some are unique for each and one of them.
In order to improve the current state it will be important to improve the test procedure with new and updated methods. Further, it will be important to, on long term perspective, improve the economy and reduce the costs related to the after flow. New test procedures, decreased usage of resources and fewer transports will in the end improve the environment as well.
5 Result and Analysis

This section holds the result from four interviews as well as the conducted study visits. Further, the section contains the details about the result for this project, i.e the improvements compared to today’s situation. The result lays under phase number 4, 5 and 6 in the project circle and has thereby been the biggest section for the whole thesis project. The foundation for the section is based on the previously described theory. The effect of the chosen solution is explained in the end of this section.

5.1 Internal Interviews

The internal interviews were based on semi-structured interviews and the interview guide can be seen in Appendix 4. As the interview guide shows, the questions were based on the 3C model and the structure was thereby based on a thematic interview. The interviews in tabular form can be seen in Appendix 5.

5.1.1 Manager Production Quality

The first interview was performed with the Manager for production quality, henceforth called respondent 1. The overall goal was to get a leader’s perspective of quality and the current situation related to quality assurance and quality testing. Respondent 1 highlights the importance of the principle ”right from me”, as the best solution to ensure high quality in the first place. With the right implementation of right from me (from supplier to assembler) it would be possible to guarantee the quality without any test. In order to implement right from me, the culture is crucial. Respondent 1 classifies culture as the most important factor to reach an existence where quality is prioritized in a desired way.

The quality work during assembly is proactive, i.e to ensure highest possible quality in the test procedure. In order to ensure standardized work during assembly checklists are used where the operators signs executed tasks. If deviations are discovered later in the process, the signature makes it possible to give direct feedback to the responsible operator. According to respondent 1, this is used to become a learning organization where everyone learns from mistakes. The newly implemented Pre Acceptance, PA, (between assembly and pressurizing) is a method to identify deviations before the machine reaches the after flow. PA has been implemented due problems with right from me (1 believes that if right from me is well working the PA would not be necessary). The PA makes it possible to analyze the machine and the discovered deviations are then readjusted by the operators, i.e they readjust their own mistakes. Respondent 1 highlights this as an important aspect to become a continuous learning organization. The interaction between quality and production department could be improved, but 1 believes they share the same goal of high quality machines.

The current test procedure is according to respondent 1 well working. The usage of checklists guarantees an equal test procedure between machines and it is thereby possible to analyze every result for what it is, without taking outer circumstances in consideration. Although the current test procedure is well working according to the respondent, respondent 1 is aware of smaller issues. With new functions on customized machines, the checklists can sometimes be outdated which requires the test operator to conduct the best, not standardized, test variant. It is important to ensure that all necessary information
is available during the test procedure, which according to 1 can be improved in today’s procedure. Sometimes the test operator doesn’t understand a specific test and conducts it in the wrong way. The desired outcome for a functional test would then might be something else than desired. Furthermore, new versions of the machinery can sometimes affect older parts and it can sometimes be hard for the test operator to identify the root cause. Respondent highlights the problem with transportation damages on the machines during the transportation back and forth Kvarntorp and classifies those damages as waste. The current test procedure is a result of both internal experience and legal requirements, but sometimes customers requires specific tests to be performed (which can be a problem for the test operator).

Respondent 1 acknowledges that some aspects on a machine is tested several times for quality assurance. To reduce the time amount for quality assurance respondent 1 believes it would be necessary to analyze every phase in the quality assurance in order to find duplicates and later decide where and when to test specific aspects. One part with continuous improvements is to find and implement new test items which is done by both the quality and engineering departments. Respondent 1 classifies the PA as a waste due the purpose is a control before the control. Although it is a waste, respondent 1 believes it has led to improved quality and fewer deviations discover during test drive. To reduce the number of test items and time in the after flow, respondent 1 states the work has to start during product development of a new machine. The number of prototypes today are low, which makes it hard to reach high quality at once with new machines, but 1 believes it is hard to increase the number of prototypes due the HMLV production. To shorten lead time in the after flow, 1 states that right from me has to work better than today. Respondent 1 believes that the quality would increase if more modules and components from suppliers would be tested, but admits it would be expensive and time consuming. If everyone followed the standardized procedure, the number of deviations would heavily decrease which in turn would reduce the required time for readjustments. In total, this would lead to a shorter time in the after flow and thereby a shorter lead time in general. Respondent 1 states that the quality tests always have to be conducted and says is important to let them take required time. It is more expensive with deviations and failures at field, than deviations in a test mine.

5.1.2 Quality Technician

The second interview was performed with a quality technician for the MH machines, called respondent 2. The purpose was to analyze a technicians point of view, regarding the current quality tests. According to respondent 2 the most important, but also hardest, aspect to increase the general quality is to reach a culture where quality is prioritized. With right culture, the principle of ”right from me” can be implemented successfully, but with insufficient culture the principle won’t work. To reach the desired culture, feedback is an important aspect to be able to learn from mistakes. According to 2 the new list of frequent deviations will improve the amount of feedback and increase the awareness of current quality problems. Deviations from the test drive are reported, but according to 2 it does not exist a standardized and structured method for how to work with these reported deviations. Every flow is supposed to work with the deviations, but 2 argues the work should be more standardized in order to be more effective and proactive. An improved collaboration between each flow, TC and the quality department would lead to a more effective and proactive approach according to 2. For some deviations, i.e leakages,
the root cause can be hard to identify which makes it hard to act proactive instead of reactive according to 2. The respondent states that some reported deviations might be a result of already detected deviations. For example, some leakages discovered in the mine could be a result of an already discovered and adjusted deviation. The respondent states that many leakages are discovered already during pressurizing.

Respondent 2 argues some machines have inadequate and outdated basis, which sometimes requires the operator to lean on experience, instead of standards, in order to fulfill a specific task. This makes it difficult to reach the strive for right from me. The inadequate basis can also be a problem for new employees who lack experience. The combination of inadequate basis and new employees is according to 2 the biggest reasons for the unstable quality. According to respondent 2 the assigned time for test drive should be extended due current problems to identify desired amount of deviations. Sometimes leakages are discovered several days after the test drive, which according to 2 is a sign of too short test time. However, the current test procedure is although well working according to 2 who highlights the importance of a profound functional test where all functions are analyzed. For a more accurate analysis, respondent 2 argues for a better control of the load weighing system for the MT machines. Today the calibration is made with weights that are fare away from the machines maximum capacity, which according to 2 makes it hard to calibrate them good enough. Furthermore, some tests are conducted several times but according to 2 that's necessary due bad quality from time to time. 2 further states that some deviations might be hard to discover in the mine and highlights deviations related to electricity. In the mine every light on the machine is turned on, which makes it hard to discover if some lights are turned on when they are not supposed to.

The current test procedure has, according to 2, been developed through experience and there are no continuous improvements or updates regarding the standards today. To be able to reduce the lead time through the after flow, respondent 2 states that right from me has to work well. If the principle was implemented throughout the organization, respondent 2 argues the visual inspection before the test drive could be removed. The test drive in mine would although be necessary according to 2. The unstable quality makes it hard to predict the lead times for the machines according to 2, who states that problems can extend the lead time with approximately 2-3 days. Although the extension, respondent 2 argues that the lead time through the after flow is relatively short compared to a manufacturing time of 4 weeks and 2 hence argues the percentage extension to be relatively low.

5.1.3 Production Manager

The Production Manager, henceforth called respondent 3, highlights the importance of product knowledge in order to reach a high quality production. With a deep understanding of the product, it’s possible for the assemblers to finish the work at the station in a desired way. Furthermore, it’s possible for the following operator to inspect the machine and determine if the previous work has been conducted in a desired way, something respondent 3 calls built in quality. Thereby it’s possible to identify deviations early in the process and hence correct them. The respondent states that the culture is crucial and highlights the principle ”right from me”. Further, updated standards and basis plays a key role when it comes to quality improvement. Respondent 3 states the quality audits is an important tool to judge the quality. Further, it’s important to analyze the result from both testing
and PA in order to judge the quality of manufactured machines. Onwards, First Time
Through (FTT) will be used as a measurement tool. The respondent states the quality of
manufactured machines is good due to it’s complexity, but admits the quality decreases
with fast production ramp-ups.

Respondent 3 classifies quality tests as waste for the customer and presumes some steps in
the current quality assurance are unnecessary. In best case scenario, with desired quality,
the machines would only require a short verification before a truck could pick them up for
shipment. By reducing the amount of quality testing the lead time as well as the amount
of wastes in the after flow would decrease. The key to shorten the lead time in the after
flow according to respondent 3 is to get the machines out from the Kvarntorp mine for
testing. Without the mine it would be possible to eliminate the transportation, washing
and re-painting of the machines according to 3, which in turn would decrease the costs
related to the after flow. To shorten the lead times the, for the moment, necessary quality
tests should be conducted at AVOS which according to 3 would significantly improve
the after flow. The respondent inquires visual KPI’s to be able to analyse the further
development regarding quality.

An important aspect to increase the overall quality is material from suppliers. The
respondent states is is necessary that both the internal as well as the external quality level
improves in order to reach the desired quality level. The key to remove the machines from
Kvarntorp is leakages according to 3. The respondent states that the new test procedure
must be able to trig leakages to appear in order to be successful and effective, which in
turn makes it possible to guarantee the quality to the customers. The respondent states
that the test personnel have a high level of commitment for quality and their work tasks.
However, the respondent argues that the level of innovation could increase in order to
reach continuous improvements regarding the test procedure. The respondent argues that
with a new test procedure the customer focus will increase, which in turn will generate
more pleased customers.

5.1.4 Test Operator

The test operator, henceforth called respondent 4, classifies most of the deviations as
frequent. The respondent states product knowledge as one of the most important factors
to reduce the number of deviations discovered during the test procedure in Kvarntorp.
Further, the respondent believes the number of deviations would heavily decrease if ev-
everyone knew the differences between manufacturing line and the work environment for
the machines. Respondent 4 inquires better feedback between the test operators and the
assemblers in order to reach a better dialogue regarding the machines and believes it would
be positive with continuous meetings which both test operators and assemblers would
attend. The respondent believes this would enable a culture where ”right from me” could
be well working and with possibilities to work proactive instead of reactive.

During the test procedure at Kvarntorp, respondent 4 states it is important to iden-
tify leakages and to check the hydraulic hoses. The test operators seeks for errors and
deviations in order to find them. The current test setup is extensive and well working
according to 4, who states that what is being tested is the right things to test, i.e critical
functions. Most of the errors and deviations that are being reported are identified during
the visual inspection before the test drive. Functional errors are mostly discovered during
the test drive. The respondent states the test operators conducts the test in different ways. Most operators conducts the visual inspection before the test drive, while some conducts the test drive first. Furthermore, the respondent believes different operators classifies deviations differently today. The respondent states it is crucial to inspect one machine at the time and not inspect and test several machines parallel. Although respondent 4 believes the current test procedure to be well working, there is room for improvements. During the test drive in the mine, the operators don’t have a computer with information about the machine, which sometimes can be a problem due lack of information according to 4. With more available information, it would be easier to seek answers during the test drive instead of after. Furthermore respondent 4 argues there are differences between test drive during summer and winter. During summer the machines are tested at the test track in Kvarntorp, which according to 4 makes it easier to test the machine in full speed, with sharper turns and with both ups- and downhills. It is therefore easier to trig deviations and errors to appear during summer according to 4. During winter, snow and ice can be problematic. According to 4 it is not possible for visual inspection with a snowy machine and the drying process thereby extends the whole test procedure, which causes problems later on.

Respondent 4 believes more deviations would occur if every machine where supposed to be driven, then cooled and then driven once again in order to reach temperature expansions. Today the test operator feels a pressure from management to conduct the tests in order to make the machines ready for shipment. Respondent 4 states the pushing flow system makes it hard to secure the quality due lack of time. The test operators signature guarantees the safety and quality for a machine and the respondent therefore states it crucial to conduct the tests in the right way. To release the pressure, the respondent believes it is necessary with an even workload. The existing checklists for the tests are not continuously updated according to the respondent who states the lists should be living in order to clarify specific deviation targets for the moment. The respondent clarifies it is also up to the test operators to identify new items and to contact responsible document owner in order to continuously update the checklists.

The focus varies between the production and quality departments according to 4. The quality focus has increased and the respondent believes the quality department has bigger mandate regarding the general quality focus during manufacturing. The respondent believes it would be good with clear and visible KPI’s for quality, productivity and production. Furthermore, the respondent inquires a better visual control system for the after flow. Today, it is common the test operators gets calls about specific machines and where they are in the flow. The respondent believes a better visual tool would reduce those calls, which would make the work easier for the operators. The current lead time through the after flow is a result of each process required time amount. The respondent believes it is hard to shorten the lead time with the same processes as today and states transportation takes a specific time due it’s distance.

5.1.5 Interview Analysis

The interviews were based on the themes from the 3C model (introduced in section 4.6.7, Summary), which in turn is based on the current situation and it’s problems. The themes in the model have been shortened to TP (test procedure), Ec (economy) and En (environment) during this analysis.
Test Procedure
Every respondent highlights the importance of a culture where quality is prioritized in order to successfully implement "right from me". The principle of right from me is furthermore the key to build in quality at once and thereby successively reduce the number of test items. Furthermore, feedback is crucial in order to become a learning organization according to all four respondents. However, respondent 4 also highlights the importance of a continuous dialogue between test operators and assemblers in order to learn from each other and thereby successively improve the result. Respondent 1, 2 and 3 highlight right from me as the key to shorten the lead time through the after flow because it would reduce the time for readjustments as well as the need for quality tests. Respondent 2 further states inadequate basis and new employees as a risk factor when it comes to quality assurance. Both respondent 3 and 4 classifies product knowledge as crucial to reach the desirable quality level. Every respondent highlights the importance of a standardized test procedure with checklists. However, respondent 1, 2 and 4 states the current checklists are not continuously updated with shifting quality issues. The three of them, as well as respondent 3, highlights the importance of updated and available information and checklists as crucial for a standardized test procedure. Which in turn is stated as crucial to guarantee the quality towards the customer. However, respondent 4 clarifies the test procedure is different between the test operators and explains how operators conducts the steps in different order. Another problem seems to be that deviations are classified differently between the test operators. The human factor and the operators personal opinion seems to affect the result.

Respondent 4 states that lack of information extends the test drive and makes it harder to judge the quality, which in turn is confirmed by respondent 1. According to respondent 1, 2 and 4 the current checklists are seen as a living document, but both 1 and 2 argues the lists are not updated frequently enough. The current test procedure makes it hard to identify root causes according to respondent 2, which is confirmed by respondent 4 who states it can be hard to see if a leakage is old or has occurred during the test drive. Both respondent 2 and 4 clarifies the test drive should be extended in order to identify more leakages and 4 believes it would be desirable to leave the machine for cooling during a test in order to reach temperature expansions. However, respondent 4 also states most deviations occur in the beginning of the test drive. Respondent 3 on the other hand, classifies all quality tests as waste for the customer and believes some steps to be superfluous. Respondent 1 and 2 acknowledges some items are tested several times, but clarifies the goal is to reduce that number. Respondent 4 states it is easier to trig deviations to occur in the summer due the test field in Kvarntorp, which is confirmed by respondent 2 who clarifies some deviations are hard to identify in the mine due lack of daylight. According to respondent 3, it is required to eliminate the tests in Kvarntorp in order to reduce the lead time. Respondent 4 believes it is necessary to reduce the number of processes in the after flow in order to reduce the lead time.

Economy
Respondent 1 highlights the problem with transportation damages between Kvarntorp and AVOS as a problem today. Those damages are readjusted at the external paint shop in Kvarntorp, which in turn affects the economy for Epiroc. The transportation problem is highlighted by respondent 3 as well, who states that it would be possible to eliminate transportation, re-painting and washing if the tests in the mine were removed.
The elimination of those processes would not only decrease the costs related to the after flow but also improve the lead time, which is confirmed by respondent 4. Shorter lead time is equivalent to improved business opportunities. Respondent 3 states that an improved test procedure would increase the customer focus, which in turn will affect the operations positively.

Environment
The current procedure affects the environment badly due the transportation back and forth Kvarntorp. As respondent 3 explains, with a new test procedure the transportation can be removed which in turn will be positive for the surrounding environment as well as for the nearby citizens.

The result from the interviews can be interpreted to the test system architecture (TSA) which was described in Section 2.5.1, Test System Architecture. At Epiroc the test team consists of the test operators which in turn is dependent of the other elements: testware, test processes and test environment. As previous described the testware consists of test documentation, test processes of the arrangement regarding the tests and test environment is all about the outer circumstances, i.e the infrastructure for the tests. The 3C and TSA can be combined in order to merge the analysis and result. The content of TSA (test team, testware, test processes and test environment) all lay under the test procedure (TP) in 3C due it’s similarities. This shows that TP consists of several important and critical aspects for further improvements while Ec and En more consists of factors that change naturally due the result from TP. This symbolises the importance of focusing on TP in order to improve the content of TSA.

Key Words
right from me, culture, learn from mistakes, wastes, root cause, product knowledge, KPI, innovation, checklists, information

Conclusion
From the interviews seven areas were identified as crucial in order to improve the current state:

- Reduce lead time
- Identify different deviations
- Minimize transportation
- Reduce test related costs
- Reduce environmental impact
- Improve flow efficiency
- Be located at AVOS
5.2 Study Visits

At the end of phase number two and three the first study visit was conducted, to Volvo CE in Arvika. The second study visit took place at Epiroc Surface and Exploration Drilling in Örebro. The third study visit was conducted at Komatsu Forest in Umeå. The purpose of those was to see the companies ongoing work with proactive quality assurance. To see inspection equipment a study visit to Opus Vehicle testing Örebro - Truckstop was conducted. The most important content for each visit will be highlighted below.

5.2.1 Volvo Construction Equipment

Volvo Construction Equipment (VCE) in Arvika is Volvo’s main production facility for wheel loaders. They produce approximately 4000 units per year and delivers all over the world. The production in Arvika is build upon Lean principles and based on a specific takt time which is applied on every station. During morning of the the study visit a team leader for the quality group (QG) was followed, henceforth called respondent A. During the afternoon a team leader for the after flow was followed, called respondent B. The study visit was based on semi-structured interviews, see Appendix 6, but also on observations at line. See Appendix 7 for a more detailed description of the visit.

The flow at VCE Arvika is based on proactive quality controls (QC) during manufacturing. The purpose of those is to identify deviations on an early stage of the process, which enables an efficient and fast way to adjust them. Figure 37 illustrates the process between end of production line and shipment. The first step after production line is the test drive (outside), followed by pressurizing. Thereafter comes test drive inside and depending on the test result the machines might be ready for re-check, but sometimes service is necessary due heavier deviations. The service stage is divided into four different scenarios depending on the issue. Takt time is not used during these four scenarios. After this stage the machines enter the normal flow and the last step in the after flow, touch-up, where the machines are washed in the washing machine. The machines are then ready for shipment. Volvo’s quality goal is 96% correct machines, i.e straight flow with no need for corrections.

![Figure 37: The after flow process for VCE Arvika.](image-url)
Proactive Quality Assurance

For VCE Arvika quality and quality assurance is essential and respondent A argues that the QG has enough resources to work proactive instead of reactive. Medium line has one QC which is manned by one controller from the QG. Large line has 3 QC’s, all manned by controllers from QG. The work at every QC is standardized, something A highlights as a key to be able to work proactive. Due takt time, respondent A states that it sometimes can be lack of time for the controllers. According to A, the checklists are crucial for the reduction of deviations during the last years. All discovered deviations gets a code and according to A the statistical data helps to identify, analyze and continuously improve the quality in a proactive way. The improved quality is a result of hard work with the culture according to A. Everyone knows how important quality is and the general goals have been divided to specific goals for the work stations which has helped to see the progress and ongoing improvements.

Test Drive

The biggest part is outside where the machines general behaviour and functionality are tested. VCE Arvika uses compulsory standardized checklists on a test computer and according to respondent B the computer minimizes the human factor due the operator doesn’t have to interpret every expression as before. VCE Arvika has significant reduced the amount of time for the test drive and respondent B states that is due the reduction of test items. To reach working temperature (at least 70°C) the test operator drives 10 laps at the test track, which is the first step of the test procedure. According to respondent B the most important test is the transmission test. Machine specific buckets are used to test and evaluate the bucket performance and the bucket is mounted on the machine and then lifted to the highest point. The test operator then controls the weight and repeats the test two times more. During the test the machines are turned off for cooling. The pause is to trig leakages to appear when the test is continued. During the test drive inside the focus is on visual control and to identify deviations regarding leakages and hydraulic system.

Differences and Similarities to AVOS

The controllers at the QC around the line have a big chance to identify deviations early which otherwise could have led to leakages later on. Furthermore, standardized work with continuously updated checklists has significantly improved the general quality according to both A and B. When it comes to proactive quality work VCE Arvika has come further than AVOS. Deviations at VCE Arvika are discovered earlier in the process which makes it easier, cheaper and more efficient to correct them compared to AVOS. At VCE Arvika every machine in the after flow are visualized at a whiteboard, i.e flow board. Respondent B highlighted the importance of the flow board which enabled a more easy way to highlight recurrent quality deviations and remaining steps for a specific machine before shipment compared to the flow system at the computer.

Both AVOS and VCE Arvika uses test drive in field as quality assurance method. At VCE Arvika transportation is not needed and washing are done in-house, which makes it easier to control the production flow. The processes are developed for high volumes (nearly 10 times more than the MH machines at AVOS) which makes it crucial with flow efficiency and optimized process steps. VCE Arvika estimates their afterflow processes extends the average lead time from 6 to 7 seven days.
5.2.2 Epiroc Surface and Exploration Drilling

Epiroc Surface and Exploration Drilling (SED) is located approximately 6 kilometers from AVOS and manufactures machines for infrastructure and mining projects above ground level. SED Örebro (called Eyra) has around 400 employees and has been operating in Örebro since 1995. During the study visit the flow manager for test/prototype and verification (henceforth called C) was interviewed with a semi-structured approach. Eyra uses a specific takt time in their production and every process outside the two main flows are based on that takt time in order to ensure a flow efficient production.

Production Flow

Eyra has two main flows where two product families are built, one on each line. A third product was built on the two lines before, but due it’s low quantity it was removed and are now being build on stations next to the line. This has improved the stability for the two flows and the production is now more efficient. Respondent C explains the receiving station conducts a quality inspection before the work starts in order to identify potential deviations which makes it possible to correct them before it is too late. After the line the machines electricity is tested before they enter the functional center. In the functional center the first step is pressurizing and thereafter some tests are conducted of two operators. One operator investigates the behaviour of the machine and tries to find potential leakages and the other one controls the machine. If deviations occur the operators tries to find the root cause and according to C the root cause are used to improve the machine. The machines vibrate which in turn can trig deviations to appear. However, due high quality very few functional tests are required to judge if the machine has desired quality or not. No ordinary machine conducts a drill test, instead the quality is classified as high enough. According to respondent C the quality at Eyra is approximately 10 times higher than at AVOS. Takt time is used in the functional center as well, making it important to conduct every step in a standardized way. According to respondent C the checklists used in the functional center are continuously updated in order to fulfill the task. Furthermore, the instructions for every machine are also continuously updated which thereby makes them relevant to use according to C.

Proactive Quality Assurance

Eyra is a quite small factory and respondent C highlights the nearness as a success factor for the atmosphere where decisions are easily spread and problems can be discussed in a fast and effective way. Eyra has worked hard to reach the current situation where quality and production effectiveness is natural for everyone. Quality and efficient production has been crucial already since the start according to C who highlights the importance of many small steps in order to improve the organization. Since the start in 1995 the focus has always been quality according to C who further classifies feedback as the key for the organization’s improvements. Today feedback is used to highlight good as well as bad work so everyone in the end can learn from mistakes. At Eyra deviations are analyzed on individual level, making it possible to give feedback to responsible assembler. According to C this enables a continuous learning process for every employee. Further, C states it is important to see deviations in reality and explains that assemblers sometimes have to assist the operators in the functional center in order to see what has happened and why it happened. According to C the situation where you have to wipe oil due bad work will generate an improved quality approach. However, respondent C clarifies everyone makes mistakes but states it is important to learn from them and interpret them to proactive
solutions in order to continuously reduce deviations. Respondent C clarifies it takes time to reach a culture where quality is prioritized, but highlights culture as crucial for continuous improvements. At Eyra feedback has been used to highlight what management demands, which C explains as a successful method.

**Differences and Similarities to AVOS**
Eyra has come further in their view of quality. At Eyra the work is conducted in a proactive way where deviations and their root causes are identified in order to implement solutions which minimizes the risk for the same deviation to occur again. The checklists at Eyra are continuously updated which makes them to relevant and important documents for the operators. Standardized methods are followed which in turn minimizes the risk of deviations to occur. Deviations are discovered already during assembly at Eyra and not during the visual inspection as the case at AVOS/Kvarntorp. The biggest difference is that machines manufactured at Eyra has significant fewer functional tests compared to AVOS. However, it should be mentioned that the MH machines manufactured at AVOS is more complex. The pressurizing is similar between AVOS and Eyra, although Eyra has a more standardized approach for the procedure. Respondent C estimates the after flow at Eyra extends the leadtime from 14 to 16 days.

**5.2.3 Komatsu Forest**
Komatsu Forest has approximately 1700 employees worldwide and is considered to be one of the worlds largest manufacturer of forest machines. Umeå, with about 500 employees, is the company’s main production facility where approximately 800 machines are manufactured every year. The visit was conducted with a quality technician, henceforth called respondent D. The study visit was based on semi-structured interviews, and the interview guide can be seen in Appendix 6. See Appendix 8 for a more detailed description of the visit.

The production at Komatsu Forest Umeå (KFU) is based on two production lines, one for forwarders and one for harvesters. The flow can be seen in Figure 38. After the line the machines enter the start-up phase where oil and media are filled. Thereafter comes the test drive. During the test drive the machines are tested in two steps, test drive one respectively test drive two. If a machine passes the test drive without critical deviations (which requires longer readjustment time than 1 hour) the next step is wash and paint. The machines are always washed and some re-painted due small damages occurred during manufacturing or test drive. KFU has an own paint shop as well as an own machine wash. The machines are then driven to the final inspection, FI, where everything is gone through by inspectors. After the FI everything has to be approved, otherwise the machine

![Figure 38: The after flow process for Komatsu Forest Umeå.](image-url)
is driven back for test and readjustments. When both machine and it’s documentation are approved the machine is approved for shipment. The longest transportation in the after flow is between washing and FI, a distance of about 300 meters. This enables an efficient handling if the machine has to be readjusted after the final inspection. The lead time is 11 days in general according to D (from pick start until shipment).

Proactive Quality Assurance
The quality focus starts already with incoming material. Every new supplier has to prove their ability regarding quality and delivery precision due the JIT production system. Every reported deviation is investigated in order to find the root cause, i.e incoming material or wrong methods. If a deviation is material related, the product will be flagged which requires the supplier to come up with both short and long term solutions. Respondent D highlights the importance of a good dialogue and states it is important to learn from each other. During the manufacturing phase KFU has inline checkers (IC) who are supposed to inspect the machines in order to verify that standards have been followed. For every deviation a PDCA report (plan, do, control, act) is written where the root cause, affects and responsible department are highlighted. Respondent D states it is important to encourage everyone to report deviations and highlights the importance of an open mindset so no one will feel supervised or accused. Frequent deviations are merged to the 0h list (deviations discovered within the production). Deviations from a machines first 100 hours are collected into the 100h list which is an important tool for IC. Specific deviations are followed up until a preventive solution has been implemented. According to both respondent D and an IC, the list is a living document for proactive solutions. Furthermore, quality technicians (QT) supports the line with quality issues. KFU used to have problems with leakages, but the proactive quality work has improved the output and the machines do not suffer from leakages in the same way.

Test Drive
The test drive at KFU is divided into two steps, both three hours each. The test operators have an own test computer with a protocol consisting of both fix test items as well as temporary, due the current items on the 100h list. The procedure starts with a visual inspection where the outer condition is inspected. After three hours the operator leaves the machine to cool down, which according to D trig deviations related to leakages to appear. If problems occurs during the first test drive they are readjusted during the waiting period which according to D shortens the lead time. After three hours the test is continued, but by another operator. This reduces the risk for the operators to miss deviations and problems according to D. The test protocol is frequently updated which D highlights as a key to reduce the deviations. The test computer requires the test operators to follow a standardized procedure, and D highlights standardization as the best procedure to reduce the amount of deviations. To use different test operators for test one and two is according to both D and an asked test operator a strength with the current system. The risk of missing deviations and problems due the human factor decreases heavily according to D.

Differences and Similarities to AVOS
According to D it takes long time to create the right culture where quality is prioritized and standards are followed. To become a learning organization feedback is used to return deviations to responsible employee. According to managers at KFU it is important to see deviations as a way for improvements, i.e to learn from mistakes. The climate regarding
deviations is more open at KFU compared to ERD. KFU measure deviations in order to see the development curve and D highlights available data as crucial to see the progress which in turn can be used to boost the whole organization. AVOS suffer from lack of good data, which according to D is a problem. The access to IC has improved the proactive quality work significant and the work is conducted in a more proactive way compared to ERD. The continuously updated checklists (new items due the 100h list) is crucial in order to test and verify, for the moment, critical items.

Both KFU and AVOS conducts quality tests to verify the quality before the shipment. The products, forest machines and mining machines, are quite similar with many similar problems during manufacturing. However, KFU shows that quality can be significant improved with right focus combined with modern methods. This shows that Epiroc can improve the quality as well and thereby build more competitive machines at once.

5.2.4 Opus Vehicle Inspection Örebro - Truckstop

The visit at Opus vehicle inspection aimed to investigate the inspection methods as well as necessary test equipment for trucks. During the visit two inspectors were followed when a truck and trailer was inspected. Opus Örebro - Truckstop (OÖT) has a inspection pit beneath ground level which enables an efficient inspection of the chassis. As can be seen in Figure 39(a) the inspection pit has good light condition as well as easy accessibility. Figure 39(b) shows how the inspection pit enables inspections of good ergonomic conditions. During the inspection procedure several tests are gone through. For several tests specific equipment is used, such as roller brakes and play detectors. The two inspectors cooperated during the inspection, which enabled a fast and smooth procedure. One operator sat in the truck with a tablet and the other was located in the inspection pit where he inspected and analyzed the truck from below. The tablet was used to analyze and interpret the test results and the inspector could manage several tests from the truck cabin by the tablet. Several tests included inspections both above and below ground level, which can be seen in Figure 40. The brakes were inspected above ground level, Figure 40(a), in the same time as other aspects were analyzed from below, see Figure 40(b).
Figure 40: Wheel inspection conducted both above and below ground level.

During the whole inspection, items on the tablet were analyzed continuously. Because of the digital format the test results could easily be printed in the end, which made the whole inspection procedure more efficient for both inspectors and truck owner.

5.2.5 Analysis Study Visits

The analysis of the conducted study visits will be based on the 3C model and TSA. Once again, the themes in the model have been shortened to TP (test procedure), Ec (economy) and En (environment) during this analysis. Most focus is on the first three companies and when OÖT is analyzed it is clearly mentioned.

Test Procedure

Common for the companies was their high production quality. The respondents saw quality as crucial for the company and as an important topic already from incoming material and respondent D highlighted dialogue with suppliers as important. Furthermore they all worked with proactive measures during manufacturing. All companies have standardized quality inspections during assembly, when special quality inspectors or receiving work station conducts inspections in order to find deviations on an early stage. This enables high quality products already from line. The usage of updated standards was highlighted as crucial in order to reach the desired culture of ”right from me”. It is a long journey to reach right culture according to all respondents, but the key is to have a strong commitment from all employees. To increase the commitment, and to continuous develop, feedback is crucial according to all respondents. Feedback makes it possible to learn from mistakes, an important aspect to become a learning organization. Every respondent saw it as crucial to allot deviations to an owner, responsible assembler, so everyone could learn from their own mistake. According to D, PDCA reports are an effective tool to implement preventive solutions. Another method to learn from mistakes, highlighted by respondent C, was to let assemblers assist the test operators with heavier deviations, such as big leakages, which in turn enables consensus regarding root cause and effect.
The respondents highlighted the importance of updated lists with quality issues for the moment, which thereby allows the inspectors/operators to search for those extra carefully. The first three companies also highlighted good reliable data as an important tool to work proactive, i.e. the data shows where to take measures, which in turn can be used to implement long term proactive solutions for a problem. The culture described above, i.e. where quality is prioritized, shows it is necessary to allot resources. The result, is less problems through the after flow. The first three companies have less problems than AVOS with quality and throughput and their test procedure is thereby less extensive. The after flow process at Volvo CE Arvika and KFU is more straight and visual, with fewer steps compared to AVOS/Kvarntorp which enables a more efficient handling. All three companies uses updated checklists on a test computer which requires the test operator to follow a specific standard. At OÖT, checklists are used on a tablet which enables a fast and smooth flow throughout the inspection. The lists minimizes the influence of the human factor. Common for the first three companies is that the machines during test drive are turned off for cooling, which the respondents motivates with temperature expansions in the tubes. At KFU deviations where in some cases readjusted already in the pause between the tests, which lowered their lead time through the after flow. Common for the companies was their strive for continuous improvements, i.e. their ongoing chase for improvements and preventive and proactive solutions in order to shorten the lead time with increased quality.

**Economy**

The proactive work analyzed above, makes it possible for the companies to adjust deviations on an early stage in the manufacturing process. According to the respondents, it is important to adjust the deviations as soon as possible. The result, reduced lead time and often less time consuming readjustments, affects the economy in a positive way. Further, the respondents states it is important to allot enough resources for sustainable and proactive solutions. These solutions will, on long term, be more effective and beneficial in terms of economy and productivity. The companies have gathered their after flow in a streamlined way, which makes it possible to control the whole flow better than the flow between AVOS and Kvarntorp. This enables the company to manage the flow all by itself, which increases the effectiveness and profitability.

**Environment**

All three companies have short distances between the processes in their respectively after flow. This reduces the need for transportations, which in term of environmental perspective is desired. The machines from the three companies are not damaged in the same way as they are in the Kvarntorp mine. The companies thereby consumes less resources in their after flow, due reduced need for re-paint and washing compared to the case at AVOS. The companies also have buildings adapted for the after flow with specific tools and equipment depending on the requirements. This enables the opportunity to collect and store dangerous liquids in a sustainable way.

Regarding the TSA, the three companies have a more effective testware due more accessible and more frequently updated documents. The test processes are more effective and the throughput in the after flow thereby higher than AVOS/Kvarntorp. Lastly, test environment is also better and more suitable for these three companies compared to AVOS. All together, the companies have a better developed TSA than AVOS. Regarding OÖT
their TSA is well developed and well suited for their operations. OÖT has a functional testware, with specific documentation as well as suitable equipment. The test process is also well working with a straight flow throughout the inspection with a standardized approach. Further, test environment is fully adapted to the operations, which thereby makes the whole procedure well working and effective. Summarized, OÖT has the best TSA which is fully adapted for the specific task.

**Conclusion**
From the study visits four areas were identified as crucial in order to improve the current state:

- Work proactive
- Increase the commitment among the employees
- Use updated checklists that reflects the actual situation
- A visual flow is easier to manage than a sprawling flow

**5.3 Sound Levels**

AVOS is located within Örebro city, i.e the surrounding buildings are both schools and homes for citizens. This causes problem regarding overcrowding as well as restrictions for the operations sound level. The new test methods must handle these sound restrictions due to current legislation's. As mentioned in Section 2.6 (Sound) the sound level from industries within cities cannot exceed 60 dB, but should not exceed 50 dB if close to schools or preschools. The sound level for the MH machines manufactured at AVOS has been investigated in order to determine their effects on the surrounding housing due legislation's. The result can be seen in Figure 41 where both external sound (affecting neighbours) as well as the sound level inside the cabin are presented. The Figure clearly shows that

![Figure 41: Sound levels for manufactured MH machines.](image)

the sound levels for the machines are considerably higher than accepted according to current legislation's. Due the result, the new test procedure thereby has to be inside to decrease the effects. Furthermore, there are constraints regarding when and how to drive the machines between the houses at AVOS’s property. The specific times and their
associated constrains can be seen in Table 5. As the Table shows, the sound levels are equivalent to zone B, explained in Section 2.6 (Sound).

Table 5: Policy for external industrial noise.

<table>
<thead>
<tr>
<th>Type</th>
<th>Day, 07-18</th>
<th>Evening, 18-22</th>
<th>Night, 22-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Level</td>
<td>60 dB(A)</td>
<td>55 dB(A)</td>
<td>50 dB(A)</td>
</tr>
<tr>
<td>Traffic</td>
<td>Where possible, minimized</td>
<td>Minimize</td>
<td>Not permitted</td>
</tr>
<tr>
<td>Noise</td>
<td>Try to limit</td>
<td>Should be avoided</td>
<td>Avoid</td>
</tr>
<tr>
<td>Testing</td>
<td>Minimized</td>
<td>Should be avoided</td>
<td>Should be avoided</td>
</tr>
<tr>
<td>Drilling</td>
<td>Forbidden</td>
<td>Forbidden</td>
<td>Forbidden</td>
</tr>
</tbody>
</table>

5.4 Requirement Specification

Seven areas from the interviews and four areas from the study visits were identified as crucial for an improved future state. These areas were categorized into requirement or request and combined into a requirement specification. The purpose of the specification was to highlight important areas as well as to clarify what to prioritize and can be seen in Table 6. The weight factor, 1-5, represents the importance and where 5 is the most relevant factor. Due to the high sound levels, the requirement "handle sound level regulation’s” has been added.

Table 6: Requirement Specification.

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce lead time</td>
<td>5</td>
<td>Requirement</td>
</tr>
<tr>
<td>Identify different deviations</td>
<td>5</td>
<td>Requirement</td>
</tr>
<tr>
<td>Minimize transportation</td>
<td>3</td>
<td>Request</td>
</tr>
<tr>
<td>Reduce test related costs</td>
<td>3</td>
<td>Request</td>
</tr>
<tr>
<td>Reduce environmental impact</td>
<td>3</td>
<td>Request</td>
</tr>
<tr>
<td>Improve flow efficiency</td>
<td>4</td>
<td>Requirement</td>
</tr>
<tr>
<td>Be located at AVOS</td>
<td>4</td>
<td>Request</td>
</tr>
<tr>
<td>Handle sound level regulation’s</td>
<td>5</td>
<td>Requirement</td>
</tr>
<tr>
<td>Handle proactive solutions</td>
<td>3</td>
<td>Request</td>
</tr>
<tr>
<td>Increase the commitment</td>
<td>3</td>
<td>Request</td>
</tr>
<tr>
<td>Adaptable due varying checklists</td>
<td>5</td>
<td>Requirement</td>
</tr>
<tr>
<td>Increase the visuality</td>
<td>4</td>
<td>Request</td>
</tr>
</tbody>
</table>
5.5 Finalized Solution

Every machine type has a specific testing protocol, i.e., checklist, with a number of test items distributed into 4 categories; visual inspection, functional check, test drive and post inspection. The specific numbers can be seen in Appendix 9. Important for the new test procedure is to handle all those items in order to fulfill the task, i.e., ensure quality assurance.

5.5.1 Process Mapping

The new after flow consists of fewer processes between line and shipment. The mine is replaced by a new test facility and the transportation is no longer necessary. The new after flow can be seen in Figure 42, which illustrates a more compact and faster flow compared to the current. A pre acceptance is still conducted at production line where the machine is either approved or rejected. If rejected the machine is readjusted before it enters pressurizing, conducted in the same way as today. If the machine completes pressurizing without heavier deviations, next step is the visual inspection. In this improved system, the tests will have to be conducted according to a compulsory checklist on a tablet, i.e., to minimize the risk of interference from the human factor. The new test facility will be more ergonomic suitable for such tests and will have better and stronger lights. The visual inspection is followed by test drive, deeper explained below. The tests will in the new system be conducted during three hours, divided into two steps, instead of two. This enables the possibility to drive and then cool down the machine before the last drive step, which will trig more deviations to occur. After the test drive the machine will be readjusted at AVOS and when all deviations are acknowledged the machine can be added to stock before shipment to customer.

![Figure 42: The improved after flow process.](image)

5.5.2 Test Equipment

The new system is based on a vehicle inspection procedure where the machine is driven and measured on rollers, inspected via an inspection pit and where equipment is fully adapted to the certain task. Due to heavy axle loads and machine weights, see Appendix 10, existing test equipment from suppliers cannot be used. Therefore, 10 manufacturers of such equipment were contacted. Due to the extreme requirements, very few manufactures were able to deliver a proper solution. The equipment, its design and functionality will be explained below.
**Inspection Pit**

In order to improve the visual inspection, i.e. find more deviations, it’s crucial with an adapted and improved inspection facility. To ensure high quality inspections two major improvements have to be considered; lights and ergonomics. With a suitable inspection pit, see Figure 43, both those two items can be achieved. The inspection pit will heavily improve the ergonomics during the visual inspections, making it easier and safer to inspect the machines from beneath. By improving the current light system (flashlight) to an adaptable one, it will become easier to find and locate deviations and their root causes. By improving those two items, the general result from the visual inspection will increase as well. More deviations will thereby be discovered already during the visual inspection instead of during test drive. The inspection pit makes it possible to collect hazardous waste, such as oils and other leakages, instead of wiping it up manually like today. The price for them varies due to equipment and therefore no manufacturers were contacted.

![Figure 43: Equipment for improved visual inspections. Source: Lucaside-Gems (2019).](image)

**Chassis Dynamometer**

These manufacturers were contacted: CFM Chiller, AIP Automotive, MTS, Powertest, Burke Porter Group, Hofmann Tesys, Mustang Advanced Engineering, Taylor Dynamometer, Continental Emitec and Durr. Of those, only Taylor Dynamometer and AIP Automotive were able to deliver a proper solution. The two companies have different solutions and which one to prioritize will not be analyzed in this project. The price for the two solutions can be seen in Appendix 11.

The chassis dynamometer (CD) from Taylor Dynamometer is based on rollers which the machines are supposed to drive upon. Furthermore, the CD will provide the opportunity to conduct brake tests and to analyze test data due to available data acquisition control systems. These data systems, such as Taylor Dynamometer’s DynPro2, offers the possibility to measure and analyze test data in a customized way. The system can thereby be adapted to Epiroc’s demands and requirements. The solution will be equipped with movable rolls, i.e. to enable different wheelbase configurations. Due to this project’s short time frame it was not possible for Taylor Dynamometer to develop the vibration solution. According to the company more time is needed to develop the desired shake possibility. The purpose of the vibration possibility is to trigger deviations related to leakages to occur. To vibrate the machines the CD’s rollers will be equipped with roll bumps in order to shake it during each test drive cycle. A typical CD from Taylor Dynamometer can be seen in Figure 44. The bumpers will shake the machine in the same way as the rough environment in the Kvarntorp mine.
The solution from AIP Automotive differs from Taylor’s. Their solution, see Figure 45, is not based on rollers. Instead the wheels on the machine are attached to axles which in turn rotates during the test procedure in order to simulate the driving procedure. This solution enables good vibration possibilities, which according to the company can be adapted to Epiroc’s heavy machines.

Bucket Test
The current bucket test, where the operator fills the bucket with gravel, will be replaced by a quality verification method where the bucket can be tested without damages. The method, an adapted drag test, will be able to verify the bucket specification as well as to deliver test data for future analysis. This method has similarities to the current drag test, however this test will use proper equipment to avoid damages. The equipment consists of two chains, with adapted shackles, and a dynamometer in between those two chains, as seen in Figure 46. The dynamometer allows the operator to analyze the drag capacity and the operator will mount the shackles on the bucket and then lift and lower the bucket in order to test the functionality. The dynamometer allows the operator to verify the lift capacity due to the machine’s ability to lift it’s corresponding weight, i.e 14 tons for a ST14.
With the improved bucket test procedure, the bucket can be verified without any damages. The test will be performed in the test facility on a specific place, due to the chains. The test operator who performs the test will, as today, sit in the cab during the lift test. In order to analyze the lift capacity a hand display in the cab will be used, which ensures the operator to see the actual lift capacity. Several manufactures and suppliers of suitable dynamometers was contacted and three suppliers delivered a price for the dynamometer, inclusive hand display. The prices stretched between 22 000 SEK up to 58 000 SEK and for shackles and chains the price was estimated to approximately 5500 SEK. More details can be seen in Appendix 11.

### 5.5.3 Improvement Results

The new after flow is a major improvement compared to the current system. Appendix 12 shows a VSM over the new system and shows significantly lower lead time through the after flow for a ST. However, these times are theoretical calculated, but based on the, for ST, previously conducted VSM. In that VSM the amount of test drive was calculated to 1.9% of the total time, i.e 2 hundredths of the total time. In the theoretical VSM, the amount of test drive increased to almost 5.7% of the total time, i.e almost 3 times better than current system. Further, the process times has decreased 17% and the total waiting time in the new system has decreased almost 89%. A significant reduction of nearly nine times. The lead time through the new system has decreased almost 75%. However, it has to be mentioned that this lead time is straight through the after flow with no problems or queues. The new after flow has increased the flow efficiency and shortened the lead times heavily.

Due to the elimination of transportation, re-painting and washing the corresponding cost, $F$ SEK, can be removed from the costs related to the after flow. The total cost for the after flow can thereby be calculated by following expression

$$X - F = ESEK.$$  \hspace{1cm} (8)

The remaining cost is thereby equal to the cost for pressurizing, test drive and readjustments in average. With a total production of $L$ machines per year (preliminary production plan,
for 2019, from February), the cost reduction can thereby be calculated through

\[ E \times L = 16224000 \text{SEK}. \]  

As the equation above shows the costs will be reduced by more than 16 000 000 SEK per year, without depreciation, with the average numbers for 2019. The costs for the after flow have been summarized for year 2018 for both the current and new system. In the current system the costs for pressurizing, test drive and readjustments (from the operation cards) have been summarized together with the standard cost for transportation, re-paint and washing. Corresponding cost for the new system was calculated as well, however the standard cost was removed this time. The reduction, with the new system compared to the numbers for 2018, gave a cost reduction of just over 16 400 000 SEK.

In the current system the costs for a ST14 can, once again, be analyzed through the operation cards. The times for pressurizing (M), test drive (N) and readjustments (O) can thereby be interpreted to a cost by the time cost 800 SEK according to the following expression,

\[(M + N + O) \times 800 = P \text{SEK},\]  

where \(P\) SEK corresponds to the cost for one ST14 except the standard costs. In addition, those costs for transportation, re-paint and washing have to be added, giving a total cost of

\[P + F = 93400 \text{SEK}.\]  

The total cost for a ST14 through the after flow can thereby be summarized to 93 400 SEK. These numbers can in turn be compared to the numbers from the theoretical VSM. The new times times for pressurizing (7h), test drive (4h) and readjustments (8h) can be calculated to a cost with the following expression

\[(7 + 4 + 8) \times 800 = 15200 \text{SEK},\]  

which thereby gives a cost of 15 200 SEK through the after flow with the new solution. The cost for the current system is in this example thereby approximately 6 times higher compared to the new. As mentioned earlier the new test facility is supposed to be located at AVOS, which enables a visual flow. The flow will be more predictable, i.e easier to follow the steps for every machine. This will be positive for every involved. With the test facility located at AVOS, the transportation time between AVOS and Kvarntorp will be eliminated, i.e from 167 hours per test operator and year to zero hours.

5.6 Short Term Improvements

The improvements described above is the best solution for AVOS on long term, however major investments are required for the implementation. For AVOS improvements are necessary, on long as well as on short term. Regarding short term perspective, the focus will be on improved work environment and smaller test improvements. For the short term improvements, the test drive will still be conducted in Kvarntorp, but with smaller adjustments. However, these short term improvements should not be seen as the final solution.
5.6.1 Work environment

In order to improve the conditions during visual inspection as well as the succeeding readjustments, some smaller improvements can be implemented. During the visual inspection, the test operators inspect the machines with only a flashlight today. In order to discover more deviations, better light conditions is crucial. Important for these lights is to lighten the machine from below, i.e. underneath the chassis. For the readjustment operators it is crucial with adequate equipment and tools in order to work more efficient. To procure an adapted and functional exhaust extraction system will improve the work environment significantly to a low cost. A more functional exhaust extraction system will also increase the ergonomic for the operators. By improving the accessibility in today’s work shop the amount of unnecessary motions will be heavily reduced, which in turn will increase the amount of value-added work within the readjustment phase. By adding a temporary inspection pit to Kvarntorp the work environment during the visual inspection would increase heavily. Probably more deviations would be discovered as well, making it natural to invest in a temporary inspection pit equipment.

5.6.2 Test improvements

Due to short term perspective, the current test procedure will be used. However, some improvements can be done with small resources. To minimize the need for re-painting, it is crucial to replace the current bucket test with the new approach described in Section 5.5.2, Test Equipment. That bucket test procedure can be implemented on both short and long term perspective. The usage of a dynamometer and chains can be implemented on short term perspective, due to the relatively low investment cost. The solution should be built near the Kvarntorp mine in order to ensure an efficient test and verification procedure.

As previously mentioned, all machines conducts the drag test today. The test is conducted in order to verify the powertrain of the machines, however it damages the machines and therefore extends the lead time. The combination of a new bucket test and removed drag test would heavily reduce the need for re-paint, which in turn would be positive for the overall lead time. The decision to remove the drag test must be based on facts and statistical data and therefore all machines between 2013 to 2018 have been investigated in order to analyze deviations related to the drag test. Table 7 shows the deviation distribution between those years, both as amount of total tested machines but also as amount of the total number of drag test deviations.

<table>
<thead>
<tr>
<th>Data type</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number per year</td>
<td>Q</td>
<td>R</td>
<td>S</td>
<td>T</td>
<td>U</td>
<td>V</td>
</tr>
<tr>
<td>Amount of total tested machines</td>
<td>1.3%</td>
<td>0.2%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.5%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Amount of drag test deviations</td>
<td>48.8%</td>
<td>7.3%</td>
<td>4.9%</td>
<td>4.9%</td>
<td>19.5%</td>
<td>14.6%</td>
</tr>
</tbody>
</table>
As the Table shows the amount of deviations related to the drag test is very low, especially after 2013. The amount of total tested machines is very low between 2014-2018 and varies between 0.1 percent up to 0.5 percent. During these six years only one machine failed the drag test completely while the biggest deviation portion is concentrated to paint damages affected by the test. The second largest category is deviations related to “outside of specification”, i.e the result deviated from the machine specification. In all cases except one the machine was too strong compared to the specification. Some deviations above is related to gearbox problems, which led to downtime. However these deviations were discovered before the drag test and hence the test was not vital in those cases. The decision to remove the drag test must be taken by managers, but the Table above clearly shows that very few deviations are discovered during the test which in turn shows the potential of removing it.

5.6.3 Work Methods

To ensure an increased quality already on short term perspective it is crucial to increase the dialogue between different categories of employees, also stated by several respondents. To improve the daily work it is crucial to learn from mistakes, i.e learn from deviations, and a well working dialogue regarding the subject is hence crucial. To increase the dialogue and reduce the barrier for communication it is necessary that the test operators can inform the assemblers how certain parts behave during test drive, i.e to increase the product knowledge.

The current test protocol should be replaced by a more modern approach, i.e a continuously updated checklist which reflects current quality issues. This list should further be on a specific test computer/tablet, i.e to ensure a standardized procedure for every test operator. Instead of photograph deviations, a tablet should replace the current actionlist. The deviations should be reported on the tablet where those could be marked on a 3D picture of the machine. By such procedure, it would be possible to generate statistical data of where a specific deviation occurs. It should also be possible to insert photos of deviations if more than a marked area on the 3D picture is desired.

The highlighted improvements above, Section 5.6, should not be seen as a final and sustainable solution in the long term perspective. Small improvements are crucial in the strive for continuous improvements. Pending the long term solution, these short term solutions should be implemented directly in order to improve both the after flow as well as the whole organization.
6 Discussion

This section holds the final discussion over this thesis project, a critical review over the results and the target fulfillment. In the beginning of this section the execution as well as validity and reliability will be discussed. Later on, the results will be discussed in terms of current problem areas (test procedure, economy and environment) and how the finalized solution differ from the current system. In the end, future research and recommendations to Epiroc will be discussed.

6.1 Project Execution

The thesis objective was to evaluate how tests, for trucks and loaders in the Kvarntorp mine, could be replaced with new test methods at AVOS. Throughout the thesis project the aim has been to investigate how to adapt the current test procedure with a more modern approach in order to shorten the lead time and reduce environmental impact as well as to increase the productivity. The project description has thereby been wide, making it possible to take several different paths during the spring. Although the wide description, the project has worked smooth and it has been possible to follow both time as well as project plan. The project has been conducted at AVOS at the department for operations development, an ideal place during the project due to several committed colleagues.

The project has been performed by one student, which has been both advantages and disadvantages. An advantage has been the possibility to plan and act on one persons behalf, making it easy and possible with quick decisions. However, it has also been disadvantages during the project. In the project’s beginning it would have been advantageous with discussions and inputs from another student. Lack of discussions and dialogue was most obvious in the beginning when everything was new and unknown. However, when the projects guidelines were set the advantages have transcend the disadvantages heavily. Furthermore, several employees have been part of the project through interviews and observations, making it possible to discuss ideas and solutions from different point of views.

6.2 Validity and Reliability

Throughout the thesis project data of different kind have been of crucial importance for the finalization. These data has been both primary and secondary, classified as both qualitative and quantitative. A lot of effort has been put on the deviation analysis, quantitative and secondary, in order to analyze the current situation and what types of deviations the new solution must be able to discover. In consultation with the supervisor from LTU, it was decided to investigate deviations from 2018. This enabled a deep analysis of one year. In order to increase the validity it would have been preferably to investigate and analyze several years instead of one. However, the drag test analysis was based on several years of data due to the importance of taking important decisions based on extensive fact. The validity in that case is thereby higher then in the other cases. The economical analysis were hard to conduct due to the lack of good reliable data. The goal was a deep analysis with high standard, however the result is of lower standard than wished. In order to perform an extensive analysis later on, it is crucial for Epiroc to identify all the missing aspects before the analysis can be performed at desired quality level. This fact, lowers the validity for the economical analysis. Further, the lead time analysis is based on manual time registration.
It is commonly known that these times are different from reality, which of course affects the validity badly. Also, data is hidden in this thesis due to confidentiality. This was necessary due to regulations at Epiroc, but does indeed lower the validity.

The interviews have been based on a semi-structured approach making the data primary and qualitative. All the answers have thereby been interpreted by the author in order to find similarities and differences between the respondents. In order to increase the validity of the interviews it has been a well working dialogue between every respondent and their answers. In total four interviews have been performed during the thesis project. However, due to the time that elapsed between the first and last interview the knowledge was higher in the end compared to the beginning. The knowledge has thereby fluctuated during the interview process. This might have affected the performance during the interviews and thereby the analysis afterwards. Every respondent have been chosen by the author, which decreases the risk for biases which could have occurred if someone else selected the respondents. The goal was to interview different positions and backgrounds, all affected by the current system. The majority of the respondents are managers and only one respondent is from worker level. To increase the validity it would have been preferably with more respondents among the workers.

Observations have been an important tool during the project. Observations have been used both internally at Epiroc, but also during the study visits. However, every observed person knew they were being watched which might have influenced their work performance. If someone knows they are being observed they will probably improve their performance. Although this affects the validity badly, it should be mentioned that these observations have been conducted during the whole spring. This has enabled a good relationship with several observed persons, which probably has led to a sustainable attitude regarding the observations. This in turn has probably minimized the risk for influenced work performance.

An important aspect during the whole thesis project has been transparency. As mentioned earlier, transparency can increase the reliability. The used methodology is well documented
explained in the thesis, making it easy to analyze how every phase has been conducted. Further all analysis are explained how they have been performed, which thereby increases the reliability for the project. However, due to the projects objective some ideas have not been canalized to every stakeholder. By hiding some information the goal was to get clear and honest answers during the interviews. Honest answers were considered more important than clear transparency throughout every phase during the thesis project.

6.3 3C and TSA

As mentioned in Section 4.6.7 three problem areas were identified in the current system. The improvements and the new solution will be discussed in terms of those three areas below.

6.3.1 Test Procedure

The current test procedure is linked to problems as extensive and time consuming tests, bad quality from production line and lack of questioning of current regulations. As mentioned in Section 5.1.5, 3C and TSA can be combined for a deeper analysis due to the fact that the content in TSA all lay under TP in 3C.
Test Team
With the new solution the same test team as today will be used. However they will operate in another way compared to today due to the new test processes. With the new solution it will be necessary to educate every test operator to all the new standards and procedures implemented with the new solution.

Testware
Testware contains the documentation and the test tools to be able to perform the tests. The testware enables collection of data which can be analyzed later on. Due to the new possibilities with test computer/tablet the documentation will be heavily improved. With frequently updated test protocols and checklists, due to varying quality issues, the overall standard regarding documentation will increase. These digital lists makes it possible to analyze data better than today. Furthermore, when it is possible to map the deviations directly on the tablet the location on every deviation will be logged which in turn makes it easier to work proactive instead of reactive with deviation issues. This will increase the amount of data for Epiroc, an important aspect to find root causes which in turn makes it possible to reduce the number of deviations. With better documentation the test operators won’t lack information as they to today, which will make their work more efficient and smooth. With proper tools, such as improved lights, the testware will reach a new standard compared to the current level.

Test Processes
With the new solution the processes, i.e how to conduct the tests, have changed significantly. The biggest change is the reduction of several steps in the process flow compared to current process map. This enables an efficient and fast flow, with updated test processes. As today, the test still begins with visual inspection. However, due to the test computer/tablet the process will be structured according to a compulsory checklist. Hence, all test operators will have to start with the visual inspection, an important aspect in the strive for standardization. The tablet will enable a standardized approach during the visual inspection, which is important to reduce the interference from human factor. This thereby minimizes the risk of forgetting items, which in turn probably lower the amount of deviations discovered during the test drive instead of visual inspection. With the inspection pit the work environment beneath the machines will increase, which most likely enables better inspection of those areas. With increased work environment as well as better light conditions beneath the machines, more deviations will probably be discovered beneath the machines. With the new test drive solution, it will be possible to measure the performance of each machine, making it possible to analyze them deeply. The test drive itself might have to be adapted to the equipment. In order to adapt successfully both production engineers, quality technicians and test operators should contribute with their own perspective in the development phase. With such different perspective it will be possible to combine them all in the best way. With the new solution (and thereby shorter lead time) it will be possible to conduct the test drive in two episodes; the first half, cool down time and then the second half. With the cooling pause, it will be possible to trig more deviations to appear. The shorter lead time makes this possible due to more available time for each machine. However, the new test drive process should not be a fix system. It is important with continues improvements and adaptions in order to become better and more productive.
Test Environment

Test environment is the biggest change compared to the current system, at least when it comes to hardware. The mine is replaced with the new test facility, making it possible to implement the described solution. By the removal of the drag test the need for the mine has been eliminated. For quality assurance such as the processes in the after flow, the new test environment will be a significant improvement. The rollers used for the test drive enables a drive with and without vibrations, which probably will provoke deviations to appear during the quality assurance instead of at the customer. The new bucket test eliminates the need for re-paint, making the whole flow for ST machines more efficient.

6.3.2 Economy

As Section 4.6.7 showed, current issues related to economy were mostly due to the transports to and from Kvarntorp, the damages and the external companies. The transports are now eliminated, making the costs related to them eliminated as well. With the reduction of transportation damages as well as test drive damages the costs related to product damages have decreased heavily. With the new solution the machines won’t be damaged during the test drive, making the whole handling more cost efficient. The transportation time for every test operator corresponds to approximately 167 hours every year. By locating the test facility at AVOS this transportation time will be reduced to zero hours per year. The extrication of those hours should be used to further develop the flow, i.e continuous improvements. The reduced lead time affects the economy positive as well. Shorter lead time is good for both customers and Epiroc, making the time between pick start and payment shorter than today. The annual saving, around 16 000 000 SEK without depreciation, clearly shows the potential when it comes to economical savings on long term. As Appendix 11 showed, the cost for a chassis dynamometer system is relatively low, especially if you compare it to the annual savings. However, depending on the solution the dynamometers have different investment costs. Furthermore, the cost for a new bucket test is also low. The only costs that has not been taken in consideration is the costs for the inspection pit and the building, i.e the costs for the test facility building. Those costs have not been analyzed due to outside of project scope. The cost for the inspection pit is directly linked to it’s equipment, which makes it necessary to decide all equipment before the cost can be analyzed. The combination of relatively short pay back time (depends on chosen dynamometer type), combined with high saving is a good combination for Epiroc. However, the costs related to reparations and readjustments have not been reduced within this solution. However, a discussion regarding those issues can be read in Section 6.4.

6.3.3 Environment

With the current setup the environment is mostly affected by the pollution from the heavy transports between AVOS and Kvarntorp. These heavy transports have been eliminated with the new solution, a positive improvement for the environment. Heavy trucks also affects the roads between AVOS and Kvarntorp, but also the nearby citizens. The reduction of the heavy transports is thereby positive from a civil perspective as well. Product damages affects the environment badly with the current system due to the need for extra processing as well as the usage of unnecessary paint. The new solution decreases the product damages and has eliminated the need for paint, positive effects for the environment.
6.4 General Implementation

In operations development, awareness of the need to change is fundamental to succeed. This improvement affects several positions at URE, which has to been considered before the implementation. This improvement must be based on a long term perspective to reach it’s full potential, which Bergman and Klefsjö (2012) highlights as crucial during big changes. Common reasons for change initiatives to fail are according to Stanleigh (2008) not engaging all employees, managing change at management level, sending employees to short programs and not giving time to adapt. Both ADKAR and Kotter’s 8 steps highlights the importance of awareness to maintain committed and motivated employees. Kotter’s 8 steps focuses on three areas during a change; ”Climate for change”, ”Engaging the organization” and finally ”Implementation”.

Climate for Change

To convert a change into an improvement the company’s climate and culture is crucial. First of all, management has to prepare the employees for continuous improvements due to a world in constant change. If everyone is prepared for changes, the changes will be implemented easier throughout the organization. According to the interview respondents, the principle of right from me is only possible with the right culture. This clearly shows the importance of culture and it’s magnitude. None of the respondents seems to be pleased with the current culture. In order to reach a culture where right from me is followed and where changes are accepted and expected, the first task for management should be to improve the company culture. According to me company culture can be interpreted to company language, making it crucial with a shared and accepted belief. I believe the culture would increase with a better understanding. If everyone was building for their next customer the final quality in the end would heavily increase for the buyer. By focusing on everyone’s next customer, I believe the understanding would increase which in turn would affect the culture positively. By increasing the dialogue between different positions I believe the product knowledge would increase, which in turn would generate more committed and engaged employees.

Engaging the Organization

To engage the organization, support from management is essential. According to the theoretical framework for this master thesis, everything starts with a supportive and committed leadership. Management must be clear they believe in the changes in order to spread their belief. To engage the employees in the change program (and this improvement) education in the new solution is crucial. However, I believe it’s important with a combination of education and the possibility to adapt afterwards. The educations must be seen in a long term perspective, and management cannot presume everyone will accept the change program directly afterwards. A deep understanding from the management that a big change like this will take time, will in turn generate more engaged employees if everyone believes they are seen and heard and feel their work is meaningful for the company. Everyone must be prepared how the changes will affect them, their work and how it will affect the company on long term. A deep understanding why this change is necessary allows for a better understating and thus the commitment will increase with good dialogue and communication.
Implementation
I believe the implementation should be executed when the tasks above are fulfilled, i.e. the right climate is achieved and the employees are all engaged. Only when the prerequisites are right, the change will be implemented in a successful way. I believe the implementation phase is both the easiest and the hardest one. It’s the only of these three phases with a direct output, however it’s the hardest to decide when to start it to reach a successful and desired end. By being cautious the solution described in this master thesis can be implemented successfully, making the after flow more productive and efficient.

6.5 Future Research

Future research projects should focus on mapping the economical reality for the machines manufactured at AVOS. The current available data is mostly based on manual time registration, i.e. deviations from reality is probably common. Conclusions should be based on real facts and not estimated times, as in this project. Due to time constraints it was not possible to map every phase in the after flow for more than two machines, but in order to map the current state in a more detailed way further data is essential. When more data has been gathered the economy can be analyzed in a better way than through the operation cards. These cards are only estimated times, but an economical analysis should be based on actual numbers. The first intention during this master thesis was to analyze the economy through invoices from previous years. However, it was not possible to sort these from different categories, such as ST and MT. Due to the lack of sorting possibilities, the invoice strategy was not possible in this master thesis. However, with more available time another attempt should be considered due to the possibility to map the actual costs from previous years.

In order to implement this solution free space at AVOS must be available. Future research should therefore focus on where to implement the result from this thesis project. It is probably possible to locate it on AVOS if the whole area is deeply analyzed. Some functions can probably move, be relocated or removed in order to create free spaces. When enough area is free, the result described in this thesis can be implemented. By locating the test facility at AVOS the rental work shop in Kvarntorp will be unnecessary, i.e. the activities there will move to AVOS. This will in turn increase the need for free space at AVOS, making it even more important to investigate this.

Future research should investigate chassis dynamometers in a deeper way than what was possible in this thesis project. To reach good test result, i.e find the deviations, the chassis dynamometer has a key role. In order to reach the potential of the whole solution it will be necessary with a vibration/shake possibility. Due to this project’s short time frame it was not possible for one manufacturer to develop this vibration possibility. Future research should therefore focus on the vibration capability to find the best solution for Epiroc’s machines. It is also important to further investigate more solutions from more manufacturers. Due to this project’s short time frame it was not possible to look into every alternative, but more time will make it possible.
6.6 Recommendations

The recommendations for Epiroc is divided into both short and long term recommendations. The partition is crucial due to different focus areas depending on short or long term.

6.6.1 Short Term

These short term recommendations should be implemented quickly in order to improve the afterflow. They should be implemented despite the fact that the general goal is to build the test facility described in the previous chapter.

- **Increase the dialogue between assemblers and test operators.**
  
  In order to learn from mistakes and in the end becoming a learning organization the dialogue between assemblers and test operators must increase heavily. The commitment at AVOS exists, but Epiroc is responsible to use it in the right way, i.e. to make sure the test operators can inform the assemblers how and why certain deviations occur during test drive and not PA.

- **Improve work environment.**
  
  It is hard to discover deviations in inadequate work environment. To visualize all deviations the current light system must be improved, both at AVOS and Kvarntorp. The light solution in Kvarntorp can, with small adjustments, later be placed in the test facility. A real exhaust extraction system should be mounted in Kvarntorp, which in turn would increase the value adding work. Making the afterflow more productive. An inspection pit would heavily improve the work environment for the test operators compared to today. Epiroc should therefore decide where to build the inspection pit, a temporary in Kvarntorp or a final one at AVOS. If Kvarntorp the focus should be temporary, i.e good but not adapted for future inspections. If AVOS, then the focus should be future. By adapting it for the future test facility, all equipment for it could be acquired with the future solution in mind. This would probably end up with a better, more durable and more long lasting solution compared to the one in Kvarntorp.

- **Replace the current test protocol with a digital format.**
  
  By replacing the current test protocol with a test computer or tablet it will be easier to update the number of test items due to existing quality level. By using a digital solution it would be possible to mark deviations on the tablet, making it possible to map the position on all deviations. When data regarding positions is gathered it will be possible to find root causes and thereby work proactive instead of reactive.

- **Remove the drag test.**
  
  As showed, the deviations related to this test is almost none. By removing it, the foundation for the new test facility is laid. However the decision to remove the drag test must be taken by top management. To dare removing it, it is crucial to look at the broader picture for the afterflow. It is important to question current system, which is a result of old decisions, to reach sustainable long term improvements.

- **Replace the current bucket test with the new solution.**
  
  By removing the current bucket test, the need for re-paint would heavily decrease. The standard cost could thereby be updated due to lower amount of paint costs. However some machines will although need to be re-painted due to the test procedure,
but to lower that amount will be positively. To evaluate the bucket function in an optimized way the new bucket test should be implemented.

### 6.6.2 Long Term

The recommendations below should be implemented and considered on a long term perspective. They will improve the after flow significantly, making it more productive and competitive. However, due to some time consuming and expensive activities they should be implemented successively.

- **Invest in the new test facility.**
  In order to reach the potential described in Section 5.5.3, Improvement Results, Epiroc has to invest and implement it. The investment cost is according to Appendix 11 relatively low despite it’s complexity and high requirements. The annual savings is calculated to just over 16 000 000 SEK which shows great potential for such investment. The pay back time is thereby relatively short (depending on what solution to be chosen), making the investment interesting on both short and long term perspective.

- **Implement a quality team.**
  To reduce the number of deviations a quality team, responsible for the machines quality, should be implemented. With a dedicated quality team the inspections during assembly would heavily increase, making it possible to identify more deviations earlier in the process. The team could thereby be Epiroc’s answer to Komatsu’s inline checkers, making it possible to control hydraulic tubes among others. Higher quality is the only way to reduce the number of deviations, which in turn will be the most important factor to reduce the time for readjustments and thereby reduce the cost for the after flow.

- **Improve the data supply.**
  In order to evaluate and improve the production flow on continuous basis, the data supply has to be improved and increased. Management has to implement better measuring tools in order to find deviations earlier in the manufacturing process.

- **Improve the culture.**
  The only solution to reduce the need for readjustments is to reduce the number of deviations. To reach such stage it is important to build correctly at once, i.e right from me. Therefore, the focus on long term should always be to work proactive with the company culture in order to improve it continuously. By reducing the need for readjustments the lead time will decrease as well, making the whole after flow more productive in terms of both lead time and economy.
7 Conclusion

This section, the last one, holds the conclusions for the project and thereby summarizes the whole master thesis project in one way. In the beginning the section is based on the research questions introduced in Section 1.3, Objectives, followed by the projects fulfillment.

7.1 Research Questions

The thesis project’s five research questions will be answered below.

1. **How are tests regarding trucks and loaders conducted today and are they all necessary?**
   The tests today are divided into two parts; visual inspection and test drive. Both parts are conducted in Kvarntorp, approximately 20 kilometers from AVOS. The approach is different between different test operators. Some conducts the visual inspection before the test drive (and another afterwards) while some conducts the whole inspection afterwards. The visual inspection is performed in the work shop in Kvarntorp with both inadequate light and ergonomic conditions. The test drive is then performed either in the Kvarntorp mine or at the nearby test track. During the winter all tests are performed in the mine, while the test drives during summer, spring and fall are conducted above ground level. However the drag test is always conducted in the mine. For ST machines a bucket test, where the machines lifts gravel, is also performed.

   According to deviation reports between 2013 to 2018 only one machine has failed the drag test. The reports clearly shows that the most common deviations are related to paint damages due to the drag test procedure. This shows that the drag test affects the machines negatively and doesn’t help to identify deviations due to the fact that almost no deviations seems to occur. The drag test thereby seems to be irrelevant for the quality assurance.

2. **How can the tests be adapted and developed for the future?**
   In order to improve the current test procedure it is necessary to leave Kvarntorp. By replacing the tests in the mine with a new solution the need for transportations, re-paint and washing will disappear which will be positive for the machines, the environment and the economy for both customers and Epiroc.

   Crucial will be to adapt the test procedure so the tests can be conducted on other places than Kvarntorp. The mining environment in Kvarntorp must be replaced by an optimized test facility with required equipment for both inspection and test drive. Today visual inspection is conducted in an inadequate work shop with both bad light- and ergonomic conditions. With an inspection pit and improved light conditions the current system can be adapted and improved in a sustainable way. The test drive should be performed on rollers in the new test facility with vibration possibility in order to trig deviations related to leakages to occur.

3. **What methods are available for these types of machines?**
   Heavy machines such as Epiroc’s Scooptrams and Minetrucks requires special developed equipment to handle those loads. In the new test facility focus is productivity and efficiency, which in turn requires adapted and specialized equipment. In this case
Epiroc should imitate a vehicle inspection facility. For an improved visual inspection Epiroc should focus on an inspection pit with good light conditions. The equipment for the test drive has to be adapted and developed according to the properties for each machine type. This requires a deep dialogue with the suitable manufactures in order to develop the best possible solution.

4. **How can new methods be implemented at Epiroc Rock Drills AB?**
   Epiroc has three focus areas regarding the implementation process; to create a climate for change, engage the organization and finally implement the new solution. The first two areas are important in order to create the best possibilities for a successful implementation.

5. **How will the improvements affect Epiroc?**
   The improvements, both visual inspection and adapted test drive procedure, will heavily improve the after flow. The lead time through the after flow will decrease from the current 12 days in average to approximately 2 days as calculated in the theoretical VSM, i.e a 6 times improvement. The positive effects can be seen in economical terms as well. With the new solution the costs for transportation, re-painting and washing have been eliminated which in turn improves the economical output for the after flow. With the production volume for 2019 (from February), this would mean a cost reduction of approximately 16 200 000 SEK every year without depreciation.

   The benefits from the new solution can thereby be measured in terms of both lead time and economy, although those two are connected to each other. The benefits from the new after flow will heavily improve Epiroc URE as a company in terms of productivity, environment and lead time. Those three are important to reach the brand promise of:

   "United in performance. Inspired by innovation” (Epiroc 2019f)

### 7.2 Target Fulfillment

The objective for this thesis project was to, through a feasibility study, evaluate how tests for trucks and loaders in the mine can be minimized and for the future also be removed for certain types of machines. This was achieved by a new developed test procedure, based on flow efficiency. The aim for the project was to investigate how the test methods could be adapted in order to shorten the lead times and make the handling of finished mining machines more efficient. All the requirements for the project, see project specification, has been reached. By the new solution the aim for the project is fulfilled, due to shorter lead times as well as a more efficient handling of the machines. The project is thus considered to have fulfilled it’s goal.
References


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Paramanathan, Subashini et al. (2004). “Implementing industrial sustainability: the research issues in technology management”. In: *R&D Management* 34.5, pp. 527–537.


Appendices
Gantt chart for the project.
1. What's your opinion about quality assurance during and after production line?

2. What measures do you believe are the most important aspects regarding quality assurance?

3. How do you think the deviation handling from the test works today? What do you miss?

4. If you were allowed to influence freely, how would you organize the handling of deviations?

5. How do you experience the feedback from customers regarding quality to be?

6. How do you experience the quality of the machines to be?

7. How do you believe the current quality assurance of finished machines to be? Strengths? Limitations? Wishes?

8. Can you give an example of when the tests worked both well and badly?

9. Are all steps needed in today's quality assurance? Something missing? Are the methods frequently updated?

10. How was the methodology and approach initiated?

11. Are the tests continuously changed and developed?

12. How can the processes be more efficient?

13. How would you like to optimize the after flow?

14. How much do you think the lead time is extended due all processes in the after flow? Is there any problem with the extension?

15. What costs do think are associated to the processes in the after flow?

16. Do you believe the quality and production departments look differently on the tests?

17. How well do we identify root causes for leakages?

18. What's your opinion of tighten screws before test drive to prevent leakages?

19. What deviations are most difficult to detect during the test?

20. Why do you believe we discover the deviations we actually do?
<table>
<thead>
<tr>
<th>Position</th>
<th>Why Quality tests?</th>
<th>Strengths current procedure</th>
<th>Weaknesses current procedure</th>
<th>Flow Improvements</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager Production Quality</td>
<td>Better to identify deviations during tests than deliver machines with issues.</td>
<td>Standardized test procedure with checklists.</td>
<td>Inadequate lists, transportation damages, tests before tests.</td>
<td>Right from me would decrease the deviations and improve the lead time.</td>
<td>right from me, culture, learning from mistakes, wastes</td>
</tr>
<tr>
<td>Quality Technician</td>
<td>The unstable quality requires tests to assure desired quality.</td>
<td>Standardized functional tests with checklists.</td>
<td>Too short test time, outdated basis for some machines, hard to identify root causes, tests before tests.</td>
<td>Right from me would improve the quality and thereby the lead time. Functional tests still needed.</td>
<td>right from me, culture, learning organization, root causes, inadequate basis</td>
</tr>
<tr>
<td>Manager Production</td>
<td>They exist in order to analyze the machines as a guarantee towards the customers.</td>
<td>Quality focused test methods where all critical functions are tested and analyzed.</td>
<td>Quality tests are always a waste and current test procedure contains unnecessary steps.</td>
<td>Just a short verification. Eliminate transportation, washing and re-paint.</td>
<td>culture, product knowledge, wastes, KPI, innovation</td>
</tr>
<tr>
<td>Test Operator</td>
<td>Tests are necessary in order to guarantee the quality towards the customer.</td>
<td>Visual inspection as well as functional tests makes it possible to identify a wide range of errors and deviations.</td>
<td>Lack of information in the mine and differences between seasons.</td>
<td>Necessary to reduce the number of processes in order to improve the flow. Also important with a pull flow system.</td>
<td>product knowledge, checklists, information, learning organization</td>
</tr>
</tbody>
</table>
External Interviews

February 20th 2019

Date: 
Company: 
Operation: 
Location: 
Record?

1. What’s your opinion about quality assurance during and after production line?
2. Which measures do you believe are the most important aspects regarding quality assurance?
3. How do you handle detected deviations? (logging, handling, improvement)
4. Do you experience complaints from customers regarding quality issues?
5. Have customers ever complained about deviations they considered you should have discovered?
6. How do you perform quality assurance of finished products at present? Describe the process from line to delivery. Who are involved?
7. Are all machines tested in the same way or are some tested in random tests?
8. What is the strength or weakness / limitation?
9. Are all the current steps in the quality assurance required?
10. How was the methodology and approach initiated?
11. Are the tests continuously change and developed?
12. How can the processes be more efficient?
13. How much do you think the lead time is extended due to the quality assurance?
14. What costs are associated with the quality tests? If so, how much of the production cost?
15. Do you believe the quality and production departments have different perspective on the quality tests? If so, how is this handled?
16. Are the quality assurance standardized? If so, how important is it to follow the standards?

Appendix p. 7
Volvo Construction Equipment

Arvika

February 20th 2019

Volvo CE in Arvika is Volvo’s main production facility for wheel loaders. They produce approximately 4000 units per year and delivers all over the world. In Arvika Volvo has nearly 1000 employees in various positions, although most of them are connected to the production. The production in Arvika is build upon Lean principles and based on a specific takt time which is applied on every station, from the very beginning at line until the end at the last control before shipment. During morning of the study visit a team leader for the quality group (QG) was followed, henceforth called respondent A. During the afternoon a team leader for the after flow was followed, called respondent B.

1 Process Flow

The flow at VCE Arvika is based on proactive quality controls (QC) during manufacturing. The purpose of those is to identify deviations on an early stage of the process, which enables an efficient and fast way to correct them. After the production line the wheel loaders reaches “the box” where a visual inspection takes place before the loader is ready for test drive and the last steps before shipment. Figure 1 illustrates the process between end of production line and shipment. Due takt time is used, the time for every step in the Figure is time based according to current regulations regarding takt. The first step after production line is the test drive, which will be further explained below. Next up after test drive is pressure setting, where the different pressures in the machine are analyzed and measured. If necessary, oil can be refilled during this step as well. The pressure setting also works as a buffer for the next stage, test drive inside. During this step the machines are visual inspected and analyzed further, especially deviations regarding leakages and hydraulic system. Depending on the test result the machine might be ready for re-check, but sometimes service is necessary due heavier deviations. Deviations are divided to A (discovered at line) and B (discovered during test drive). The service stage is divided into four different scenarios depending on the issue; weld, electricity, corrections and re-check. The machine is then transported to different locations to be corrected. Takt time is not used during these four scenarios. At the correction stage heavier general deviations are fixed, while re-check handles smaller deviations. After this stage the machine enter the normal flow and the last step in the after flow, touch-up. In the beginning of the catch-up the machine is washed in the washing machine. Then identified flaws and paint damages are corrected and the final touch before shipment takes place. Volvo’s quality goal is 96% correct machines, i.e straight flow with no need for corrections.
2 Proactive Quality Assurance

For VCE Arvika quality and quality assurance is essential and since 2015 the QG is part of the quality department. Before 2015 the group was smaller and part of the production department. According to respondent A the new arrangement improved the quality because it highlighted the importance of continuous quality improvements. Furthermore it gave the QG more resources and possibilities to work proactive instead of reactive. The production line is divided in two separate lines, one for medium and one for large machines. Medium line has one QC which is manned by one controller from the QG. Large line have 3 QC’s, which is all manned by controllers from QG. All controllers have checklists which is divided into 4 parts; general check, critical equipment, QCP and information. QCP varies from time to time and highlights deviations discovered recently and the list is updated frequently. The information field is a way to highlight specific information related to deviations and quality. Common for all QC’s is that they all share the station with the assemblers, which according to respondent A sometimes can be problematically and crowded. Due takt time, respondent A states that it sometimes can be lack of time for the controllers. If they haven’t gone through the checklist on time, they leave the remaining content for the next QC. According to A, the checklists are crucial for the reduction of deviations during the last years. The list has standardized the quality inspections and is the key for the improvements. Due QCP the list is never finished, instead it is a living document which develops according to current conditions. All discovered deviations gets a code (i.e reason, owner, position) which helps to analyze them through statistics. According to A the statistical data helps to identify, analyze and continuously improve the quality in an proactive way. Due the statistics it is possible to divide all discovered deviations to work stations and even work teams which A highlights as the key to become a learning organization. The improved quality is a result of hard work with the culture according to A. Everyone knows how important quality is and the general goals have been divided to specific goals for the work stations which has helped to see the progress and ongoing improvements. Although some people skip parts of the the standardized work instructions, A highlights them as the key to the huge steps during the last years. To reach the right culture is hard, but an ongoing journey according to A.

Appendix p. 9
3 Test Drive

As mentioned above the test drive procedure consists of two parts, outside and inside. The biggest part is outside where the machine’s general behaviour and functionality are tested. VCE Arvika has a test track where all machines are tested in the exact same way. Since a couple of years every the test operators have own test computers with a compulsory checklist. The checklist consist of every step in the test procedure and the computer logs the data to ensure that the test are conducted in the right way. According to respondent B the computer minimizes the human factor due the operator doesn’t have to interpret every expression as before. The checklist is continuously updated due new regulations and is seen as a ongoing collaboration between both machine design and after flow department. The machine design department decides what to test, but the test methods are standardized together by the two departments. To remove test items from the checklist statistical data are used. VCE Arvika has significant reduced the amount of time for the test drive and respondent B states that is due the reduction of test items. The test track is located close to the production and it is thereby no particular transportation between line and test field.

To reach working temperature (at least 70°C) the test operator drives 10 laps at the test track, which is the first step of the test procedure. According to respondent B the most important test is the transmission test. The transmission is quality tested before VCE Arvika receives it, but B highlights the importance of testing the whole powertrain together. Another important test, to ensure a secure machine, is the parking brake. The brake is tested on two ways on different gears to ensure full functionality. Machine specific buckets are used to test and evaluate the bucket performance. The bucket is mounted on the machine and then lifted to the highest point. The test operator then controls the weight and repeats the test two times more. If the weight is similar during the three tests the bucket function is approved. The hydraulic system is cleaned during the test drive to ensure that leakages and deviations relating to the hydraulic system is identified. During the test the machine are turned off for cooling. After the temperature has lowered enough the test operator continuous the test. The pause is to trig leakages to appear when the test is continued. The time for the test drive outside is approximately 6.5 times longer than the takt time at line, which gives around 4 hours for test drive due current regulations and test items. During the test drive inside the focus is on visual control and to identify deviations regarding leakages and hydraulic system. The time for inside test drive is approximately 3 times the takt time at line.

4 Differences and Similarities to Epiroc

At VCE Arvika the proactive quality work is a vital part of the daily work. Every machine is deeply analyzed and the deviations are interpreted to measurable aspects. To become a learning organization feedback is used to return deviations to it’s owner, i.e working station. The proactive quality assurance has helped to minimize the amount of leakages. The controllers at the QC around the line have a big chance to identify deviations early which could have led to leakages later on. Both respondent A and B highlights the QC as an important factor for the heavily reduction of leakages. Furthermore, standardized work with continuously updated checklists has significantly improved the general quality according to both A and B. When it comes to proactive quality work VCE Arvika has come further than ERD. Deviations at VCE Arvika are discovered earlier in the process

Appendix p. 10
which makes it easier, cheaper and more efficient to correct them compared to ERD. At VCE Arvika every machine in the after flow are visualized at a whiteboard, i.e flow board. The purpose is to illustrate where the test operators are working, next step in the process and the current position for every machine. At the board recurrent quality deviations can be highlighted, which makes it easy to identify the current state for the after flow. Respondent B highlighted the importance of the flow board which enabled a more easy way to highlight recurrent quality deviations and remaining steps for a specific machine before shipment compared to the flow system at the computer.

Both ERD and VCE Arvika uses test drive in field as quality assurance method. For VCE Arvika this is not the same problem as it is for ERD. Transportation is not needed and washing are done in-house, which makes it easier to control the production flow. VCE Arvika’s production is based on takt time and the after flow is based on this takt time. Further, the process is developed for high volumes (nearly 10 times more than the MH machines at ERD) which makes it crucial with flow efficiency and optimized process steps. VCE Arvika cannot allow machines to wait, it is to costly for them with their short lead times. VCE Arvika estimates their afterflow processes extends the average lead time from 6 to 7 seven days.
Komatsu Forest

Umeå

March 28th 2019

Komatsu Forest has approximately 1700 employees worldwide and is considered to be one of the world's largest manufacturers of forest machines. Umeå, with about 500 employees, is the company's main production facility where approximately 800 machines are manufactured every year. With the Japanese owner Komatsu Ltd, since 2004, the productivity, product development as well as the quality increased and the production is today based on Lean thinking. The study visit was conducted with a quality technician, henceforth called respondent D, from the production quality group, but several different positions within the quality department were met.

1 Process Flow

The production at Komatsu Forest Umeå (KFU) is based on two production lines, one for forwarders and one for harvesters. During the whole manufacturing phase proactive quality assurance is a vital part of the work. The flow can be seen in Figure 1. After the line the machines enter the start-up phase where oil and media are filled, still in two separate flows. Next up is the test drive, further explained later, where the two flows are combined into one. During the test drive the machines are tested in two steps, test drive one respectively test drive two. Between those steps the machines are cooled down. At KFU deviations discovered within the production facility are classified as 0h (zero hours) and deviations reported by customers as 100h (100 hours). If a machine passes the test drive without critical deviations (longer readjustment time than 1 hour) the next step is wash and paint. The machines are always washed and some re-painted due small damages occurred during manufacturing or test drive. KFU has an own paint shop as well as an own machine wash. The machines are then driven to the final inspection, FI, where everything is gone through (both regarding technical aspects but also documentation) by inspectors. After the FI everything has to be approved, otherwise the machine is driven back for test and readjustments. When both machine and it’s documentation are approved the machine is approved for shipment. In the after flow several functions are involved, i.e. test operators, readjustment operators, wash- and painters as well as final inspectors. The steps in the after flow at KFU is located close to each other. The longest transportation is between washing and FI, a distance of about 300 meters. This enables an efficient handling if the machine has to be readjusted after the final inspection. The waiting field before shipment is located close to the FI, so the transportations does not extend the lead time substantially. The lead time is 11 days in general according to D (from pick start until shipment).
2 Proactive Quality Assurance

Quality has been crucial for KFU for a long time, however the focus increased with Komatsu as owner according to respondent D who further states quality is more prioritized than output. The quality focus starts already with incoming material. Every new supplier has to prove their ability regarding quality and delivery precision due the JIT production system. Every reported deviation is investigated in order to find the root cause, i.e incoming material or wrong methods. If a deviation is material related, the product will be flagged which requires the quality department to inspect the next three product batches from that supplier. KFU also requires solutions from the supplier, both on short and long term. When the following three batches have approved and KFU is pleased with the solutions the flag is removed. According to D, spot checks are used to inspect material. The products are scanned and compared to a 3D plot to find deviations to small for the human eye. Respondent D highlights the importance of a good dialogue and states it is important to learn from each other. During the manufacturing phase KFU has inline checkers (IC) who are supposed to inspect the machines in order to verify that standards have been followed. For example the screws are inspected so that the right torque has been used. For every deviation a PDCA report (plan, do, control, act) is written where the root cause, affects and responsible department are highlighted. Respondent D states it is important to encourage everyone to report deviations and highlights the importance of an open mindset so no one will feel supervised or accused. Frequent deviations are merged to the 0h list (deviations discovered within the production) and KFU has specific technicians only working with those in order to investigate and find preventive solutions. Deviations appeared during a new machines first 100 hours are collected into the 100h list. The 100h list is an important tool for IC who uses the list to verify machines on the line doesn’t suffer from those. Specific deviations are followed up until a preventive solutions has been implemented. According to both respondent D and a IC, the list is a living document for proactive solutions. Furthermore, quality technicians (QT) supports the line with quality issues. If a deviation is discovered, the assemblers contacts the QT who then tries to find both short and long term solutions with responsible departments. Respondent D states it is important to learn from mistakes and highlights the importance of feedback. When IC was implemented, the resistance from the older employees was massive according to D. The solution according to D, was the result. When the employees saw the improvements, the group was accepted and the whole organization has a more mature relationship to quality today according to D. KFU used to have problems with leakages, but the proactive quality work has improved the output and the machines does not suffer from leakages in the same way.
3 Test Drive

The test drive at KFU is divided into two steps, both three hours each. The test operators have an own test computer with a protocol consisting of both fix test items as well as temporary, due the current items on the 100h list. The procedure starts with a visual inspection where the outer condition is inspected. The machine is then driven for about three hours and the items on the test computer are gone through and analyzed. The test drive is conducted close to the work shop for readjustments, which enables quick solutions if problems occur. After three hours the operator leaves the machine to cool down, which according to D trig deviations related to leakages to appear. If problems occurs during the first test drive they are readjusted during the waiting period which according to D shortens the lead time. After three hours the test is continued, but by another operator. This reduces the risk for the operators to miss deviations and problems according to D. During both test one and two, it is important for the machine to reach it’s working temperature. Furthermore, timber is used to test the crane and it’s head. The test setup can be seen in Figure 2.

![Figure 2: The test field at Komatsu Forest Umeå.](image)

The test protocol is frequently updated which D highlights as a key to reduce the deviations. The test computer requires the test operators to follow a standardized procedure, and D highlights standardization as the best procedure to reduce the amount of deviations. To use different test operators for test one and two is according to both D and asked test operators a strength with the current system. The risk of missing deviations and problems due the human factor decreases heavily according to D. The manager for the test drive admits a brake test should be conducted in order to guarantee every safety aspect, but today’s test field doesn’t have the opportunity.

4 Differences and Similarities to Epiroc

KFU started their journey towards a combination of productivity and high quality many years ago and have come far. According to D it takes long time to create the right culture where quality is prioritized and standards are followed. The proactive work has been an important way to reduce the number of deviations throughout the years, which according to D only can be successful if the employees have the right mindset. To become a learning organization feedback is used to return deviations to responsible employee. According to
managers at KFU it is important to see deviations as a way for improvements, i.e to learn from mistakes. However, to create that sort of open climate takes time and KFU has been working on the culture for many years now. The climate regarding deviations is more open at KFU compared to ERD. KFU measure deviations in order to see the development curve and D highlights available data as crucial to see the progress which in turn can be used to boost the whole organization. The available data has been crucial for KFU and they are always trying to find new ways and methods to measure the business operations. ERD suffer from lack of good data, which is a frequent problem in several different cases and KFU has therefore come longer. The access to IC has improved the proactive quality work significant and the work is conducted in a more proactive way compared to ERD. The continuously updated checklists (new items due the 100h list) is crucial in order to test and verify, for the moment, critical items. Regarding those lists, KFU has come further compared to ERD. The flow is more straight at KFU with no external interference, which allows KFU to control the whole flow.

Both KFU and ERD conducts quality tests to verify the quality before the shipment. However the processes in the after flow does not extend the lead times in the same way as at ERD. The products, forest machines and mining machines, are quite similar with many similar problems during manufacturing. However, KFU shows the quality can be significant improved with right focus combined with modern methods. This shows that Epiroc can improve the quality as well and thereby build more competitive machines at once.
9 Numbers of test items for ST and MT

Items in testing protocol for Scooptrams (ST).

<table>
<thead>
<tr>
<th>Type</th>
<th>ST7</th>
<th>ST1030</th>
<th>ST14Cs</th>
<th>ST18</th>
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<tbody>
<tr>
<td>Visual Inspection</td>
<td>53</td>
<td>55</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Functional checks</td>
<td>85</td>
<td>69</td>
<td>84</td>
<td>85</td>
</tr>
<tr>
<td>Test Drive</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Post Inspection</td>
<td>27</td>
<td>20</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>189</td>
<td>168</td>
<td>188</td>
<td>189</td>
</tr>
</tbody>
</table>

Items in testing protocol for Minetrucks (MT).

<table>
<thead>
<tr>
<th>Type</th>
<th>MT2010</th>
<th>MT2200</th>
<th>MT42</th>
<th>MT5020</th>
<th>MT65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
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<td>52</td>
<td>53</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>Functional checks</td>
<td>64</td>
<td>64</td>
<td>57</td>
<td>67</td>
<td>81</td>
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<tr>
<td>Test Drive</td>
<td>29</td>
<td>29</td>
<td>23</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Post Inspection</td>
<td>18</td>
<td>18</td>
<td>21</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>163</td>
<td>163</td>
<td>154</td>
<td>166</td>
<td>192</td>
</tr>
</tbody>
</table>
Axle loads and approximate weights

Figure 1: Axle loads for ST and MT.

Figure 2: Approximate weights for ST and MT.
<table>
<thead>
<tr>
<th>Company name</th>
<th>Product</th>
<th>Model</th>
<th>Capacity</th>
<th>Included</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMH International AB</td>
<td>Weight dynamometer + hand display</td>
<td>Dynafor LLX1</td>
<td>20 tons</td>
<td>Weight dynamometer and hand display</td>
<td>58 200 SEK</td>
</tr>
<tr>
<td>Anyload</td>
<td>Weight dynamometer + hand display</td>
<td>Tenslink</td>
<td>30 tons</td>
<td>Weight dynamometer and hand display</td>
<td>25 000 SEK</td>
</tr>
<tr>
<td>Radiolink</td>
<td>Weight dynamometer + hand display</td>
<td>RLP35T</td>
<td>35 tons</td>
<td>Weight dynamometer and hand display</td>
<td>32 000 SEK</td>
</tr>
<tr>
<td>Lyft &amp; surringsredskap AB</td>
<td>Roundsling + shackle</td>
<td>US std.</td>
<td>20 tons</td>
<td>2 roundslings and four shackles</td>
<td>5500 SEK</td>
</tr>
<tr>
<td>Taylor Dynamometer</td>
<td>Chassis dynamometer and accessories</td>
<td>Chassis Dynamometer, water brake</td>
<td>All machines</td>
<td>Chassis dynamometer, exhaust, DYNPRO2 instrumentation</td>
<td>6 600 000 SEK</td>
</tr>
<tr>
<td>AIP Automotive</td>
<td>Powertrain dynamometer with shake possibilities</td>
<td>Powertrain dynamometer</td>
<td>All machines</td>
<td>Chassis dynamometer with equivalent shaker</td>
<td>54 000 000 SEK</td>
</tr>
</tbody>
</table>

11 Prices for new equipment
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