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Production Process Development

- A current situation and improvement analysis of a polymer production line

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Abstract

The master thesis is a collaboration between Trelleborg AB and the division of Production and Materials Engineering at Lund University, Faculty of Engineering. The objective of the thesis has been to analyse the current production system from a lean perspective, identify an area in need of improvement and generate concrete solutions for how the studied area can be improved in terms of cost, performance and from a lean perspective.

The production system of a polymer product consists of three major processes: molding, post-molding and packing. The lean analysis identified a bottleneck in the manual quality inspection within the post-molding process. It was discovered that an introduction of automation is needed due to the manual quality inspection having reached its lower time limit, thus limiting the overall production capacity.

Five non-destructive technologies were investigated and evaluated based on the ability to identify the known range of product defects, consisting of: cracks, surface defects and geometry defects. The evaluated technologies were vision sensors, laser sensors, leakage testing, ultrasonic testing, and computer tomography. The results showed that at best, approximately 50-70 % of the defects are possible to detect in an automated system.

The potential of an automated quality inspection is dependent on the investment cost in relation to level of automation, scalability and flexibility. A combination of vision and laser sensors is the most preferable solution and reaches an automation level of approximately 50 % together with the largest cost reduction as well as the highest scalability and flexibility.

Keywords: *Improvement analysis, polymer product, non-destructive testing, level of automation, automated quality inspection.*

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List of Abbreviations

CT	Computer Tomography
CAD	Computer Aided Design
TPS	Toyota Production System
VSM	Value Stream Map
JIT	Just-In-Time
NDT	Non-destructive Testing
CPU	Computer Processing Unit
LiDAR	Light Detection And Ranging
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CMM	Coordinate-Measuring Machine
ESPI	Electronic Speckle Pattern Interferometry
ERP	Enterprise Resource Planning
SEK	Swedish Krona

Table of Content

1. Introduction

1.1. Background

The master thesis was conducted at Trelleborg AB, a world leader in polymer engineered solutions. Trelleborg specializes in the development and production of polymer components for critical applications in high demanding environments, see figure 1 for logo.

The company was founded in 1905 in Trelleborg, southern Sweden, and it is still the location of the company's headquarter. Today, production is carried out in 51 countries and the number of employees is over 24 000. The total turnover in 2018 was 34 005 million SEK distributed over 5 business areas: Coated Systems, Industrial Solutions, Offshore and Construction, Sealing Solutions, and Wheel Systems. [1]

Trelleborg is a company that strives for excellence and to continuously improve. In order to remain competitive in a global world, continuous overviews and assessments need to be performed throughout the entire value chain. This master thesis will be focused at the production of a specific polymer product, available in multiple models, at one of Trelleborg's production sites. The production process involves three major processes: molding, post-molding and packing.

Figure 1. Trelleborg AB logo [2].

1.2. Objective

The objective of this master thesis was to identify and realize an improvement in the current production system. The final result should be suited for implementation in the current production as well as take into account future scenarios, for example an increase in demand, new products and future technologies. In order to achieve this, a deep understanding of the current production system is necessary as well as the identification of constraints. It will also require a long term scope for the entire project where today's costs must be set in relation to potential investments, long term improvements and Trelleborg's long term strategies. This overall objective has been narrowed down into the following objectives:

- Perform a lean analysis on the current production system and identify an improvement area.

- Generate concrete solutions for how the identified area can be improved in terms of:
    - Cost.
    - Performance.
    - A lean perspective.

In order to reach the objectives, a lean approach is taken where a value stream map is created, followed by the identification of the production's bottleneck. The bottleneck is evaluated from a cost perspective in order to estimate the investment potential. The bottleneck analysis reveal that the manual quality inspection is the system's bottleneck and that salary cost is the major cost driver in the inspection process. In order to not increase cost, the potential of automating the quality inspection process is investigated. The potential solutions are evaluated based on cost, scalability, flexibility and level of automation. Possible scenarios are presented and recommendations are given.

1.3. Delimitations

The focus of the thesis will lie on evaluating the current production processes from a lean, economical, and technological perspective. The lean perspective will focus on reducing the possibility of disturbances in the production rather than the investigation of the raw material and the actual refinement process. The thesis will discuss a number of technologies from a general perspective in order to be able to compare the technologies against each other. The technologies presented are those available by potential suppliers and not representative for each of the industries. The results presented may in general be applicable to polymer products and the production of polymers. However, the recommendations provided are limited to the investigated production facility and is solely intended for Trelleborg AB and the specific polymer product.

1.4. Confidentiality

All data and information shared by Trelleborg AB is considered company secret. Presented numbers and figures are either hidden or modified in order to present results but not underlying parameters. The presented methods and conclusions does not necessarily reflect those of Trelleborg, but instead of this master thesis.

1.5. Disposition

The thesis is divided into seven chapters which are presented in the following order:

Introduction - *This chapter gives the reader an introduction to this master thesis in terms of background of the company, overall objectives, and purpose. It also contains delimitations as well as background on the confidentiality surrounding the thesis.*

Theoretical background - *This is to provide the reader with the underlying theory which will be used throughout the report. The purpose of this chapter is to identify suitable theoretical models and technologies which can be applied to the challenges faced in this master thesis.*

Method - *The method applied in the thesis is presented. The method is a combination of theoretical models introduced in the theoretical background which are now applied to the investigated production system.*

Similar Applications and Implementation - *A study is conducted in order to investigate what work has previously been conducted within the field of automating a quality inspection in the polymer industry.*

Results - *This chapter presents three types of results: an analysis of the current production system, results of the quality inspection analysis, and an improvement analysis. The current situation analysis investigates the production process as a whole, identifies its bottleneck and the cost drivers within it. It also determines an area which will be focused on improving - the manual quality inspection. The quality inspection analysis provides an assessment of possible technologies' performances in an automated quality inspection. Finally, an overall evaluation in terms of cost, lean and level of automation is conducted in the improvement analysis.*

Discussion - *The results presented in the previous chapter are discussed. Challenges and uncertainties within the project are presented as well as possible future scenarios.*

Conclusion - *Conclusions are presented based on the objectives of the master thesis.*

2. Theoretical Background

2.1. The Lean Philosophy and the Toyota Production System

The lean philosophy is the idea of enhancing continuous improvements, creating a demand oriented production process and reducing non-value added activities. The philosophy received a major breakthrough in the 1990's due to its simplicity and improved efficiency. In today's world, lean processes are used to reduce reaction times in changing market, enable smaller batches as well as creating standardized and more transparent production processes. [3]

The lean philosophy was first introduced by Ohno and Toyota in the 1950's, often described as the Toyota Production System, TPS. The Toyota Production System is a series of methods to achieve the highest possible quality, to minimum cost, with the lowest possible lead time. The TPS is based on two pillars: the idea of Just-In-Time, JIT, and Built-In-Quality. JIT is a set of principles based on a pull-system where a customer order triggers activities upstream in the production system. By applying these principles, a company is able to deliver products in small quantities, in short lead times, and satisfying specific customer demands. The second pillar, built-in-quality, means that a defect should never be passed on to the next workstation. To achieve this, Toyota analyses the defects down to its core and thereby strives to remove defects all together. This is not always possible due to the fact that some defects can be caused stochastically because of human errors which requires control systems. Toyota solved this issue by, for example, implementing visual control systems, automatic stops, error proofing tasks, and in-line quality control. [4]

Defining actual value added time in a process can be complex and sometimes controversial. According to Toyota, time spent in a product can be divided into three categories:

1. *Value added time*. This is time actually spent on the transformation of a product. This is a process which is defined by creating a certain value to the customer, something the customer is ready to pay for. [4]

2. *Non-value adding time.* Time spent not creating new value to the customer, e.g. rework, wait-times or unused information. [4]

3. *Non-value adding, but required.* There are certain tasks which does not create value to the customer but must be performed under the current conditions. This type of work can include quality inspections, proper documentation, and inspections to guarantee that procedures are followed correctly. [4]

2.2. Value Stream Mapping

Value Stream Mapping, VSM, is a concept developed from the Toyota Production System tool called *the material and information flow diagram,* and is used to capture the material and information flow for a product family, in order to identify waste. It was originally applied by Toyota's suppliers as a starting point to implement the TPS into their own production systems, and is today considered the starting point in any improvement process of a large complex system. [4]

The Value Stream Map uses boxes to represent processes and triangles to represent inventories. Arrows are used to illustrate the material flow through the production process. An explanation of symbols used for the Value Stream Map can be found in Appendix A table 1. The creation of a VSM is a process which should involve all managers concerned as well as operators, suppliers, customers and other people involved in production process. [4]

The VSM has rapidly gained popularity because of its ability to identify improvement opportunities in production activities. The map should include all activities concerned in producing and delivering a specific product, as well as identify the value adding time and total lead time. The method provides a deep understanding of each process step, as well as an insight in cycle times, change over times, uptimes and the number of operators. Cycle time can be defined as the time it takes from start until the end of an operation, and is the sum of all activities involved in a process. Change over time is the time it takes from the last good piece for a certain product type is complete until the first good piece for a different product type is complete. Uptime is the ratio between the time a production equipment functions properly and when it is not. [4]

Upon its completion, the VSM created describes the production process' current state and is often referred to as the Current State Map. The Current State Map functions as a baseline view from which all improvements are measured. [5]

2.3. Bottleneck Identification

All production systems have a bottleneck somewhere. The bottleneck can be defined as the operation with the longest cycle time. [6] The longest cycle time thereby determines the production rate for the entire production system, i.e. pace, which can be defined as followed [6]:

$$Pace = \frac{Nominal\ batch\ size}{Production\ time} \qquad \text{Equation 1}$$

If an operation only has one workstation, the pace time will equal the cycle time. However, if an operation has more than one workstation, then the pace will be governed by the work station with the longest cycle time. A bottleneck can therefore be defined as the operation with the lowest pace. [4]

2.4. Ståhl's Cost Model

The cost model developed by J-E Ståhl is a model to break down a production system into individual costs. This makes it possible to analyze each cost factor individually and to study its effect on the total production cost. The model is shown in figure 2, and contains a total of 14 variables, where some of the variables consist of several variables as well. [7]

$$k = \frac{K_{sum}}{N_0} + \frac{1}{N_0}\left[\frac{k_B N_0}{(1-q_Q)(1-q_B)}\right] +$$
$$\frac{1}{N_0}\left[\frac{k_{Cp}}{60}\cdot\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\right] +$$
$$\frac{k_{CS}}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_P)}\cdot\frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}}T_{pb}\right] +$$
$$\frac{k_D}{60N_0}\left[\frac{t_0 N_0}{(1-q_Q)(1-q_S)(1-q_P)} + T_{su} + \frac{1-U_{RP}}{U_{RP}}T_{pb}\right]$$

Figure 2. Ståhl's cost model

The general costs parameters are: sum of remaining costs per batch, K_{sum}, material cost per part, k_B, hourly machine cost during production, k_{CP}, hourly machine cost during downtime, k_{CS} and hourly salary cost, k_D . K_{sum} covers costs that the model does not, for example tool cost, larger maintenance cost and inventory cost. K_{CP} consists of the parameters stated below [6]:

$$k_{CP} = \frac{a\cdot K_0(1 + k_{ren}\cdot N_{ren}) + Y\cdot k_Y + T_{plan}(\frac{k_{UHh}}{h_{UH}} + k_{ph})}{T_{plan}} \qquad \textit{Equation 2}$$

- a = annuity factor that depends on interest and depreciation.
- K_0 = *capital expenditure.*
- k_{ren} and N_{ren} = cost of renovations relative to the capital expenditure, and the number of renovations per year.
- Y and k_Y = *the area which the process requires, and the overall cost per square meter.*
- T_{plan} = Total planned production hours per year.
- k_{UHh} and h_{UH} = maintenance cost per hour, and the number of production hours per each maintenance hour.
- k_{ph} = variable machine time cost, for example electricity.

k_{CS} is similar to k_{CP} ,however, it excludes the variable cost and the maintenance cost during production [6]:

$$k_{CS} = \frac{a \cdot K_0(1 + k_{ren} \cdot N_{ren}) + Y \cdot k_Y}{T_{plan}} \qquad \text{Equation 3}$$

The cycle time, t_0, is the sum of all operations in a process that is time consuming, which include machine time, t_m, handling time, t_h and time to internally change the tool for the machine between the minor operations, t_{vb}. [7]

$$t_0 = t_m + t_h + t_{vb} \qquad \text{Equation 4}$$

Machine time, t_m, can be divided into:

$$t_m = t_f + t_{tr} + t_{sp} + t_{kvs} \qquad \text{Equation 5}$$

Where t_f is the value added time, t_{tr} is the internal transport time, t_{sp} is the time for support processes, and t_{kvs} is the time required for quality assurance. [6]

N_0 represent the number of approved parts, which means that a higher number of parts, N, needs to be produced when also taking scrapping into consideration. This leads to the expression of losses, which is divided into four terms: q_Q, q_B, q_P and q_S. The first one treats the rejection rate due to insufficient quality, q_Q. It is described by the number of parts needed to be produced to achieve the desired number of correct parts [7]:

$$q_Q = \frac{N_Q}{N} = \frac{N - N_0}{N} \qquad \text{Equation 6}$$

The next term is the material loss factor, q_B, which is described by the total material added to the process, m_{tot}, and the actual mass of one part, m_{part} [7]:

$$q_B = \frac{m_{tot} - m_{part}}{m_{tot}} \qquad \text{Equation 7}$$

Thirdly, a type of loss that is present within a production system are losses in production rate, q_P, which is when the cycle time needs to be increased to maintain the expected quality. The equation consists of the actual cycle time after the increase, t_{0v}, and the desired cycle time t_0 [7]:

$$q_P = \frac{t_{0v} - t_0}{t_{0v}} \qquad \textit{Equation 8}$$

The last factor for losses is q_S, *which* is when production is halted due to disturbances. It is described by the processing time, t_p, and the cycle time, t_0 [7]:

$$q_S = \frac{t_p - t_0}{t_p} \qquad \textit{Equation 9}$$

Parameters based on time in the model are the set-up time for one batch, T_{su}, and the total time for one batch, T_{pb}. Total batch time includes the set-up time, and is described by [7]:

$$T_{pb} = T_{su} + \frac{N_0 \cdot t_0}{(1-q_Q)\cdot(1-q_S)\cdot(1-q_P)} \qquad \textit{Equation 10}$$

The last parameter in Ståhl's cost model covers the degree of occupation, also known as the utilization factor U_{RP}. It is described as:

$$U_{RP} = \frac{T_{prod}}{T_{plan}} \quad where \quad T_{plan} = T_{prod} + T_{free} \qquad \textit{Equation 11}$$

Where T_{prod} is the actual total production time, and the total planned production time is a sum of the actual production time and non-producing time. [7]

2.5. Automation

2.5.1. Introduction to Automation

The term automation was firstly mentioned in the automotive industry back in the 1940's by engineer D.S Harder at Ford Motor Company [21]. However, automated assembly lines had already been installed at Ford in 1913 which had reduced the assembly time from 12 to 1,5 hours per car. The new, and first of its kind, assembly lines at Ford enabled mass production and thereby increased profits. [9]

Automation can be defined as a technology whose objective is to control a process by using programmed commands with automatic control to ensure correct actions with certain instructions. With a more overall perspective on automation, it is generally seen as a replacement of manual actions with machines. On the other hand, this is closely related to *mechanization*, the straightforward replacement of humans with machines. Instead, the term automation implies the introduction of machines into a system that can function by itself, except when abnormal problems occur or when maintenance is needed. [10]

The challenge in automating a system is the integration of technologies into a system consisting of information and people. Sabrie Soloman explains in the Sensors Handbook, that the information gap between the real world and the control world plays a major part when implementing automation. One solution, to erase this gap, is by using *computer-integrated manufacturing, CIM*, meaning that computers control the entire process. [10]

Both positive and negative aspects can be identified when comparing an automated system to a human being. The biggest upside with automation is the consistency throughout the whole process, since the system will only do what it has been told. The ideal scenario for an automated system is repetitive tasks due to its predictability and simplicity to automatically control. Compared to a human, a robot will neither get tired nor bored doing the same task over and over again, and thereby exclude the risk of what is commonly known as a *human error*. [11]

Another advantage, which often is an important aspect when introducing automation, are cost savings. In the western world, labor costs for manual work is relatively high and the cost savings when replacing a person with a machine can be massive. This is mainly due to added costs, for example insurance and employee benefits, above the actual salary. [11]

A third advantage is letting a machine perform tasks in extreme conditions, for example heavy operations and warm/cold locations. Machines can handle exposed situations better than human operators, and are replaceable if something would go wrong. [11]

There are potential downsides with automation, one being the initial cost. When replacing a human with a machine, it can be difficult to estimate the amount of data and decisions a person makes. The system's complexity grows fast when trying to add all necessary decision capabilities of a human. This impacts the cost of the system as a whole, including the actual machine/robot and its subsystems for data processing and decision-making. [11]

As previously discussed, it can be difficult to implement the decision-making capabilities of a human for a machine if the process is somewhat complex, for example when several variables needs to be considered at the same time. Technology has not yet evolved enough to cover all manufacturing processes, and still, in some cases the need of high-order thinking cannot be met. It is common when designing an automated system, that the production itself will become less flexible since the automated system only covers certain predetermined tasks. Adding tasks or inspections to an already working automated system can be surprisingly though, if even possible. When creating a system, it is important to consider both current and future production system requirements, even though there is no way around the fact that the production will be more restricted and less flexible in certain tasks. [11]

Each manufacturing facility requires a unique solutions when introducing automation. This is dependent on several factors, for example type of production and the number of different products. When deciding on an automation system and thereby level of automation, both cost and automation flexibility has to be considered. [11]

The total cost per product versus level of automation is shown in figure 3. The figure shows that when the level of automation increases, the personnel costs decreases linearly and the cost for equipment, for example maintenance and operational costs, increases faster than the linear decrease of personnel costs. In theory, this means that there will be a minimum for the total product cost, as it is the sum of personnel and equipment cost. [11]

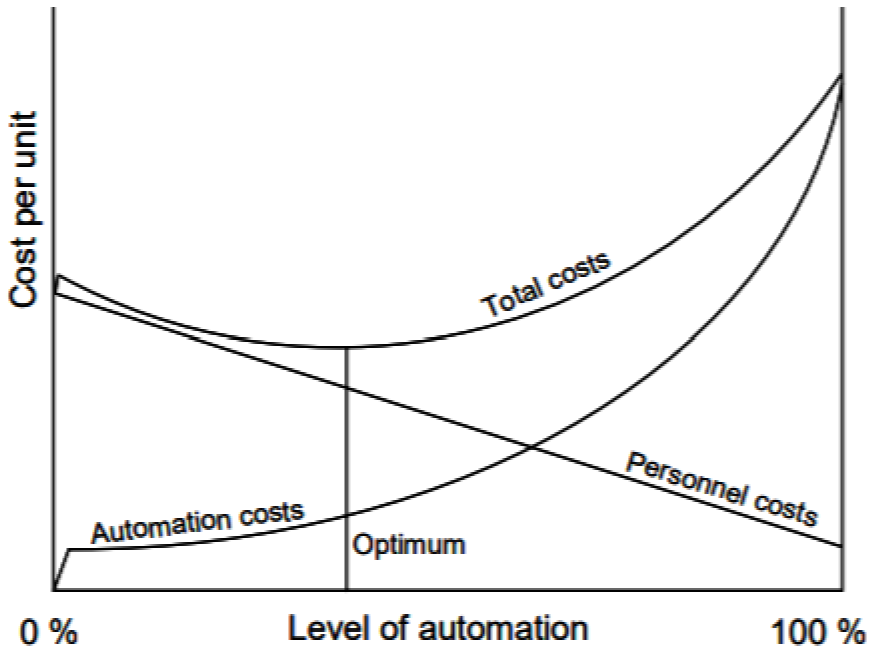

Figure 3. Optimal level of automation. [12]

When designing a detection system, there are three basic approaches: a system of sensors, smart cameras or PC-based vision. The term sensor is broad, because it only describes a device that detects a physical property, for example heat or light, from the environment. The input will be converted to an output that is useful for processing. [13] Some types of sensors that are commonly used are proximity sensors, which can sense if an object is near using a number of different technologies, for example the reflection of emitted light. [14]

Smart cameras are cameras with an integrated computer, which means that the camera itself makes all the necessary calculations. Smart cameras are in favor when relatively easy calculations are required in a short period of time. When using a separate PC for all logic and vision processing, the processing power and computing possibilities are much greater compared to a smart camera. It is preferable to use a connected PC-system when a large camera installation is required, since it is more cost effective and flexible. [14]

2.5.2. Non-Destructive Testing

2.5.2.1. Introduction to Non-Destructive Testing

A customer purchases an industrial product in order for it to fulfill a specific function. In order for the supplier to remain competitive on the market, the product must meet the customer's expectation in terms of trouble-free service for a certain amount of time. Quality assurance, i.e. to be able to guarantee that the customer's expectations are met, are therefore an important part in every production process. Quality inspection can be divided into *destructive* and *non-destructive* inspections. Though there is no explicit defined boundary between destructive and non-destructive inspection, non-destructive testing, NDT, is defined as a method to examine materials of components in ways that do not impair with its usefulness and survivability. NDT evaluation methods include the ability to detect, measure and locate discontinuities as well as other imperfections in finished or half-finished products to determine whether or not it fulfills the requirements. [15]

A basic definition of NDT methods can be based on whether or not contact between the sensor and the tested material is required. Generally speaking, contact between the sensor and tested material produces more accurate data, while non-contact methods tend to speed up the data gathering process and thereby reducing the total inspection time. [16]

There are a number of methods that requires contact in some way to be able to perform non-destructive testing. Common methods are for example the use of an electrical current, electromagnetism/magnetism, pressure or the adding of different penetrants to reveal defects. Since these are in direct contact with the object, the properties of the object plays a considerable part when determining the possibility of a successful method. Some products react poorly when exposed to an electrical current or magnetism, while others have restrictions when adding a layer of penetrant that might be troublesome to remove. [16]

Some of the more common contact and non-contact NDT methods are presented on the next page.

2.5.2.2. Non-Destructive Testing Methods

X-ray and Computer Tomography

X-ray, or radiographic, is one of the most commonly used NDT methods. Today, there are many types of radiographic methods on the market, used for various types of internal inspections. Low voltage radiography uses gamma rays to detect for example large voids and cracks and is used when the material is neither too thick nor to thin, between 1-5 mm. A second method is gamma ray radiography and can be used to detect defects in thicker part, due to a shorter wavelength than low voltage radiography. [16]

Computed tomography is an imaging technique developed in the 1970's for the medical industry. In recent years, it has gained interest from other industries as well. The CT-scan uses a series of two dimensional x-ray images taken and then reconstructs these, using an algorithm, to create a 3D volume. Modern CT-scanners rotate around the object which is to be scanned while taking 2D X-rays. Usually, between 360 and 3600 individual 2D X-rays are required to create a 3D model. Depending on the required resolution, the number of voxels, i.e. 3D pixels, the process time to create a 3D model varies from a few seconds up to an hour. A comparison between the model and actual part can be used in order to perform a dimensional analysis, measure surface requirements and locate inclusions in the material. By creating a 3D model of a product, it can be compared to the set requirements through a metrology software or CAD. [17]

Ultrasonic

There are two types of ultrasonic NDT methods applicable in a production line: pulse echo and through transmission. Both methods transmits frequencies of about 50 kHz and while pulse echo requires contact between the product and transmitter, the through transmission is placed on a fixed distance from the inspected product. The pulse echo approach is suitable for production lines where large defects, or inconsistencies in the material are to be detected, and lead time is to be minimized. The through-transmission on the other hand is suitable for the inspection of large products with a complex geometry. [16]

Vision

The definition of machine vision according to AIA, Automated Imaging Association, is a combination of hardware and software that can give guidance for operating decisions, by analyzing images. [31] The hardware is often a camera of some sort, which captures light and transforms it into a picture consisting of pixels. An advanced camera together with the suitable software can give feedback on areas like position and orientation, surface texture and color. [19]

Laser

LiDAR, Light Detection And Ranging, is a sensing technique that uses a laser beam to detect, determine the distance to, and analyze the properties of an object. This is performed by analyzing the reflection, absorption and scattering from the reflection of the object. [20]

LiDAR technology provides distance measurements in a chosen direction, which makes it excellent for capturing the surface of an object. By rotating the actual object or the LiDAR-tool around the object, it is possible to create a full 3D-model, which can be analyzed after combining LiDAR technology with photogrammetry. Photogrammetry is a technology that makes it possible to perform measurements on the product from the created 3D-model, to inspect if certain conditions are fulfilled. [21]

Leakage Test

Leakage test is a type of contact NDT which can be performed in a number of ways, based on the properties of the product that is being tested. A common method is where the product is pressurized, for example with dry air, and monitored to determine if the pressure is dropping, i.e. if a leak is present. This method is favorable for small objects, due to it being easier to stabilize the internal pressure. The method is relatively cheap, dry, compact and easy to implement, given that the stabilization can be achieved within the limited cycle time. [22]

A second and common way of performing a leakage test is by extracting a medium, often air, and thus creating a vacuum inside the sealed object. A leak can thereby be identified by monitoring the pressure. If the pressure is rising, a leak is present somewhere within the object. This method also requires to be stabilized before monitoring and can only be used on objects that are strong enough to withstand the pressure difference. If the walls of the object are too thin, the risk of the product collapsing during testing is immense. [22]

2.6. Quality control

Quality control is part of the total quality concept, the other two being quality assurance and quality management. Quality control aims to in a scientific manner measure, analyse and interpret how different factors correlate and influence the overall quality. Part of quality control is to monitor and measure process performances in order to study how improvements in the overall production system can be achieved. Just like the concept of lean, the Japanese developed the in-line inspection, where each workstation is responsible for their own quality inspection, instead of performing the quality inspection at the final workstation. By doing this, the operators are able to adjust the quality-related operations directly. Figure 4 illustrates the relationship between quality control and the previously presented NDT technologies. [4]

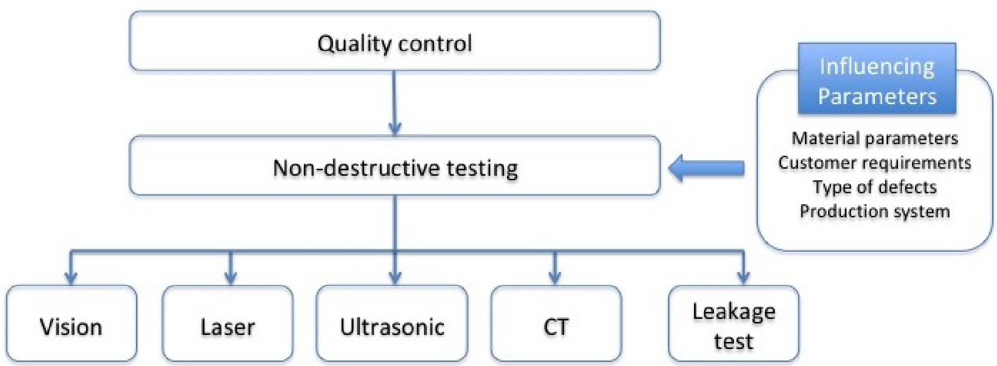

Figure 4. Shows the relationship between quality control and specific technologies used in quality inspection.

By using systems such as CAD/CAM tied together with computer aided inspection and testing systems, a low cost inspection of products can be achieved. The use of non-contact sensors and automated non-destructive testing allows for a low handling cost while also reducing the risk of damaging the product. [23]

2.7. Assessment criterias

When adopting new technology, Toyota suggest two main assessment criterias: dependability and flexibility. All new technology should be properly tested both in terms of technology advancement and in terms of suitability in the current production. Implementing a technology to eliminate waste, that is more complex than actually needed may be counterproductive and lead to production disturbances and increased costs. Instead focus should lie on implementing technology which meets the set criterias, but not more, and that has a proven high dependability and functions well with the rest of the production system in terms of people as well as other machinery. [4]

The second criteria, flexibility, is the ability to not be locked in to certain automation solutions. The technological solutions created should as much as possible be customized to fulfill a function, not a certain task. A specific task might become obsolete, but the function itself is often still required. To have the ability to change specific tasks makes the production system more flexible and increases the ability to handle production changes. [4]

When increasing the level of automation to perform a quality control, it is important to consider hard and soft influencing parameters as assessment criterias. Hard parameters could be the planned number of products, number of workers involved in the process, or parameters such as cycle time and set-up time. Soft parameters could instead relate to the flexibility of being able to produce multiple models within the same production line. [24]

2.8. TPS implemented in automation

In the Toyota Production System, reliability is highly valued and this philosophy is applicable in the implementation of new technology. Before any new automated solution is brought into the actual production, it must first be thoroughly tested and evaluated. The evaluation process tries to determine exactly how the new technology will affect the current processes in terms of: eliminating wasteful tasks, balance with the current production flow, and how its effect on the people around it. In the Toyota philosophy, people are valued over technology. This means that if an automation system may cause uncertainties for the people working around it, or if the automated system's contribution to the rest of the production system is neither considered intuitive nor visual, it will not be implemented. The stability, reliability and flexibility of the production system are higher valued than the potential cost savings when automating a process. [4]

After a new technology has been thoroughly evaluated and tested, it may be implemented in the production system. Because of this long and thorough process, the actual implementation is often smooth and the employee resistance towards the new technology is often low. [4]

3. Methodology

The methodology of this thesis is presented in figure 5. It shows the overall structure of the analysis together with the processes involved in each step. As a final outcome, conclusions are presented and recommendations given.

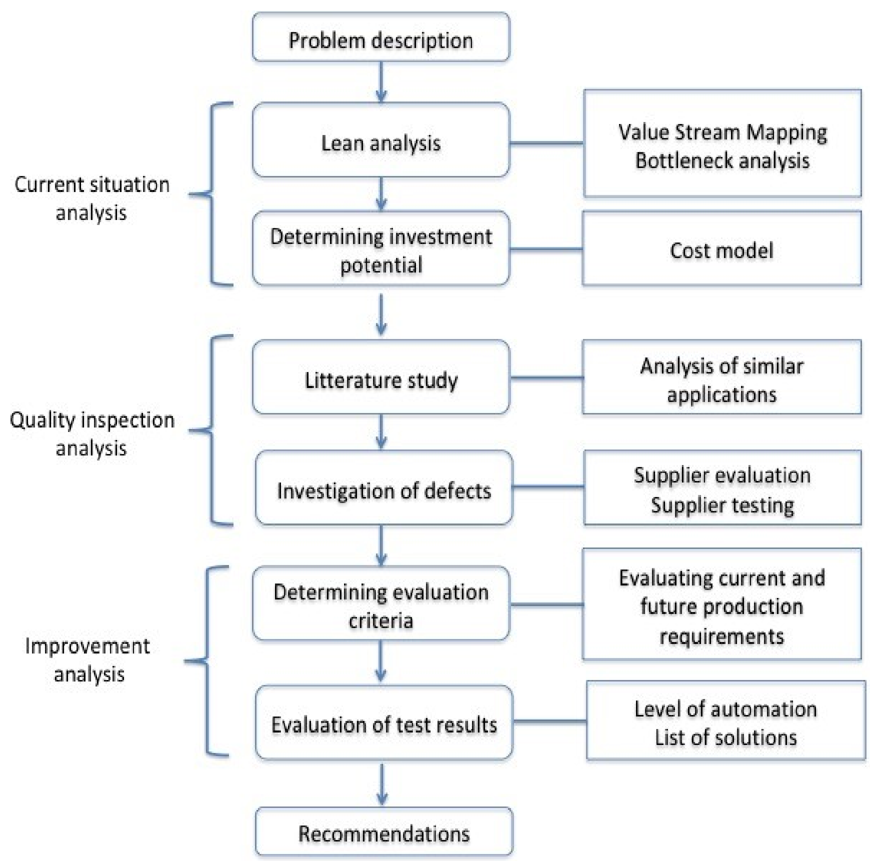

Figure 5. Displays the methodology of the thesis.

3.1. VSM

A Value Stream Mapping was performed as a descriptive study to create an understanding of the production flow and production processes. The tools used to gather data were interviews with the production planner, the production manager and operators for each of the processes. The production planner provided information about lead times and production flows, and the production manager gave an overall perspective of the production site as well as data regarding set-up times, change-over times and molding times. To create an understanding and to complement data gathered through interviews, observations and measurements were taken. Because of the large number of different product models available, an average lead time and cycle time were established.

3.2. Bottleneck

The bottleneck identification was a descriptive study based on the data gathered in the Value Stream Mapping process, to understand what part of the production process has the lowest production capacity and therefore has the greatest vulnerability to disturbances. An analysis of the process capacity based of the VSM revealed the bottleneck of the production system.

3.3. Cost Model

The cost model was an exploratory study of the bottleneck revealed in the bottleneck analysis. The study began to break down the post-molding process into individual costs, to create an understanding of each cost factors' effect on the total cost. The model was used as a tool to identify cost drivers and thereby potential cost savings.

Data used to create the cost model was gathered through interviews with the production management, i.e. the production manager, production planner and plant manager, together with data already obtained from the VSM study.

3.4. Similar applications and Implementation

An analysis was performed to create an understanding of previous and similar projects within the field of automating quality inspections for polymer productions. The aim was to gain knowledge of what technologies have previously been used, on what scale, what accuracy has been achieved and what that did not work. The focus of the study has been to investigate how non-destructive testing on polymers can be performed in mass production with a high accuracy.

To ensure that only studies of high quality were examined, literature and studies which are peer reviewed where chosen for the similar application and implementation process. Most of the literature was gathered by using the search engines LUBsearch and Google Scholar. The aim of the literature study was to determine if and how vision, laser, ultrasonic, leakage testing and CT technology have been used for products and production processes similar to the ones at Trelleborg.

3.5. Supplier Evaluation and Testing

A list of specifications was established to ensure that the recommended improvements of the production system will achieve the system's quality requirements. To be able to tell a defect product from a correct product, a specification of requirements was established.

A first contact and screening of possible suppliers was established at an industry fair in Malmö, Sweden. At this point, a short list of all possible hardware suppliers was gathered. The next step was to identify companies which had knowledge in these areas and could supply the hardware. This was the case for technologies that uses retailers, but for more expensive technologies, direct contact with the manufacturers was required. When direct contact with manufacturers was established, a list of candidates was created on industry reputation, global presence and previous collaborations with Trelleborg.

Initial contact with suppliers was made either via email or a phone call. The first step was explaining the objectives of the project and how the suppliers could facilitate to reach those. These discussions were kept at general level and regarding typical defects. If the evaluation was positive, the next step was to perform tests to receive a confirmation of what kind of hardware and supporting systems that can detect the sought after defects. After receiving the result of the testing, an evaluation between suppliers was made to determine if, and then who, Trelleborg wants to proceed with for further testing and implementation.

3.6. Assessment of Solutions

The assessment criteria for each of the technologies are determined together with the management at Trelleborg to assure that the evaluation parameters are firmly established internally and are in line with the long term strategy. These parameters are evaluated against each other as either hard or soft parameters. Hard parameters are evaluated against each other and an optimal level of automation is determined, while soft parameters are considering possible future changes in the production system. Finally, five cases, for each of the investigated technologies, are presented and discussed.

4. Similar Applications and Implementation

4.1. Similar Applications and Implementations study

The objective of this chapter is to provide knowledge in applied NDT where components with properties similar to polymers are automatically quality inspected. The aim is to find reliable NDT technologies for detection of the three major types of defects: cracks, surface and geometry abnormalities. The investigated applications and implementations are shown in figure 6.

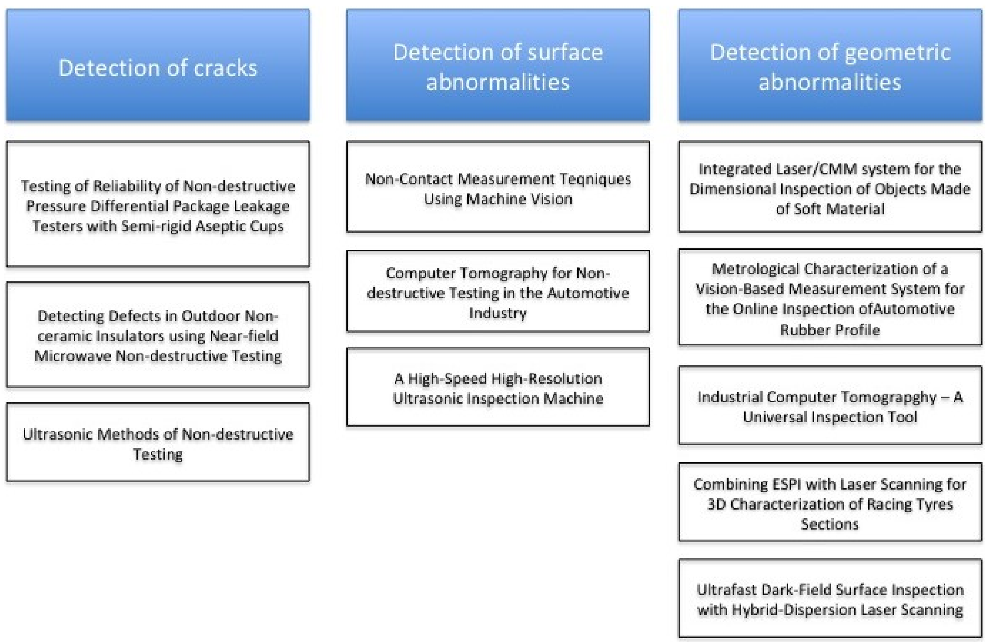

Figure 6. Studied applications categorized for each type of defect.

Testing of reliability of non-destructive pressure differential package leakage testers with semi-rigid aseptic cups

Two types of non-destructive leakage test methods were studied to determine the possibility to detect small holes in semi-rigid cups containing food. Quality assurance in the food industry is crucial, since even low volumes of microbiological contamination can affect the quality. The first method investigated was to monitor the external vacuum decay inside a test chamber, while the second method studied the internal pressure decay inside the cup after applying mechanical pressure. Not all constructed holes, i.e. leakages, could be detected by either methods. However, the first method was more sensitive and reliable compared to the second method, and was therefore preferable for the detection of leakages. [25]

Detecting Defects in Outdoor Non-ceramic Insulators using Near-field Microwave Non-destructive Testing

When transmitting a microwave towards the silicone rubber shed in a non-ceramic insulator, it will reflect the signal based on the dielectric properties. If a defect of some sort, in this case an air void, is present, the reflection will vary, since the dielectric properties changes if a defect is present. The scan of the shed can be made by rotation while continuously directing microwaves through the shed, as illustrated in figure 7. The voltage is measured, which is proportional to the reflection coefficient, along the circumference of the non-ceramic insulator, and reveals reflection deviations where air voids occur. [26]

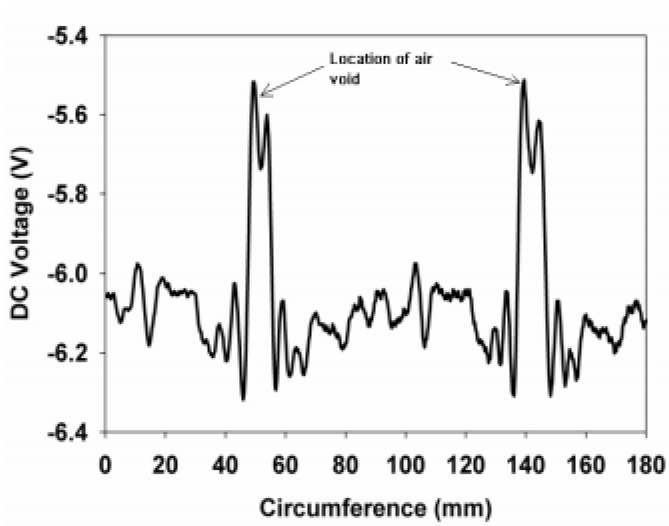

Figure 7. Shows deviations in the measured voltage due to air voids.

Ultrasonic Methods of Non-destructive Testing

Ultrasonic quality inspections are often performed in early production runs in the tire industry to guarantee that no tread separation is present, the geometry is acceptable, and that the thickness and porosity of the rubber is sufficient. In the study performed, the tire is submerged under water where the water is used as a media for the ultrasonic waves. There are two types of ultrasonic technologies used in order to achieve this: pulse echo technique and the through-transmission method. The difference between the two methods lies in where the sent out signal from the probe is picked up. The pulse echo method uses the echo from the back wall of the material, while the through-transmission technique uses probes on the opposite side of the material to gather the signal, see figure 8. Since rubber has a characteristic impedance close to water, the through-transmission technique is used in the study. The results show that by spinning the inflated tire in water the through-transmission technique is sufficient to detect possible defects. [27]

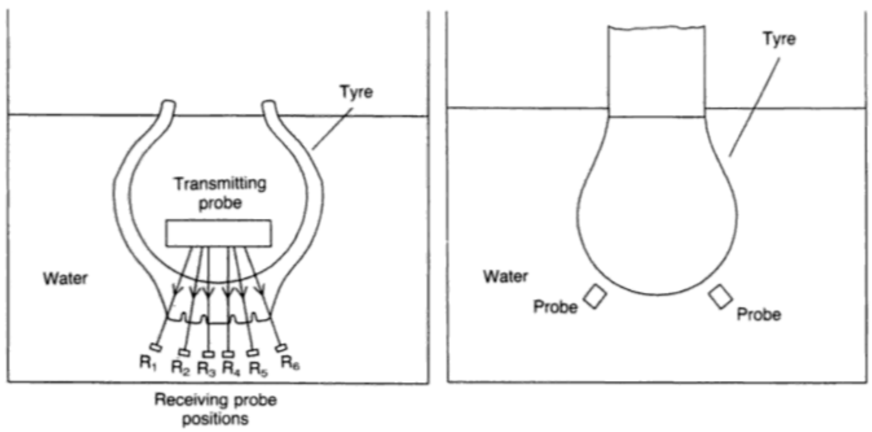

Figure 8. Shows the through-transmission technique to the left and pulse echo method to the right.

Non-Contact Measurement Techniques Using Machine Vision

The potential to use a machine vision system in an in-line dimensional measurement system for the production of rubber gaskets in the medical industry, was examined. Common defects for this type of product are blemishes, cut marks, flashes and molding defects. A machine vision system was designed consisting of a high resolution camera, a light source, i.e. high bright low angle ring light, and an image processing algorithm. A large number of gaskets without defects were fed to the system to function as references. If a gasket would deviate from the references, the gasket would be considered faulty. The system was able to measure the dimensions and surface quality at a speed of five rubber gadgets per second, thus increasing the production capacity in the quality inspection as well as reducing the number of human errors. [28]

Computer tomography for non-destructive testing in the automotive industry

The report highlights the differences between the medical computer tomography and the use of computer tomography as non-destructive testing method for industrial products. The high costs associated with CT is much due to patient safety, and minimizing the amount of potential hazardous radiation, while the resolution requirements are relatively low. For industrial applications and NDT, radiation is no limiting factor for most products while the requested resolution and cycle time is of importance. In order to achieve high precision measurements the voxel size together with the greyvalue contrast is of importance. The greyvalue contrast is not entirely restricted by voxel size but can be increased through sub voxel interpolation. However, the challenge remains in determining the threshold value, which defines the edge of a part. Figure 9 illustrates the relationships between measurement time (cycle time), cost, resolution and the greyvalue contrast. [29]

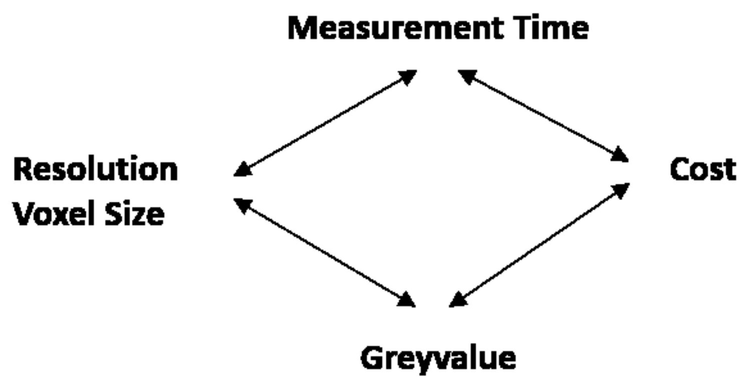

Figure 9. Shows the factors influencing the performance of a computer tomography system.

A High-Speed High-Resolution Ultrasonic Inspection Machine

An improved ultrasonic measuring method has been tested on truck tires, to detect defects in casings. If defects are present, failure is most likely to occur after retreading, i.e. applying a new set of rubber on the outer part of the tire. Having both high speed and high resolution result in huge amount of data gathered and processed in short time intervals, which increases the requirement for top end computer power. In the study, a test with a step of 1/8 inch generated approximately 200 000 data points, and an increase in resolution to 1/16 inch every step generated 800 000 data points. The line-scan method is used to scan the side surface of the tire, followed by a displacement in the z-axis triggered by a receiver placed inside the tire, see figure 10. The entire scan of a tire took 7 minutes, and was only limited by the maximum revolution of the tire, not the pace of the data acquisition. [30]

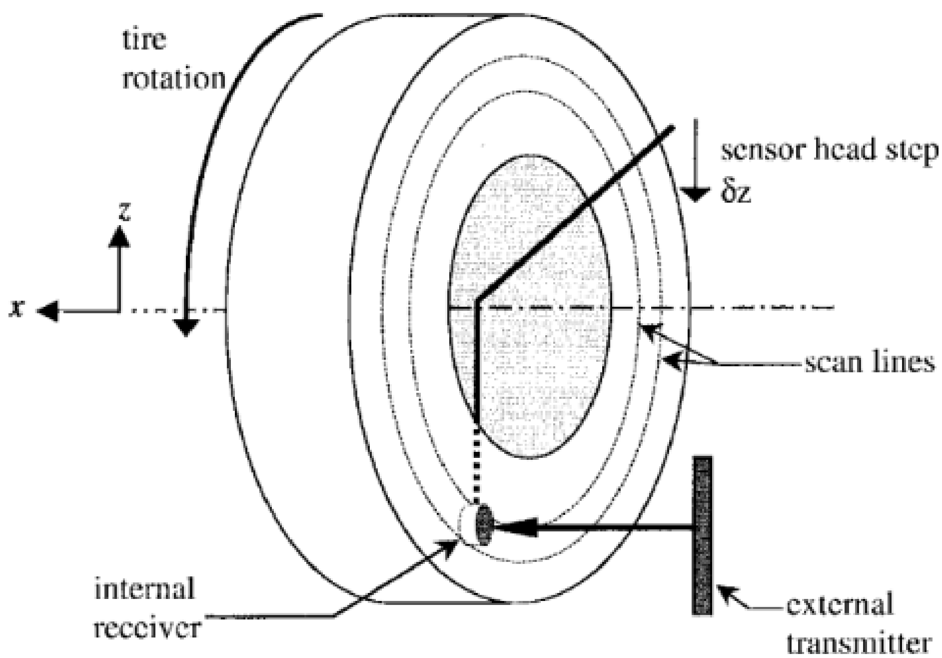

Figure 10. Shows the set-up of the high speed-high resolution inspection machine.

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Integrated laser/CMM system for the dimensional inspection of objects made of soft material

The conventional method for inspection of dimensions with a Coordinate Measuring Machine (CMM) is by using a probe that is in contact with the measured object. When applying the same method on soft materials, the probe may deform the surface since it being harder than the measured object, and will therefore provide incorrect results since it is measuring the deformed surface instead of the previously undistorted surface. Replacing the contact probe with a laser eliminates this issue, since it is not in contact with the measured object. It is thereby possible to eliminate factors such as surface deformation, deflection due to contact and calculations for probe tip compensation. Combining a CMM with a laser instead of a probe is advantageous for measuring the surface on soft materials. However, to perform the measurement, the laser beam needs to be aimed at the normal of the measured surface, which leads to complex and time consuming rotations and movements when measuring complex details. [31]

Metrological Characterization of a Vision-Based Measurement System for the Online Inspection of Automotive Rubber Profile

An online stereovision inspection system has been implemented at the automotive manufacturer Metzeler's extrusion lines within their Automotive Profile Systems to guarantee dimensions within a certain interval. The extruded rubber profile is characterized by its dark and poorly reflecting surface. By taking two 2D pictures, from two different angles, it was possible to create a 3D reconstruction of the object. In order to achieve a high accuracy, a reference target was used whose geometrical dimensions were known to a very good degree of precision. This calibration had to be performed off-line. From a database containing specific key measurement techniques, the created 3D model could be evaluated and assessed to determine its compliance with the set tolerances. The implemented system met the requirements from the manufacturer as a quality inspection process for this type of product. The authors argue that the solutions adopted can be implemented for other vision measurement systems as well. [32]

Industrial Computer Tomography - A Universal Inspection Tool

According to Reinhart, the development and practical usefulness of computer tomography have been closely linked to the development of PC hardware and software. With the introduction of digital graphics and increased computing power, the technology became interesting for industrial applications in the 1990's. In order to make the CT-technology a competitive non-destructive testing tool, software able to handle large amount of data is necessary. By using a developed software, VGStudio MAX 2.0, a scanned object can be evaluated without first being converted into a scatter plot triangle grid system, thus reducing cycle times and measurement uncertainties in the file conversion. Instead the program is able to directly perform the metrological analysis from the voxel data. Tests have been performed on cylinder heads with known geometries, and shows that the developed software was able to reduce the total processing time from 90 minutes to 15 minutes. By reducing the number of conversions needed the processing time was drastically reduced and also resulted in an increased measurement accuracy due to fewer file conversions. [33]

Combining ESPI with laser scanning for 3D Characterization of racing tyres sections

The article examines two types of laser techniques, ESPI and laser scanning, and their application in the quality inspection of cross section of racing tires. ESPI, Electronic Speckle Pattern Interferometry, is a technique based on two laser beams, one being projected onto the object and one functioning as a reference, thus creating a high accuracy. Laser scanning on the other hand is based on triangulation by a reflection on a charge-coupled device sensor. The study showed that laser scanning was a full-good method for detecting surface abnormalities, while ESPI provided a higher accuracy and was able to detect material differences, such as different rubber compounds. The authors recommended laser scanning to be used in the overall surface inspection, while ESPI was able to generate a much deeper understanding of the individual tire components. [34]

Ultrafast dark-field surface inspection with hybrid-dispersion laser scanning

An ultrafast surface inspection technique was introduced demonstrating the possibility of scanning a circular object for defects as small as 10 µm at a speed of 3 m/s. The tests were carried out by the ultra-fast laser scanner as well as by an image sensor, on a dark surface, where a text in metallic ink was written. The results showed that the image sensor was not able to create a clear image, while the ultrafast laser sensor was. [35]

4.2. Conclusions from similar applications and implementation study

Leakage testing has been studied on food packages, in this case cups. Semi-rigid cups share similar material properties to the investigated polymer product, even though there are differences in for example toughness. The study described the complicity in stabilizing the internal pressure for soft materials due to high elasticity.

Ultrasonic non-destructive testing is being used in the tire manufacturing process on a large scale. The study brings up challenges in accuracy, but states that the resolution is sufficient to detect porosity and defects in the tred stock. The amount of generated data points is a challenge, where an increased resolution result in an exponential increase of data points. This results in the need of great computing capabilities in order to handle the large amount of data.
A challenge in the implementation of ultrasonic technologies is the requirement to be able to place detectors either next to the probe or on the opposite side. As a combination of rubber having density similar to water and complex geometrical features, an ultrasonic system will require a receiving probe on the opposite side.

A Machine vision system has previously been successfully implemented in the quality inspection of black rubber components, for measuring geometry and surface deviation on a detailed level. While a single camera system is able to inspect products in 2D, combining multiple cameras from multiple angles, a 3D model can be created. In the development of a vision system, it is of essence to find the right combination of camera and lightning source for the specific conditions and products. When implementing machine vision in a quality inspection, it is important to create an extensive library of references. The reference library has to reflect the range of accepted deviations in the production. If not, the risk of rejecting non-defective products is present.

When measuring the surface of soft objects, there is the risk of measuring a deformed surface due to the contact of the measurement equipment. To avoid this issue, one could change from a probe, which is in contact with the surface, to a laser beam, to assure that the surface is not altered by the testing equipment.

Using acoustic methods to detect defects in rubber is difficult. Since rubber is a high damping material, the transmission of sound waves are tough. Together with a small deviation from defects like cracks, the method has a limited performance. When provoking cracks, both the direction and location of the crack is of importance. For example, the location of a crack has to be near the surface in order to be able to detect.

Industrial computer tomography is a technology which is becoming more and more applicable as computing power is becoming less and less expensive. Four aspects are of interest when evaluating the applicability of industrial CT: measurement time, cost, resolution, and grey value contrast. These aspects are in conflict, and can prove difficult to find the right balance between. However, the competitiveness of industrial CT increases as computing power becomes less expensive, the overall technology more accurate, and calculating programs smarter. To be able to detect abnormalities when using radiation on polymers, the dielectric properties of the observed polymer is of interest. As technology develops, and especially since software is becoming more and more efficient, the total cost and measurement time (cycle time) continues to decrease. In order for industrial CT to become competitive in an industrial environment, it is important to assure that the latest and most suitable technology is used, as this can influence the overall cost.

Laser can be used to detect surface abnormalities, both by triangulation and by ESPI. By applying laser scanning, a full 3D model can be created, and the surface evaluated. ESPI is a powerful technology in reverse engineering, but not applicable when searching for surface deviations. Laser scanning can be used to retrieve great numbers of data in a short period of time, and thereby outperform a regular vision sensor in terms of data acquisition. Thus proving that fast laser scanners are suitable for surface inspection in high volume mass production and can be preferable over vision sensors.

5. Results

This chapter is divided into four sections; Current Situation Analysis, Quality Inspection Analysis and Improvement Analysis, together with a summary. The first section begins with a lean analysis of the current situation to reveal that an introduction of automation for the manual quality inspection is necessary to be able to increase the production rate. Technologies within the area of NDT is studied together with several suppliers, to verify the capability of each technology. Following is the process of evaluating each technology to identify an optimal level of automation, which result in the selection of the most suitable solution. Five possible solutions are identified, and a summary of the concluded results is presented.

5.1. Current Situation Analysis - a lean approach

This chapter will provide an overall analysis of the current production cycle by the creation of a Value Stream Map, locating the current bottleneck and closely examine the performance of this bottleneck from a cost perspective. Finally, an area of improvement will be presented.

5.1.1. Value Stream Mapping

A current Value Stream Map was created following the methodology presented by Suciu et al. Data was gathered through live observations and time taking as well as from interviews with operators, the production manager, the purchasing manager and the plant manager. The production is run on a forecast which is regularly updated based on customer demand. The raw material is delivered to an on-site warehouse in proximity to the production line. In the Value Stream Map produced, see figure 11, the production parameters measured were: number of operators, number of shifts, cycle time per polymer component, change-over time, and utilization rate.

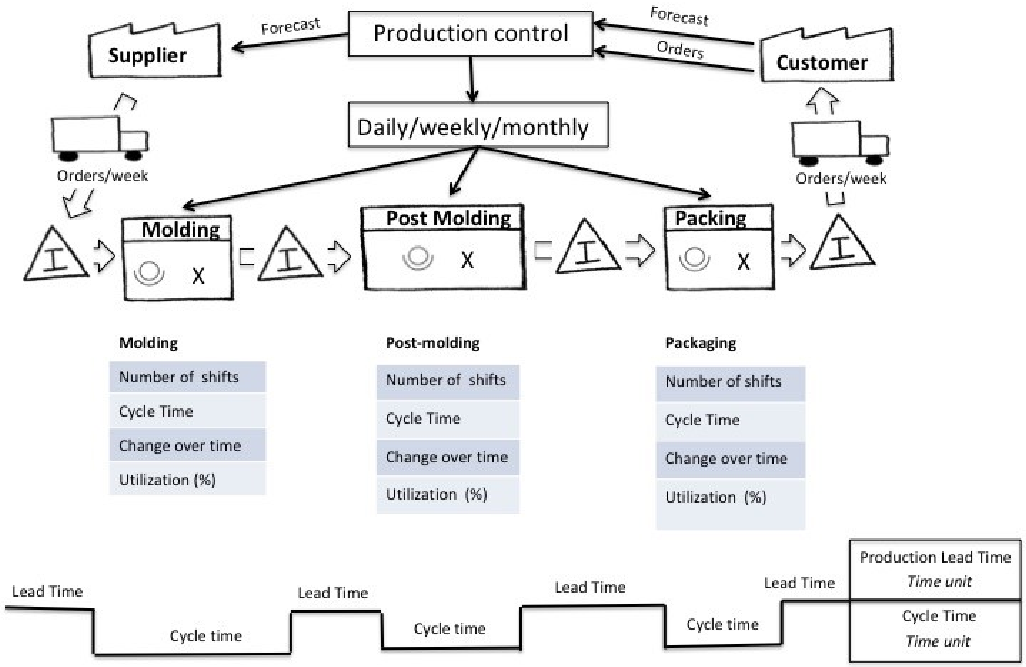

Figure 11. Shows the result of the Value Stream Mapping.

While the number of operators, shifts and cycle time were measurable through observations, the change-over time and utilization rate were gathered through interviews and from the ERP system. Following the molding process is the post-molding process, which contains the quality inspection. The quality inspection, see figure 12, is performed as the first step of the post-molding process and is conducted for each product. The last step in the manufacturing process is packing, before the product is shipped off. In between the molding and the post-molding process, as well as between the post-molding and packing process, inventories are being held. These inventories vary in size and lead-time depending on the current order situation, thus leading to approximations being made based on historical data. The inventory between the molding and post-molding process is held for two purposes: working as buffer for the post molding-process and for improved material properties. This is why the quality inspection needs to take place after material properties have been stabilized, in the post-molding process.

Figure 12. Shows the steps involved in the post-molding process.

The Value Stream Map created revealed that the current production process is unbalanced. The map also showed that the current production system relies on relatively high inventory levels. Because of material properties, the inventory between the molding and post-molding process is necessary, and thereby bound to be rather large.

5.1.2. Bottleneck Analysis

The bottleneck analysis is based on data gathered in the Value Stream Mapping and is focused on production capacity. Unit of measurement used was products per second, and was gathered through live observations over a number of days.

The molding process is a mostly automated procedure, illustrated in figure 13. Raw material is fed to the molding process without assistance of the operator and the process itself does not require any personnel. The operator is required mainly for the packing of the ejected products as well as for supervising the molding machines. The production rate is limited by the speed of the actual molding process.

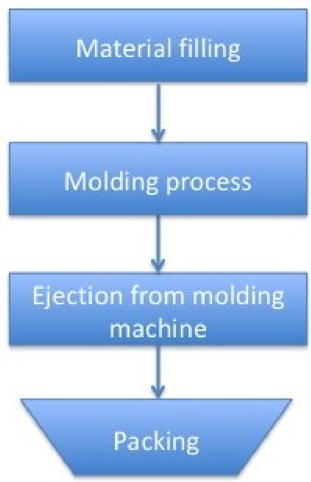

Figure 13. Shows the process steps involved in molding.

The working procedure in the post-molding process is divided into two parts: quality inspection and loading of the automated post-molding machine. The machine is run on a certain pace which is not influenced by the speed of the quality inspection. The results showed that the operator of the machine, which performs the quality inspection, is not always able to meet the machine pace. This results in a loss of production capacity. The bottleneck process in the post-molding process can therefore be seen as the manual quality inspection.

The packing process is divided into two steps: packing of the products into a sealed package which is then put into a larger package, see figure 14. The sealing of the package is automated while the filling is performed manually. The larger cartons are filled in a similar way, where the sealed packages are manually placed inside the larger carton. The carton is then automatically sealed and labeled, before being either shipped or sent to the warehouse. The production capacity at the packing station is mainly limited by the filling of the sealed packages.

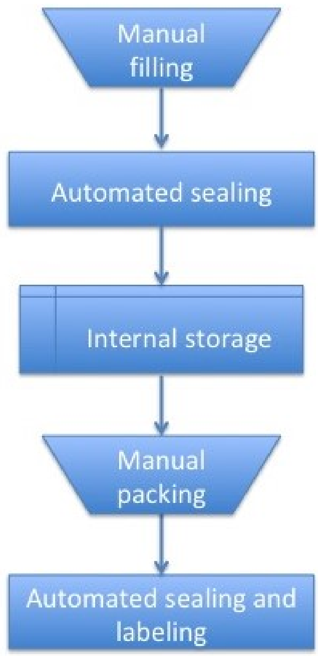

Figure 14. Shows the process steps involved in the packing process.

Table 1 shows the cycle time and production rate relative to post-molding, for each of the production processes. The cycle time only considers the average production time per workstation, while the production rate also considers the number of workstations. The production rate shows that the molding process has a 25% times higher production capacity and that packing has a 60 % higher production capacity, when only considering cycle time. This number does for example not take into account change-over time nor down-time. The decision of not including change-over time nor down-time in the production capacity is due to the fact that it varies greatly depending on demand and product model. The results show that when considering a stable and continuous flowing production line the post-molding process is a bottleneck.

Table 1. Cycle time and production rate relative to post-molding, for each of the production processes.

Process	Cycle time relative to post-molding	Production rate relative to post-molding
Molding	3.0	1.25
Post-Molding	1.0	1.0
Packing	0.625	1.6

There are two ways of increasing capacity by eliminating the current bottleneck. The first being an increase in the number of workstations, which means an increase in the number of post-molding machines and an increase in the number of operators. The second one being an increase in pace. The pace is today limited by the time needed to perform the quality inspection. Since the quality inspection today is performed manually, by skilled operators, the time required can be assumed to have reached a lower physical limit. Therefore, in order to increase capacity, while not increasing cost, the possibility of automating the current quality inspection will be investigated in this project.

5.1.3. Determine Investment Potential using Cost Model

The cost model developed by Ståhl was applied to the post-molding process. By modifying Ståhl's original model, an investment basis for a potential automation of the process was established. The model has been adjusted from the original model to be applicable to post-molding process only. This means that no material cost is present and the tool cost, because of its low cost compared to life time, has been included in maintenance cost. The modified model is shown below:

$$k = \frac{k_{CP}}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)\cdot\ (1-q_P)}\right) + \frac{k_{CS}}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)\cdot\ (1-q_P)} \cdot \frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right) + \frac{k_D}{60N_0}\left(\frac{N_0 \cdot t_0}{(1-q_Q)\cdot(1-q_S)\cdot(1-q_P)} + T_{su} + \frac{1-U_{RP}}{U_{RP}} T_{pb}\right)$$

Equation 12

Since each batch vary in size, an average batch size for the entire production has been calculated. Several weeks of data, consisting of hundreds of orders, was gathered from the company's ERP-system to calculate the average batch size. The results calculated have been validated by the purchasing manager as a good approximation of an average batch size.

The following parameters have been provided directly from the production manager through interviews:

- Quality losses, q_Q.
- Production rate losses, q_P.
- Downtime losses, q_S.
- Set-up time, T_{su}.
- Utilization factor, U_{RP}.

The following parameters have been provided directly from the plant manager through interviews:

- Machine-time cost during production, k_{CP}.
- Machine-time cost during downtime, k_{CS}.
- Salary cost, k_D.

The results from the modified cost model are illustrated in the following pie chart, see figure 15, where each cost segment is represented as a portion of the total cost per product.

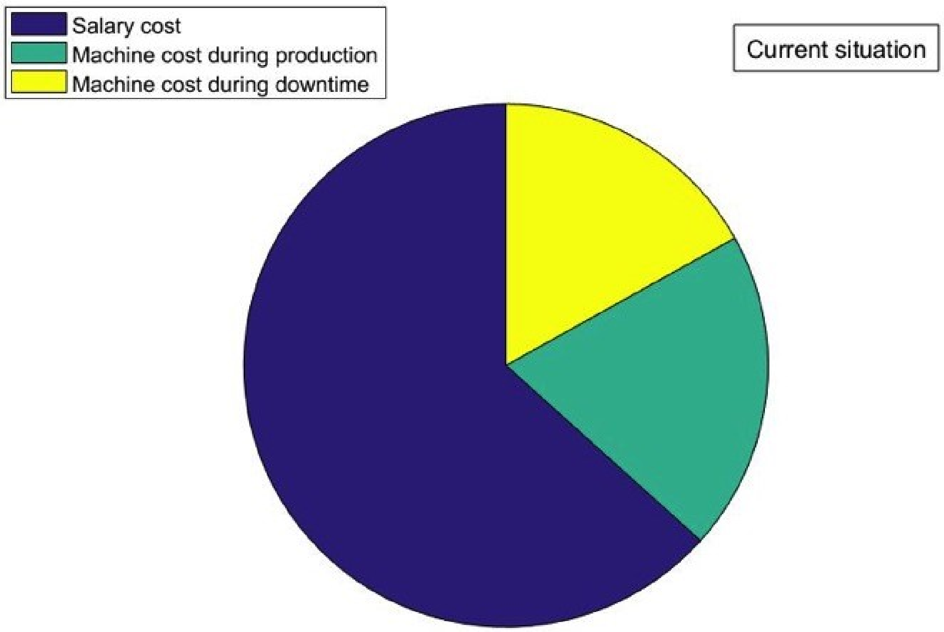

Figure 15. Displays the cost of each segment in the post-molding process.

5.1.4. Summary Current Situation Analysis

The results from the current situation analysis showed that the current bottleneck in the production system is located in the manual quality inspection. By analyzing the total cost, using Ståhl's cost model, it has been concluded that salary cost is the major cost driver within the post-molding process. The bottleneck analysis revealed that the manual quality inspection has reached a lower time limit at which it is possible to inspect the product. Following these two conclusion, the focus has been on investigating the possibility of automating the quality inspection station.

5.2. Quality Inspection Analysis

As a first step in the investigation of automating the quality inspection, the process of studying the current inspection methods and defects will be conducted. The chapter will summarize the different types of defects that can appear and how they can be categorized. This is followed by test results for each of the selected NDT's conducted on the specific polymer product.

The investigated NDT's have been selected based on material properties of the specific polymer product. The product itself is black, cylindrical shaped and like most polymer materials, dielectric. It can also be described as non-magnetic, damping and highly elastic. The area of use must also be considered, since the product requires high standards in terms of material purity and absence of regions prone to contamination.

5.2.1. Description of Defects

A description of defects are available to the employees at Trelleborg. The first step was to analyse the list of possible defects and categorize them into type of defect and location. The list originally contained 15 separate defects. These 15 defects and their possible locations were translated into three categories: cracks, surface defects, and geometry defects. The defects can appear in 19 possible locations, both on the outside and inside of the product. These three categories, together with their location, were determined in collaboration with suppliers and their experts within each respective field. The new and extended list of defects are described in general terms and categorized as shown in table 2.

Table 2. Categorization and description of defects.

Geometry defects	Surface defects	Cracks
• Geometry defect located at the inside and top. • Geometry defect located at the outside and bottom. • Geometric processing error on the top. • Geometric processing error at the bottom. • Geometry defect from the molding process.	• Surface defect 1 at the inside of the top. • Surface defect 1 at the outside and bottom. • Surface defect 2 at the inside of the top. • Surface defect 2 at the outside and bottom. • Surface defect 3 at the inside. • Surface defect 3 at the outside. • Surface defect 4 at the lower outer part of the product. • Incorrect labeling (treated as a surface defect).	• Large thoroughgoing crack on the top. • Crack, not thoroughgoing, on middle section. • Crack, not thoroughgoing, on bottom section. • Delamination on the top. • Small thoroughgoing crack on the top. • Small thoroughgoing crack on the bottom.

The 19 defects were closer studied and attempted to be quantified. The results showed that all geometry defects and cracks were able to be quantified, while surface defects did not have such specifications available.

5.2.2. Test Results

The test results have been conducted through possible suppliers. In each technology field, two or more competitive suppliers, except for leakage test, were invited to perform initial tests and propose suitable solutions.

5.2.2.1. Vision

The results provided by the suppliers' tests indicate that cracks and surface defects are difficult to detect. The challenge in these areas is mainly a combination between finding the correct lighting and resolution. Since the location of the defects are not pinpointed exactly, but can instead appear in a more general area, the resolution cannot always be as high as needed to guarantee a correct computer analysis. For geometry defects, several cameras are preferable, where each camera is focused on a specific part of the product to increase the accuracy by increasing the resolution. Installing multiple vision system cameras together with sufficient background lightning, may cause interference between the lighting sources. It is of essence to assure that no disturbing lights are present in the quality inspection, and may require a separation of each vision camera system. The advantage of using a vision system camera is the ability to quickly, usually in under one second, gather information and perform quality measurements such as: lengths, angles, roundness, and parallelism. A second approach is to compare the product to a predefined correct template. This can be achieved well under the targeted cycle time and the needed investment in the actual hardware for one vision inspection station is estimated to approximately 30 000-70 000 SEK.

5.2.2.2. Laser

The results provided by the suppliers and from tests performed together with a manufacturer, shown in figure 16, suggests that laser point sensors can provide a sufficient quality inspection for geometric and surface defects located on the outside of the product. The tests show that quantifiable surface abnormalities on a small scale can be detected and thereby also automated. This is also the case for geometry defects, which are larger and easier to detect. To achieve the required resolution, it is suggested to use two or three connected sensors simultaneously, each focusing on a specific part of the product. By using multiple laser point sensors and rotating the entire polymer product, a 3D model can be created from which the surface and geometry can be inspected. Cracks are difficult to detect due to the flexibility of the material, thus sealing the cracks when no force is acting upon it, resulting in no quantifiable deviation on the surface.

A challenge when scanning the polymer product will most likely be the speed at which the product can be rotated without deflecting. The actual cycle time of a laser scanner is within a few seconds, thus meeting the cycle time requirements. In the tests performed, the rotating speed was set to 30 rotations/minute, which would result in a cycle time of 2 seconds, and the required cycle time can thereby be met. The advantage of using laser scanning as an inspection method is the robustness. The wavelength used is highly unlikely to be interfered by the surrounding environment. This means that a laser scanning quality inspection can be easily implemented in the current production system. The cost for one of the investigated laser point sensors varies between 100 000 and 150 000 SEK.

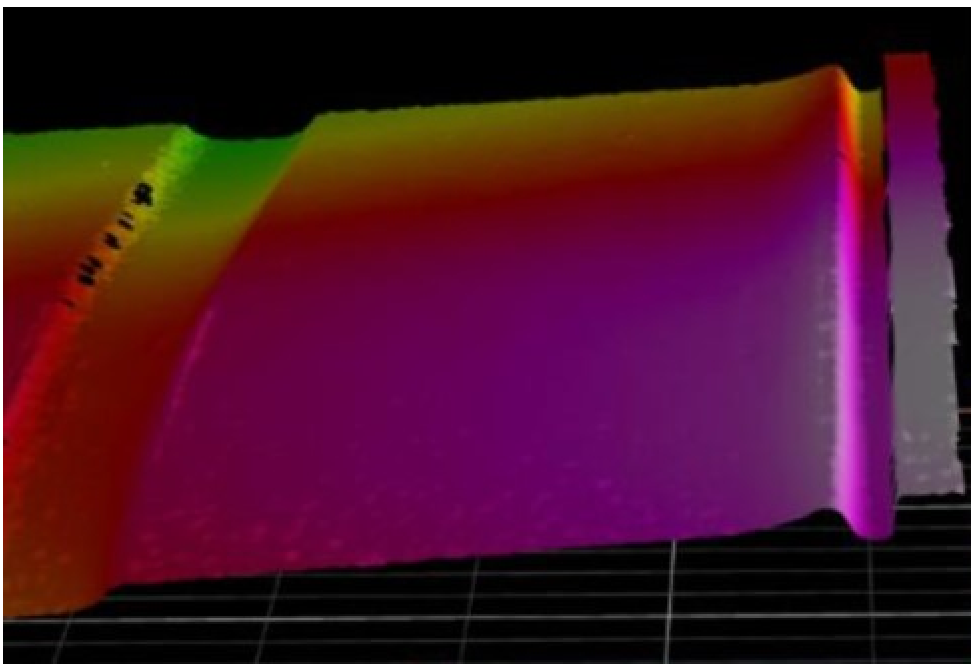

Figure 16. Displays test results from a laser scan.

5.2.2.3. CT/X-ray

Two suppliers have been contacted and asked to perform tests. The results showed that all of the defects are possible to detect. The tests were performed on a type of CT which have a cycle-time of approximately 15 minutes, and the result is shown in figure 17. The resolution of the CT heavily depends on the proximity to the scanned product. The smaller the defect, the closer the product needs to be placed to the X-ray source, thus increasing the cycle time. For geometry and surface defects, the scanning process can be performed in a large and automated CT currently on the market. These types of scans can be performed in matter of minutes and hold several products at once, thus reducing the cycle time to approximately 40 seconds. However, to be able to detect crack formations, a more advanced and accurate CT machine is required. The cycle time will increase to 15 minutes and the scan can only be carried out on one product at the time. The advanced CT operation will most likely not be able to automate, and instead require a skilled operator to perform the inspection on the created 3D model.

By using a CT scanner in the quality inspection process, a deep and precise understanding of the product can be achieved. This information can be beneficial in the development of new models and production processes by being able to compare a model to the actual outcome. Because of the relatively high cycle time, implementing a CT inspection system will require multiple machines which in turn will increase cost. The cost of a CT scanner lies between 3,5 and 5 million SEK.

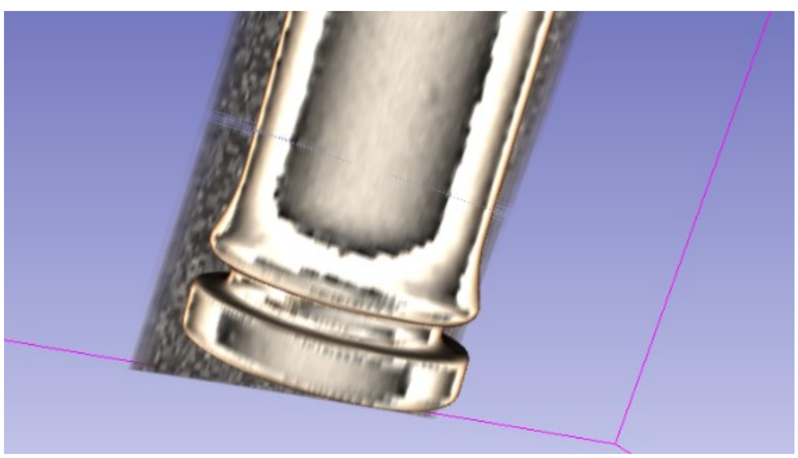

Figure 17. Displays test results from a CT scan.

5.2.2.4. Ultrasonic

The test results from ultrasonic testing have been negative. Both of the inquired suppliers reported back difficulties with the polymer material. Because of material properties, the signal was not able to give rise to a correct echo and the geometric features of the product resulted in difficulties to place a receiving probe on the inside. If the product had had a simpler shape, for example a flat surfaces or a sufficient large thoroughgoing hole, ultrasonic testing may have been possible even with the current material properties. However, it is unlikely that ultrasonic testing would have been able to detect smaller defects, such as small cracks and surface defects, of the polymer product due to very small differences in the material.

5.2.2.5. Leakage Testing

A leakage test using compressed air was performed by a supplier, and the result showed that it was possible to detect the large thoroughgoing crack on the top. The top was plugged and an overpressure of 50 mbar was initiated from the bottom. If the leakage was more than 5 mm^3/s the system alarmed with a red light, to signal the presence of a defect. The supplier considered leakage test to be an easily implemented in-line solution. The price of the instruments and fixture is estimated to 150 000 SEK.

5.2.3. Summary Quality Inspection Analysis

Table 3 summarizes the results provided from the contacted suppliers. Each defect has been categorized as a crack, geometry or surface defect. The table only considers the potential to automate the quality inspection for each specific defect. This requires quantifiable data and methods available to perform an evaluation. The results do not evaluate the actual capability of the technologies but focuses on the potential to automate the inspection of the defects.

Table 3. Summary of the investigated technologies and their ability to detect defects.

		Technology				
Type of Defect	**Description**	Vision	Laser	CT	Ultra sonic	Leakage test
Geometry defect	Geometry defect located at the inside and top of the product.	-	-	Yes	-	-
	Geometry defect located at the outside and bottom.	Yes	Yes	Yes	-	-
	Geometric processing error on the top.	Yes	Yes	Yes	-	-
	Geometric processing error at the bottom.	Yes	Yes	Yes	-	-
	Geometry defect from the molding process.	Yes	Yes	Yes	-	-
Surface defect	Surface defect 1 at the inside of the top.	-	-	Yes	-	-
	Surface defect 1 at the outside and bottom.	-	Yes	Yes	-	-
	Surface defect 2 at the inside of the top.	-	-	Yes	-	-
	Surface defect 2 at the outside and bottom.	Yes	Yes	Yes	-	-
	Surface defect 3 at the inside of the product.	-	-	Yes	-	-

	Surface defect 3 at the outside.	-	Yes	Yes	-	-
	Surface defect 4 at the lower outer part.	-	Yes	Yes	-	-
	Incorrect labeling (treated as a surface defect).	Yes	Yes	Yes	-	-
Cracks	Large thoroughgoing crack on the top.	-	-	-	-	Yes
	Crack, not thoroughgoing, on middle section.	-	-	-	-	-
	Crack, not thoroughgoing, on bottom section.	-	-	-	-	-
	Delamination on the top.	-	-	-	-	-
	Small thoroughgoing crack on the top.	-	-	-	-	-
	Small thoroughgoing crack on the bottom.	-	-	-	-	-
Number of detectable defects		**6/19**	**9/19**	**13/19**	**0/19**	**1/19**

Table 3 shows that 14 out of 19 defects can be detected. The results show that most of the geometry and surface defects can be detected with the technologies investigated. It also shows that cracks, both on the inside and outside of the product are difficult to detect. It can be concluded that ultrasonic testing does not fulfill the requirements for the detection of defects and is therefore not considered as a suitable inspection technology. The rest of the investigated technologies: vision, laser, CT and leakage testing, all show potential to be implemented in an automatic quality inspection. The test results in this report have not included any provocation, such as bending or squeezing, of the product. This is due to the automation complexity involved in the creation of such a system.

The challenge remains to find a suitable implementation strategy where cost, possibility to automate and level of automation is optimized. These factors needs to be considered from a practical and lean perspective to make sure that improvements can be implemented without affecting the current production negatively. The next chapter will evaluate how this can be achieved in the most efficient way.

5.3. Improvement Analysis

The improvement analysis will focus on future implementation scenarios of an automated quality inspection. The first step in this process will be to determine which parameters future scenarios should be evaluated upon. Together with Trelleborg, four criterias have been established. These criterias will be evaluated for each of the investigated technologies together with a comparison between required investments, compliance with a lean perspective, and an optimum level of automation. Finally, five possible cases will be described from a cost perspective.

5.3.1. Evaluation of Solutions

Three main objectives have been established together with the plant manager in terms of automating the quality inspection:

- Assure an equal or improved detection rate of quality defects.
- Assure that the production volumes can be met and remain economically profitable.
- Compliance with today's production processes and flexibility for future changes.

The assessment criterias from management have been further developed for each of the quality inspection technologies into the following:

- Ability to detect sought defect.
- Capital expenditure for the quality inspection technology.
- Scalability.
- Flexibility in detection of new defects.

To evaluate investigated inspection technologies, the ability to detect sought defects must be met, followed by an evaluation of the remaining criterias. The ability to detect sought defects is the most crucial above all other criterias. Capital expenditure is considered as a consequence of the objective to increase the capacity while at the same time maintain the product's quality level. The capital invested should therefore be evaluated based on the number of detectable defects, since this affects the possibility to reduce the total time needed for manual inspection, and thus increase the production capacity. The third criteria, scalability, is of value to be able to adjust the new system to potential changes in the production. Production systems need to have a high flexibility to be able to adapt to changes of production processes without affecting the overall capacity and quality. The system must be able to adapt to changes in the production, for example due to an increase or decrease in demand. Also, it is of importance to consider the flexibility and expandability of the technology to detect new defects in the near future. When handling a polymer material, small changes in composition can have a large impact on the final result. This leads to the possibility of new defects occurring, that must be able to cope with. Therefore, the inspection system must have a high technology level, while also the potential to detect defects of new characters.

5.3.2. Evaluation of Scalability and Flexibility

The ability to detect sought defects has been presented in table 3, and the initial capital expenditure will be covered in the following two sections: Level of Automation and Future Scenarios. In this section, flexibility and scalability will be investigated from a lean perspective for each technology and then evaluated from a practical point of view. This means that scalability and flexibility will not be directly compared to initial capital expenditure and ability to detect defects, but instead from general lean guidelines.

5.3.2.1. Computer Tomography

Computer tomography is a technology which requires large investments in the surrounding production system in order to automate. Since the machine itself is encapsulated, loading and unloading machinery is needed as well as sufficient buffer capacity in order to minimize the CT scanner's downtime. This can result in difficulties in the implementation phase and may create a sense of uncertainty for the people working at the post-molding process and who are responsible for the quality. This is due to the inspection process being difficult to overlook and thereby also difficult to trust. Since testing is of great importance to minimize production disturbances, it can prove difficult to introduce a CT scanner without affecting the entire production system. CT scanning can also create scaling difficulties in terms of potential downscaling since the cycle time is fixed. This means that inspecting the polymer products for only a few of the known defects will most likely not reduce the cycle time, thus decreasing the overall performance of the CT. The overall scalability of computer tomography can therefore be seen as low.

By inspecting the products by computer tomography, an exact 3D-model can be created, which in turn can be compared to the original CAD model. This means that all possible deviations from the original model can be inspected for. In the scenario of new defects, previously unknown, a CT scan have the potential of detecting these defects. This means that automation flexibility in CT scanning is considered high.

5.3.2.2. Vision

The hardware cost is fairly low, and together with the small size of cameras and lightings, the scalability, both in terms of downscaling and upscaling, of a vision system is good. A possible downside is the interference between different lighting sources for newly added vision systems, which may result in the need of a new inspection station, and therefore results in a lower scalability.

A vision inspection system can overall be considered easy to implement since it will have a limited effect on the overall production system and can easily be scaled up. It is also an intuitive system which operators can work side by side with, without risking their own safety. The technology is capable of detecting geometry defects, and some of the easier surface defects, which in the end limits the capability of detecting new defects. On the other hand, since the data gathered can be processed by a several different types of software, the flexibility for the detection of geometry defects is high.

5.3.2.3. Laser

Compared to a vision system, the hardware is more expensive. However, the actual size of the laser sensor is smaller since the system does not require certain supporting lights. Because of the small size of the hardware, lasers can easily be implemented in the current production system, and in a later stage be expanded for an entire quality inspection. Depending on type of laser and required resolution, safety precautions may need to be taken. Certain types of wavelengths can be harmful if exposed to the naked eye and it may therefore be necessary with some sort of encapsulation in order to avoid this risk.

The laser technology is able to detect geometry and surface defects, and thereby increases the capability to detect new defects in both areas. The construction of a 3D-model is possible, which supports the ability to cover larger parts of the studied object, and thus increasing the possibility to examine new surfaces and sections. Similar to the vision system, data gathered by the laser is handled by a software that is flexible, and thereby easy to introduce to new defects.

5.3.2.4. Leakage Testing

Leakage testing is a technology that is easy to implement in the current production system. It requires its own inspection station since it needs to be in contact with the actual product, but the cycle time at such a station will most likely not affect the total production rate. It is a safe and intuitive inspection method, which have the potential to function well side-by-side with operators. However, since the leakage testing is a technology only capable to detect large thoroughgoing cracks, the flexibility of the quality inspection station would be highly limited to these types of defects, and the total flexibility is therefore low.

5.3.3. Level of Automation

In theory, it is possible to reduce the number of operators at each workstation by a specific percentage, which then reduces the salary cost by the same percentage. The result for the cost reduction for each of the technologies is shown in figure 18, where CT results in the highest savings per part and leakage testing the lowest. The level of automation is based on the number of defects able to automate the detection of. In this scenario the potential of lowering the salary cost is dependent on the level of automation. The results are gathered from table 3 in the summary of the Quality Inspection Analysis, and matches each of the technologies against the listed defects.

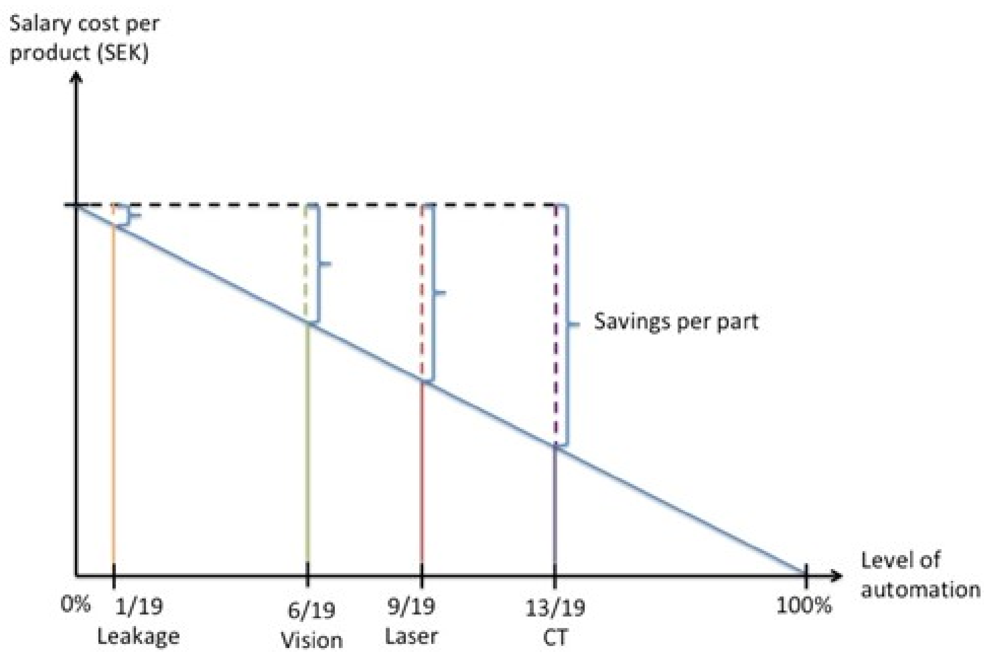

Figure 18. Illustrates the theoretical linear relation between level of automation and salary cost.

However, in reality a decrease in number of workers in the production system must be of an integer which results in a stair-decline as shown in figure 19. The stair-decline reflects the situation in the investigated production system since the demand of operators is not of a linear relation. If the number of operators (n) is large, the steps will be smaller and the appearance of the decline will look similar to the theoretical model in figure 18.

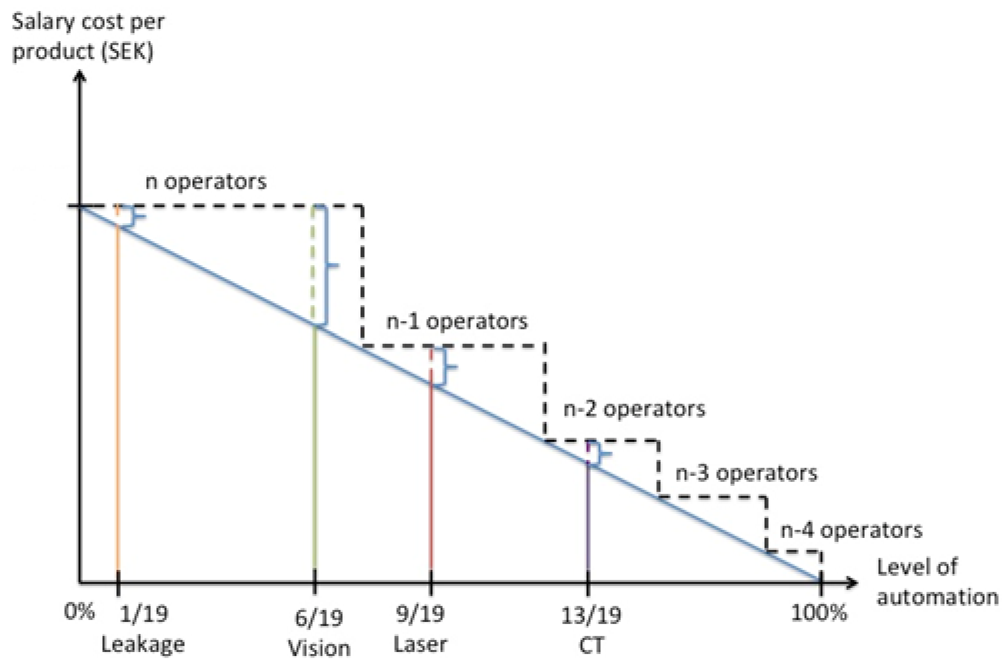

Figure 19. Illustrates the theoretical linear relation between level of automation and salary cost, and an approximation in the reduction of operators.

As a result of this analysis, an increase of automation, in the end, does not necessarily reduce the total salary cost since the increase of automation does not outweigh the time/work previously required for the operator to perform the same task. One aspect is that the operator can use its freed up time to perform other tasks, and the salary cost will instead be spread on several workstations, this may however prove difficult to implement. The character of the steps are becoming smaller and smaller, due to the fact that when automating the detection of larger and more visible defects, the amount of time saved for the operator becomes less. When automating the detection of less detectable and thereby more time consuming defects, the amount of defects required to replace the operator is lower.

5.3.4. Future Scenarios

In order to determine the most cost efficient level of automation, five cases have been studied, shown in table 4. The aim is to find a balance between cost and the actual performance of the automated quality inspection. To do this, each of the technologies have been evaluated based on initial cost of the hardware. These costs have then been compared to the number of detectable defects and the number of reduced operators.

Table 4. Presents the five cases, the technology investigated, level of automation and the estimated initial cost

Cases	Technology	Level of Automation	Initial cost
Case 1	CT	13/19	25M SEK
Case 2	Laser	9/19	600' SEK
Case 3	Vision	6/19	280' SEK
Case 4	Leakage Test	1/19	150' SEK
Case 5	Laser + Vision	9/19	520' SEK

Case 1

In this scenario, the quality inspection is being performed by an industrialized CT scanner, which is able to detect 13/19 defects. This means that the need of a manual quality inspection will still be present for the most difficult defects. Assuming a linear relationship between type of defect and time required for quality inspection, this results in an automation level of approximately 70 %. Because of the high cycle time, approximately 40 seconds per CT machine, multiple machines will be required in order to retain the current production rate. The total investment, per production line, will therefore be approximately 25 million SEK. This investment will generate a partly automated quality inspection system within itself since only the transportation of products will be further required in order to fully automate the system.

Ståhl's cost model shows that this investment will result in a cost increase of 150 %, which cannot be tolerated. Therefore this automated quality inspection option is rejected and is not recommended as a future solution.

Case 2
A laser based quality inspection system has the potential of detecting 9/19 defects. From test results it has been concluded that a minimum of four laser scanners will be required to inspect the entire polymer product to a satisfying resolution. Again, assuming a linear relationship between type of defect and time required for quality inspection, laser scanning have the potential of achieving an automation level of nearly 50 %. To achieve this level, an initial hardware investment of 600 000 SEK will be required. This results in a lowering of the part cost by 26 %. Since the price estimation only considers the actual hardware, the 26 % cost reduction in the post-molding process can be expected to be lowered when the total cost of automation is considered.

Case 3
Implementing a vision based system will result in an automation level of approximately 32 %. The detectable defects are mainly larger geometry defects and only represent 6/19 of the ones identified. However, since vision technology is relatively cheap, with an initial investment of 280 000 SEK, the cost savings per product have been calculated to 13 %. This provides a limited capacity for further investment costs in the automation process.

Case 4
Leakage testing have been investigated to determine the impact the solution would have on the quality inspection system. Since the number of defects the system would be able to detect is limited to only one, the investment potential is considered low. With an estimated price of 150 000 SEK and the ability to detect 1/19 defects, the cost per product would increase by 1 %. This means that the economic incentive can only be motivated by an increase in quality performance. The assessment is that the quality inspection will not be able to increase performance by applying leakage testing. Therefore, leakage testing is rejected as a possible future solution.

The results presented in the four cases are summarized in figure 20, where each technology have been plotted against their impact on the total cost. In this scenario, only the total investment cost and level of automation, i.e. number of reduced operators, are considered. The results show that case 2 is the most cost efficient solution.

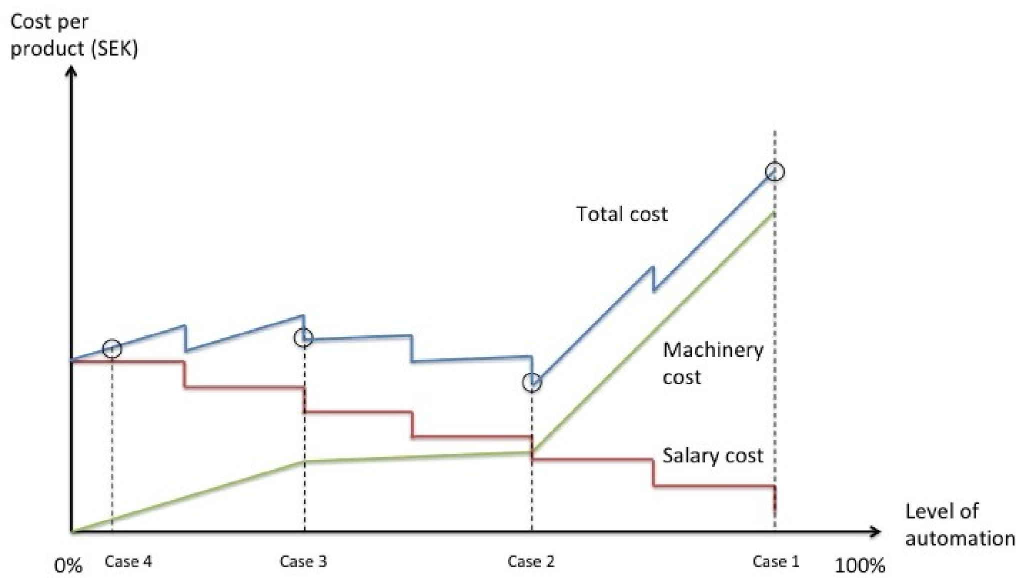

Figure 20. Shows the level of automation for each case, and the impact this would have on the part cost.

Case 5

The results of case 1 and 4 showed that CT and leakage testing will cause an increase in the overall cost, and that laser and vision sensors are the only two technologies which have the potential to lead to cost savings. Therefore, an additional case have been created, which combines the cheaper vision sensors with the more accurate laser sensor. The laser sensor is applied where high accuracy is needed and vision sensors is used in situations where suitable. The results show that a combination is technologically possible, and will reduce the initial investment to 520 000 SEK, while still being able to detect 9/19 defects. This would lead to a potential cost saving of 28 % compared to the current production and an automation level of nearly 50 %. Case 5 is thereby the preferable case, and allows for the highest potential cost savings which has been illustrated in figure 21.

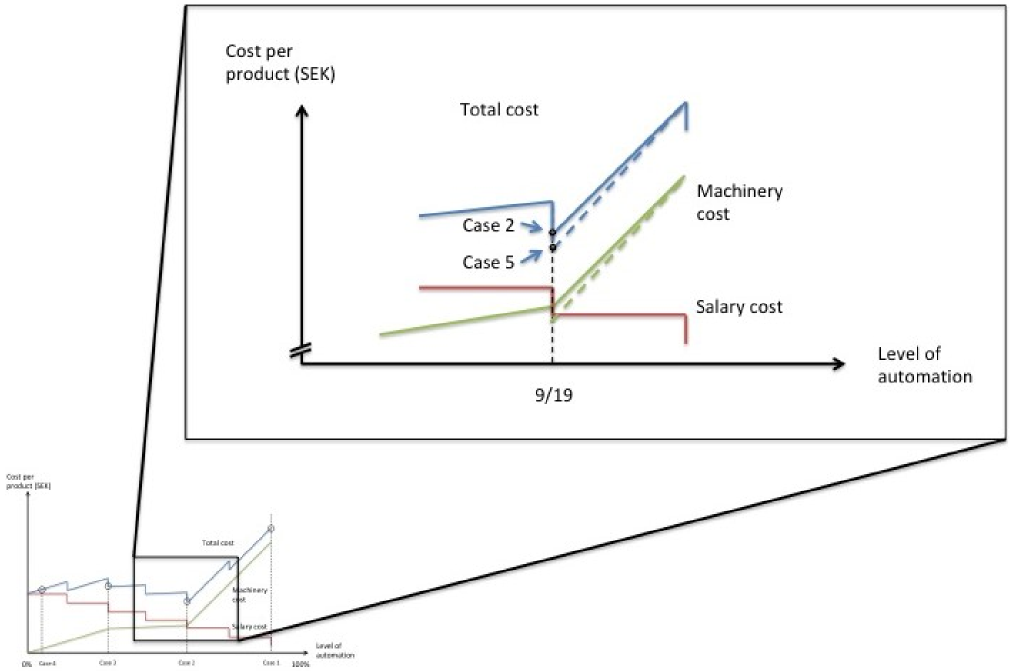

Figure 21. Shows an enlarged version of the total cost per product and the impact of case 5.

5.4. Summary of Results

5.4.1. Summary Current situation analysis

The Value Stream Map revealed an unbalanced production process where the post-molding process was determined as the bottleneck. The modified cost model revealed that salary cost represent a majority of the total cost in the post-molding process. To achieve a reduced salary cost and an increased production rate, an introduction of automation was investigated.

5.4.2. Summary Quality inspection analysis

The quality defects can be divided into three groups: cracks, surface defects and geometry defects. Cracks are difficult to detect, and especially difficult to automate the detection of. This is due to the complexity of the material. Leakage testing can be used for the detection of large thoroughgoing cracks. Surface defects can be detected both on the inside and outside of the product by the use of computer tomography, and on the outside by laser scanning. Geometry defects have a high likelihood to be detected with an automated quality inspection system, by using either vision sensors, computer tomography or laser scanning. In total, 14/19 defects are able to automate the detection of.

5.4.3. Summary Improvement analysis

Together with Trelleborg, four criterias have been established to evaluate each of the technologies: the ability to detect sought defect, capital expenditure, scalability and flexibility.

Laser and vision sensors have a medium to high flexibility, where laser performs best out of the two. Much of the flexibility of future production scenarios is limited by a potential software's ability to be programed to distinguish new types of defects. CT have a high flexibility but a low scalability, while the opposite is true for leakage testing. Laser and vision technology is efficiently scalable. The conclusion is therefore that vision and laser sensors are the overall best solutions.

Each technology has been studied regarding their influence on the level of automation, and how these affect the total cost by reducing the number of operators required in the quality inspection process. The analysis showed that some technologies, for example leakage test, may not reduce the number of operators due to the fact that the level of automation is low, and the covered defects does not eliminate enough inspection time to remove an operator. At the same time other options, such as laser, may reduce the salary cost enough to motivate an investment. To be able to provide recommendations, the reduction of operators needs to be combined with the capital expenditure for each of the technologies. Five cases were therefore studied, where case 1-4 covered each technology on its own and case 5 handled a possible combination of laser and vision.

Case 5 resulted in the highest cost reduction per part (28 %) closely followed by case 2 (26 %), while the others resulted in either a minor decrease (case 3 with 13 %) or increase of the total cost (case 1 and case 4 with 150 % and 1 % respectively).

6. Discussion

6.1. Discussion Current situation analysis

The current situation analysis was performed in order to develop an understanding of the production processes involved. In order to do this, a Value Stream Map was created which illustrated the flow of products and production capacity. Due to the limited time and complexity of the production, assumptions on parameters such as lead time, change over time and cost factors for the machines were made in order to create a general model. Measured parameters such as cycle time, may have insecurities due to two major reasons. One being that several, processes are heavily dependent on the operator, which results in the inspection time varying depending on who is performing the task. In order to provide as fair and general results as possible, an average time was calculated.

The second factor is the amount of data collected to determine the cycle time. Because of limited time in the creation of the VSM and the sensitivity of directly measuring operators performing tasks, the available data were somewhat limited. These two factors may have influenced the accuracy of the determined cycle time, but most likely to a limited degree.

When creating the VSM, the suggested approach from the theory is to gather all involved personnel in one room and together create the VSM, in order to open up for discussion. This was not possible due to limited time frame, and instead information was gathered through interviews. This may have resulted in information not being questioned by other team members in the organization. However, none of the information gathered was contradicted by the employees being interviewed, thus suggesting that the information provided was accurate.

6.2. Discussion Quality inspection analysis

The quality inspection analysis was a major focus areas within this thesis. The initial objective was to provide implementable solutions to a minimum cost, and to perform actual tests of the solutions in-line. This objective had to be adjusted due to the fact that certain key criteria were not able to be set. An example of these key criterias was a complete quantifiable specification of requirements. This specification has to be developed by Trelleborg and their customers. A second being the complexity of polymer materials. There is a risk of new defects occurring due to the nature of the raw material, which lead to the insight that an automated quality inspection will have to be able to be adjusted or extended to handle new types of defects. An adjustment of the original objective was made towards clarifying possible solutions for an automated quality inspection and evaluating these based on Trelleborg's prerequisites.

Even though multiple suppliers of each technology have been contacted in order to have multiple inputs, it can be assumed that not all have put an equal effort into the evaluation of the product's defects and the quality inspection solution to it. This can be due to limited specifications or experience working with the specific type of product and material. However, the process of establishing an exact price and performance for each of the presented technologies is an iterative process that requires much time and resources on testing, since it must be tailored to the specific product and production line. The actual price might therefore not be able to specify exactly until the fully automated quality inspection process is in place, even though more accurate estimations can be made along the way. A second consideration which must be kept in mind, is that the suppliers quoted are aware that the price indications given will be made available to the management team, which means that there may be hidden costs in their offers. This risk must be considered and avoided throughout the rest of this project. This is a project which will most likely last for years, even though actions can be taken and partial automation can be started at this stage.

6.3. Discussion Improvement analysis

A major challenge in this thesis has been to establish evaluation criteria and especially comparing criteria against each other. This is due to the fact that when automation is to be introduced, it has to be considered from a number of perspectives, many of which are not able to quantify, but instead relies on subjective evaluations. In the report, these types of comparisons had to be separated. Soft parameters, such as scalability and flexibility, and hard parameters, such as cost and level of automation, have been evaluated separately in order to clarify what type of evaluation criteria that is discussed. However, these evaluation criteria must in the end all be considered together in order to provide recommendations. It is therefore important to be aware of this process.

The thesis brings up the complexity involved in defining the time required in the inspection of one specific defect. Since the operators are highly skilled, they can often check for multiple defects at once. Reducing the number of defects to look for, might therefore not reduce the time needed linearly. The level of automation is considered from a theoretical point of view while in reality the time needed can vary greatly between operators and thereby also the level of automation. Automating the quality inspection for 50 % of the defects might result in a 50% time saving for one operator, while it only leads to, for example, 30 % for another. This can be due to the first operator being more skilled and being able to inspect for the other 50 % of defects in half of the time available today.

The total cost when introducing automation in a system is difficult to estimate. It is easy to only consider the cost of the hardware, but there are several other factors affecting the total cost. One of them is the implementation cost, and can differ greatly depending on if an already automated system is in place. It can be difficult to synchronize an automated system, for example conveyor belts and robots, with a control system containing sensors. The cost will therefore increase as more people and time is needed to combine several individual systems into one. A major cost not considered in this thesis is the cost of the implementation of a software for the quality inspection system, and the time needed for repeating tests and modifications until the system can reach a satisfying level accuracy. The relationship between the investment cost in hardware and the total cost for the entire automation varies greatly depending on type of technology chosen, and is difficult to estimate. While the cost of implementing computer tomography in the production line is estimated to be approximately equal to that of the hardware, the relationship for laser and vision is many times greater than that of the hardware. The total cost is also highly dependent on what type of automation Trelleborg is aiming for, and is in the end a long term strategic decision, which this thesis can provide some answers to.

7. Conclusion

In this thesis, the identification and realization of an improvement have been analysed. The conclusions presented are based on the current situation analysis and the investigated cases in the improvement analysis. The solution presented is based on case 5, which is considered to be most suitable for the production system.

Perform a lean analysis of the production system and identify an improvement area

The bottleneck in the production system has been identified to the manual quality inspection in the post-molding process. In order to increase the production rate while at the same time not increasing the cost, an automation of the quality inspection is recommended. Ståhl's cost model has been modified to be used for the investigated production system, to determine the potential cost savings per product and year.

***Generate concrete solutions for how the identified area can be improved in terms of*:**

Cost:
From a cost perspective, an optimal level of automation is achieved by a combination of vision and laser sensors. This solution would result in a level of automation of approximately 50% and require an initial hardware investment of 520 000 SEK. However, it should be noted that the hardware investment does not necessarily reflect upon the total cost of automation.

Performance:
The recommended solution is a combination of high accuracy laser sensors and vision technology. Laser sensors are applied and automated for the detection of surface defects, and the less expensive vision sensors are used for the detection of geometry defects. This solution would result in an automated system with a medium to high flexibility and scalability.

A lean perspective:
From a lean perspective, introducing new technology is a risk and should only be done after thorough testing. As a starting point, the automation of the entire quality inspection system has to be considered and planned for. The next step is the implementation of the sensor solution presented above in one of the post-molding stations. Once this have been

achieved and is considered reliable, it should be implemented in all post-molding stations.

8. References

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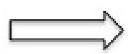
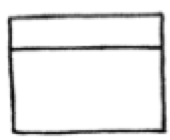
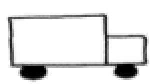
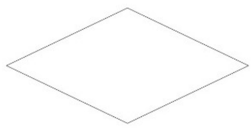
9. Appendix A

The content from appendix A table 1 is from *An introduction to value stream mapping and analysis* by J. Langstrand [36] and appendix A table 2 is from *Flowchart Symbols Defined* by N. Hebb [37]

Appendix A table 1. Symbols and their definition in the value stream mapping process

	Information
	Transportation of materials
	Operator
	Operation
	Inventory/buffer
	Shipment to/from external sources
	Customer/Supplier

Appendix A table 2. Describes the symbols involved in the process flowcharts.

	Manual operation
	Decision
	Process
	Internal storage