Strategies to reduce efficiency losses during production rate reductions

A master's thesis conducted at Scania

Authors:
Jacob Olofsson
Fredrik Persson

Supervisors:
Jan Olhager, Faculty of Engineering, Lund University
Magnus Rosvall, Scania CV AB

Preface

This master's thesis has been conducted during the spring of 2014 at Scania's cab production site in Oskarshamn, Sweden. It has been the final part of our education, Master of Science in Mechanical Engineering, Faculty of Engineering, Lund University.

The work has been highly valuable and great fun thanks to numerous individuals. We would like to thank all employees of the top coat paint shop in Oskarshamn who have always helped us when needed. Special thanks are directed to our supervisor Magnus Rosvall for great input during the entire time period. Special thanks are also directed to our desk neighbor Pernilla Zackrisson who was asked "Do you have time for one brief question?" countless times this spring.

Finally we would like to thank our supervisor Jan Olhager, Faculty of Engineering, Lund University for his feedback and guidance.

Lund, May 30th 2014

Jacob Olofsson

Fredrik Persson

Sammanfattning

Titel: Strategier för att reducera effektivitetsförluster vid taktnedgångar

Författare: Jacob Olofsson
Fredrik Persson

Handledare: Jan Olhager, Lunds Tekniska Högskola, Lunds universitet
Magnus Rosvall, Scania CV AB

Bakgrund: Företag utvecklar och förbättrar sina tillverkningsanläggningar för att öka kapaciteten och kunna tillgodose en ökad efterfrågan. Stundtals sker det dock en tillfällig nedgång i efterfrågan och anläggningens effektivitet och lönsamhet minskar. Det är därför viktigt att förbereda verksamheten för nedgångar och generera strategier för att bibehålla effektiviteten och lönsamheten.

Syfte: Det huvudsakliga syftet med examensarbetet var att generera strategier för att minimera effektivitetsförluster vid taktnedgångar.

Problem beskrivning: Två huvudsakliga forskningsfrågor kan kopplas till syftet:
- Vilka parametrar är kopplade till effektivitetsförluster vid taktnedgångar?
– Hur påverkas parametrarna och vilka strategier kan implementeras för att minimera effektivitetsförluster vid taktnedgångar?

Metod: Eftersom att examensarbetet genomfördes för att lösa ett redan definierat problem användes en problemlösnings angreppssätt. Det praktiska tillvägagångssättet som användes under examensarbetet var inspirerat av ”Lean cykeln”. Metoden som användes var även abduktiv för att ständigt jämföra teori och empiri. Förutom en litteratursammanställning användes observationer och intervjuer frekvent för att samla in data och information.

Slutsatser: Det finns ett tydligt samband mellan effektivitetsförluster och taktnedgångar. Som teori antyder identifieras flera tidsförluster i en produktionsanläggning. Effektivitetsförlusterna visualiseras främst i form av kostnad per hytt och produktionsstörningar. Genom att implementera strategier, men tanke på relevanta kostnader och produktionsstörningar, i produktionsanläggningen vid olika produktionstakter kan företag minimera de effektivitetsförluster som uppstår.

Nyckelord: Effektivitet, effektivitetsförluster, produktionstakt, taktnedgångar, strategier, produktionsplanering, modell.

Summary

Title: Strategies to reduce efficiency losses during production rate reductions

Authors: Jacob Olofsson
Fredrik Persson

Supervisors: Jan Olhager, Faculty of Engineering, Lund University
Magnus Rosvall, Scania CV AB

Background: Companies modify and improve their production systems in order to maximize production volumes and meet an increased customer demand. However, occasionally the customer demand decreases and the production system is therefore not the most profitable. It is therefore important to prepare for downturns and generate strategies to maintain efficiency and profitability.

Purpose: The main purpose of the master's thesis was to develop strategies to cope with the losses in efficiency during production rate reductions.

Problem definition: Two main research questions can be linked to the purpose:
- What parameters are related to efficiency losses during production rate reductions?
- How are the parameters affected and what strategies can be implemented to reduce efficiency losses during production rate reductions?

Method: Since the thesis was conducted to solve an identified problem, a problem solving approach was used. The practical methodology used throughout the master's thesis was inspired by the "Lean cycle". An abductive reasoning was applied to continuously compare theory and practice. Except for literature reviews, observations and interviews were frequently used tools during the thesis.

Conclusions: It is evident that there are efficiency losses connected to production rate reductions. As theory implies, there are numerous time losses within production processes. In practice the efficiency losses are mainly visualized in terms of cost per cab and production disturbances. By implementing strategies, with regards to relevant costs and disturbances, throughout the production facility at various production rates companies are able to reduce efficiency losses.

Keywords: Efficiency, efficiency losses, production rate, production rate reductions, strategies, production planning, model.

Table of contents

1 Introduction 1

1.1 Problem description 1

1.2 Company introduction 1

1.3 Purpose and problem definition 1

1.4 Delimitations 2

1.5 Target audience 2

1.6 Report outline 2

1.7 Confidentiality 3

2 Methodology 4

2.1 Research approach 4

2.2 Reasoning approach 4

2.3 Data Collection 5

2.3.1 Primary and secondary data 5

2.3.1 Qualitative and quantitative data 6

2.3.2 Data collection methods 6

2.4 Practical methodology 8

2.5 Quality of the thesis 9

3 Theoretical framework 11

3.1 Lean manufacturing 11

3.1.1 Background 11

3.1.2 Principles of Lean 14

3.1.3 Lean tools 16

3.2 Efficiency 19

3.3 Effectiveness 21

3.4 Productivity 22

3.5 OEE and OPE 24

3.6 Scientific models 26

4 Empirical data 28

4.1 Company description 28

4.2 Scania production system 29

4.3 Performance measurements 31
4.3.1 Jobs per hour (JPH) 31
4.3.2 Cost per cab 32
4.3.3 Overall process efficiency (OPE) 32
4.4 Cab production process Oskarshamn 33
4.4.1 Top coat paint shop 34
4.4.2 Anti corrosion line 43
4.4.3 Process ventilation 46
4.4.4 Maintenance 47
4.5 Production data 49
4.5.1 Production rate 49
4.5.2 Cost per cab 50
4.5.3 Production distribution 51
4.5.4 Color distribution 51
4.6 Production disturbances 54
4.6.1 BCA 55
4.6.2 BCM 55
4.6.3 CCM 56
4.6.4 Variation in disturbances 57
4.7 Energy consumption 59
4.8 Cost distribution 62
4.9 Production planning model 64
5 Analysis 69
5.1 Understanding the problem 69
5.1.1 The theoretical perspective 69
5.1.2 The empirical perspective 69
5.2 Generating strategies 77
5.2.1 Strategy 1 - Closing the night shift 78
5.2.2 Strategy 2 - Closing one shift throughout BCM/CCM 82
5.2.3 Strategy 3 – Oven standby mode 88

5.3 Production planning model 90
5.3.1 Disturbances..91
5.3.2 Equipment utilization 92
5.3.3 Production distribution per shift..93
5.3.4 Logic and user friendliness 93
5.4 New production planning model...94
5.4.1 Disturbances..94
5.4.2 Equipment utilization 95
5.4.3 Production distribution per shift..95
5.4.4 Logic and user friendliness 96
5.5 Model comparison...96
5.6 Feasibility of strategy implementation...98
5.6.1 Strategy 1 98
5.6.2 Strategy 2 99
5.6.3 Strategy 3 100
6 Recommendation and conclusions 101
6.1 General conclusions..101
6.2 Recommendations..102
6.3 Future research..103
6.4 Authors’ reflections 104
References...106
Appendix 111
Appendix A – Top disturbances throughout the painting lines...111
Appendix B – Energy consumption per month 112
Appendix C – Scheduled maintenance off production...113
Appendix D – Start up and shutdown of ovens...115
Appendix E – Instructions for new model 117

1 Introduction

This chapter will provide an introduction to the problem underlying this master's thesis. Further, the purpose of the thesis will be defined and research questions are denoted. The chapter ends with the delimitations of the work and the target audience.

1.1 Problem description

Manufacturers commonly design their production systems to suit operations for maximizing production volume and secure future profitability (Uzun & Ozdogan, 2012). However, the customer demand in most industries varies and maximizing production volume is not always the most profitable option with regards to over production. It is important for manufacturers to prepare for downturns in demand and plan their production system accordingly, developing strategies to reduce the losses in efficiency and profit during these periods (Uzun & Ozdogan, 2012). Scania is one of the manufacturing companies that have realized the importance of this. Scania's cab production in Oskarshamn will need an expansion in capacity the coming years, due to an increase in demand. However the production rate is variable and periodically the production rate will decrease due to different reasons. During these periods Scania struggles with losses in efficiency.

1.2 Company introduction

Scania is a major automotive industry manufacturer of commercial vehicles, mainly producing heavy trucks, buses and industrial as well as marine engines. The company has production facilities in numerous countries worldwide. One of the production facilities is located in Oskarshamn, Sweden where cabs, trucks excluding chassis, are produced. The facility in Oskarshamn consists of five workshops and employs approximately 2500 people.

1.3 Purpose and problem definition

The main purpose of the master thesis is *to develop strategies to cope with the losses in efficiency during reductions in production rate*.

To clarify the purpose of the thesis, three research questions have been defined and listed below:

- What parameters are related to efficiency losses during reductions in production rate?
- How are the identified parameters affected and which parameters are most crucial to consider?
- What strategies can be implemented to reduce the efficiency losses connected to the identified parameters?

1.4 Delimitations

Due to the time horizon for the thesis work and the complexity of the production facility in Oskarshamn delimitations have been established. The identified issue originates from the top coat paint shop, i.e. this will be the main area of focus for the thesis. The thesis will therefore not include previous or following areas of the production process. The boundaries of the thesis are in other words the buffers before and after the top coat paint shop. Further the thesis will primarily touch upon aspects such as costs and production data. Other aspects, more subjective, such as quality have not been of primary focus for the thesis. The quality is affected by numerous parameters, including parameters beyond the top coat paint shop.

1.5 Target audience

The main audience of the master thesis is the employees of Scania in general and the employees throughout the top coat paint shop in particular. General aspects of the thesis may also be valuable for engineering students with an interest within production.

1.6 Report outline

Chapter 1 – Introduction
This chapter will provide an introduction to the problem underlying this master thesis. Further the purpose of the master thesis will be defined and the research questions are denoted. The chapter ends with the delimitation of the work and the target audience.

Chapter 2 – Methodology
This chapter will provide an overview of research and reasoning approaches as well as the methodology chosen for the thesis. The characteristics of different types of data are discussed. Further the chapter describes a number of data collection methods and how to reason regarding the quality of master thesis.

Chapter 3 – Theoretical framework
This chapter will provide an introduction to the relevant theory used throughout the master thesis. The literature used concerns understanding efficiency, effectiveness, productivity and the difference between the concepts. A thorough understanding of Lean manufacturing and its content is necessary for understanding Scania's production system. The chapter ends with an overview of performance measurement regarding efficiency.

Chapter 4 – Empirical data
This chapter will provide an overview of Scania worldwide, Scania Production System and the production site in Oskarshamn. Further the topcoat paint shop is thoroughly described from numerous perspectives such as cost, production history, disturbances, energy consumption and performance measurement. The information and data presented throughout this chapter is

gathered through interviews with employees from several functions of the company and from numerous information systems.

Chapter 5 –Analysis
This chapter will analyze the relation between efficiency, mainly in terms of costs and time losses, and production rate. Further the chapter will present several strategies to cope with the loss in efficiency and the impact of the strategies. To finally identify when the strategies are feasible, a production planning model will be presented.

Chapter 6 – Recommendations and conclusion
This chapter will summarize the general conclusions from the analysis, present recommendations to cope with efficiency losses during production rate reductions and state recommendations regarding future work to support the reasoning. Finally authors' personal reflections regarding the thesis and construction are presented.

1.7 Confidentiality

Due to the sensitivity regarding the data from the production facility in Oskarshamn several figures and information has been removed from this issue of the thesis. In several cases the sensitive information has been customized. Since a large part of the thesis concerns production rates, a fixed production rate X has been chosen and the remaining production rates presented throughout the thesis are described as a percentage of X.

2 Methodology

This chapter will provide an overview of research and reasoning approaches as well as the methodology chosen for the thesis. The characteristics of different types of data are discussed. Further the chapter describes a number of data collection methods and how to reason regarding the quality of master thesis.

2.1 Research approach

Methodology is the fundamental approach that is chosen for the work at hand. There are four main types of approaches relevant for master thesis projects. The four approaches are briefly described below, together with the main purpose of each (Björklund & Paulsson, 2003).

- *Descriptive approach* is used when the purpose is to discover and describe the main aspects and functions of a subject.
- *Exploratory approach* is used when the purpose is to gain a thorough understanding of a subject.
- *Explanatory approach* is used when the purpose is to investigate the relations to be able to explain the problem.
- *Problem solving approach* is used when the main purpose is to find a solution to an identified problem.

Since the task at hand is predefined by Scania, the approach chosen for the thesis is mainly of a problem solving nature. Even if the main purpose of the thesis will be orientated to problem solving, parts will include descriptive, exploratory and explanatory approaches. Approaches that are considered exploratory and explanatory are analyzes where it is crucial to obtain an understanding of important relations throughout the thesis. This approach is considered valid to secure the required level of knowledge to be able to provide a thorough solution to the main issues identified and to be able to communicate it properly. The method is the foundation for the thesis work and will determine relevant boundaries and principles for the approach.

2.2 Reasoning approach

During scientific research, there are different approaches to combine theory and empirical data. There are three main approaches; inductive, deductive and abductive (Kovács & Spens, 2005; Höst et al. 2006). The main features of the different approaches are described below.

Inductive reasoning

- Begins with empirical observations
- Aims to develop theory
- Identify new constructs, and establish relationships between these
- Observations will lead to emerging propositions and their generalization in a theoretical frame

Deductive reasoning

- Begins with theory
- Aims to test or evaluate theory
- Establish relations between already known constructs
- Derives logical conclusions and establish hypotheses and proposition from theory, which are tested in empirical settings and present general conclusions

Abductive reasoning

- Begins with empirical observations
- Aims to develop new knowledge and theory
- Match empirical observations with suitable theory simultaneously
- “Back and forth” direction between theory and empirical study
- Develop conclusions based on the back and forth study

Throughout this thesis an abductive approach is conducted, given that the aim is to solve a predefined problem with the help of theory. The abductive approach is also suitable due to the complexity of the problem where it is appropriate to initially develop an understanding of the problem at hand and further search for theory to compare it with.

2.3 Data Collection

Since data is one of the major foundations that a thesis is built upon, it is crucial to consider relevant aspects connected to this field. There are different types of data that are used differently and that are collected through different methods. There are a large number of aspects to consider when collecting and working with data, several important areas of focus are described below.

2.3.1 Primary and secondary data

Gathered data can be divided into primary and secondary data. The different type of data is distinguished by the purpose for which it was collected. Both types are described below (Björklund & Paulsson, 2003).

- Primary data is data collected by the researcher during the current research, i.e. data from first-hand experience that is collected to directly support the current research. An example of primary data is information gathered during an interview.
- Secondary data is already existing data, i.e. data that has been collected to support former research projects. An example of secondary data is scientific articles.

This thesis is built upon both types of data to secure a proper analysis of the identified problem. The methods used to gather data during the thesis are described in chapter 2.3.3.

2.3.1 Qualitative and quantitative data

There are two main characteristics of the data collected, both types and the characteristics of the data are described below (Höst et al. 2006).

- *Qualitative data* is information that consists of words and interpretations. This data is rich in details and is of subjective nature. Qualitative data requires sorting and categorizing to be properly analyzed.
- *Quantitative data* is information that can be classified or counted. Examples of quantitative data are numbers, parts or weights. This data can be analyzed from a statistical perspective.

This thesis is complex with regards to the involvement of humans and their behavior; therefore the thesis will involve analysis of both quantitative and qualitative data (Björklund & Paulsson, 2003).

2.3.2 Data collection methods

As mentioned earlier, there are numerous ways in which data for thesis work can be collected. The main methods used are described below (Björklund & Paulsson, 2003).

Survey

Surveys are forms of questionnaires. The questions are primarily fixed and often include a number of predefined answers for the respondent to choose between. The main purpose of a survey is to gather the opinions of a large group of people concerning a certain subject. Important aspects to consider when performing a survey is the population of respondents, language used, time frame, leading questions, units of measure etc.

Interviews

Interviews are more or less an interrogation of relevant people to gather their opinions regarding specific areas or themes of interest. An important difference between surveys and interviews is the wider range of answers that can be collected from an interview. Interviews can mainly be performed in three different ways.

- *Unstructured interviews* are similar to open discussions with predetermined areas of conversation. Specific questions could be used, but the questions can be asked in different sequences as well as in different formulations. This type of interview is often controlled to the areas of the interviewees' interests or expertise.
- *Structured interviews* are more strict than unconstructed and the interviewees are asked predetermined questions in a sequenced order, similar to an oral survey. This type of interview is easier to control and there is only a small risk to get of topic.

- *Semi-structured interviews* are a mix between the previously discussed interview methods. This type of interview demand a clear focus when the interviewer seeks open answers to some questions and more strict to some.

During this thesis, numerous interviews have been conducted. The interviews have almost exclusively been performed unstructured or semi-structured due to the complexity of the processes and variation in knowledge regarding among interviewees. Further, continuous discussions and interaction with employees during the thesis have been vital to ensure a thorough understanding of the production process.

Observations

During an observation a course of events is observed; the outcome of it can be recorded in numerous ways. When observing, the observer can either be participating or not participating in the observation, in other words observing from a distance.

The observations conducted during this thesis will not be of participating nature. The reason for this is to not affect or change the original environment. In order to further evaluate and generate solutions regarding the current situation it is of great importance that the situation is observed as it actually progresses.

Measures

Measuring is an important method for collecting data. The main purpose is to connect a number or a unit of measure to describe an attribute or a phenomenon. Different scales can be used in order to put the measure into different contexts. Measures can be used in different manners and can be a tool for collecting data within different areas. A thesis work often requires measurements of physical units as well as organizational ones (Björklund & Paulsson, 2003). When measuring physical phenomenon it is important to use well functioning equipment to reduce errors. There are three main types of errors, described below (Jönsson & Reistad, 1987).

- *Major errors* are radical deviations from other measurements of the same subject. These errors are often caused by manual mistakes.
- *Systematic errors* are errors caused by constant disorders in the measurement equipment or process.
- *Temporary errors* are minor errors caused by random deviations.

When measuring aspects connected to humans or organizations other aspects are more important, such as defining what to measure and how to measure.

Data collected by others

Due to time constraints or occasionally access-issues, not all data can be collected by the researcher. Therefore, data collected by others is an important source for data collection. This type of data can be divided into four categories (Rosengren & Arvidson, 2002), all described below.

- *Processed material* is data that has been collected and processed in a scientific context, such as in academic research and scientific journals.
- *Available statistics* is data that has been collected and processed but without conclusions. This type of data can often be reached through major statistics organizations.
- *Register data* is data that has been collected but not processed, such as a customer registers.
- *Archived data* is data that is not systemized as actual data. Examples of archived data are protocols or project documentation.

During this thesis, data collected by others will be frequently used. Processed material will be the major source of information during the theoretical part of the thesis. This type of data will mainly consist of literature review, described below. In the empirical data, register data will be more frequently used. Other types of data are relevant for different parts of the thesis.

Literature review

Literature is defined as all types of written material such as books, journals, articles and newspapers. Further, all written material found throughout the Internet can be classified as literature. During a literature review published information of a specific area of interest is gathered, analyzed and discussed from numerous perspectives.

The literature review throughout this thesis was mainly conducted throughout different databases containing scholarly journals. To be able to gather relevant and value adding information it is of great importance to use appropriate keywords when performing the searches. When searching and gathering information for this thesis keywords such as “efficiency”, “cycle time”, “production rate”, “lean”, “losses” etc. have been used.

2.4 Practical methodology

In order to grasp the complex environment of the production facility as well as working methods and other related aspects, both from a theoretical- and a practical point of view, this thesis was initialized by gathering data. Among other aspects, interviews and observations were used to gain relevant knowledge. This process step enabled the understanding of the current state and generated ideas for further work towards fulfilling the purpose of the thesis. Generated ideas served as a basis for developing strategies, focusing on future actions to solve the identified issues. Finally, in order to investigate the feasibility of the strategies, a model was developed. The model accuracy was evaluated by comparing it with actual production outcome. The practical approach for constructing this thesis is visualized in figure 1.

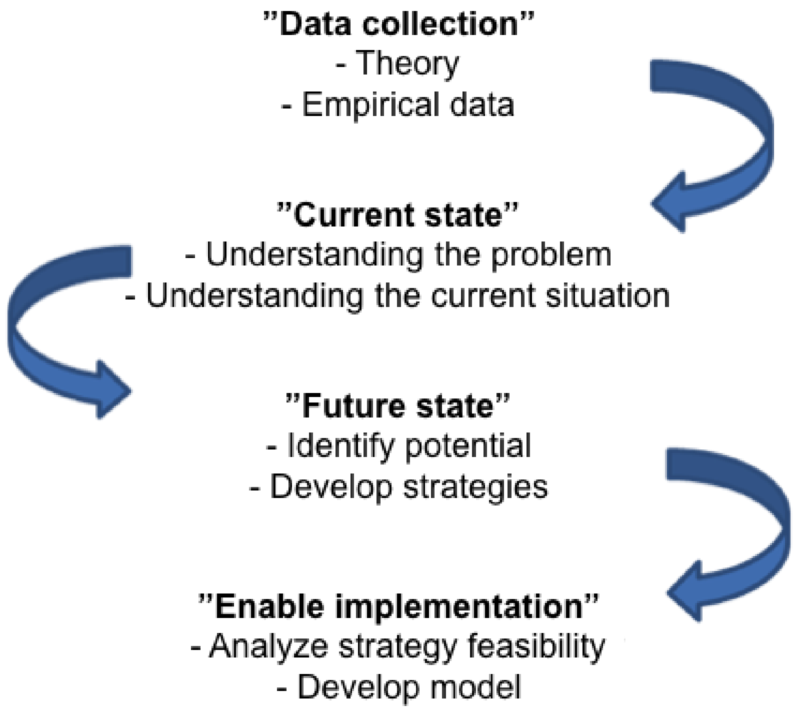


Figure 1: Practical methodology for the thesis

The practical approach used is closely related to the “Lean cycle” (Liker, 2007). The first two steps in the practical methodology used are similarly used in the first step, “Plan” of the “Lean cycle”, where a problem is defined and analyzed in order to identify the root cause. The third and fourth step of the practical methodology used are similar to the second step, “Do”, and to the third step “Check” of the lean cycle, where solutions are developed and the results are evaluated. The fourth step, “Act”, of the lean cycle, where solutions are standardized, is however not included in the practical approach used. This step is left for Scania to perform, by keeping the model parameters up to date.

2.5 Quality of the thesis

It is crucial to construct a thesis with a high level of research design quality. There is no universal definition to measure the research design quality but there are numerous guidelines in previous research. Aspects that are frequently mentioned are validity and objectivity, see figure 2, there are however several different subcategories connected to each aspect. For a thesis to reach a level of good research design, certain levels of external, internal and construct validity as well as reliability must be accomplished regardless of the study is of a qualitative or quantitative nature (Elram, 1996). According to Näslund (2002), qualitative and quantitative researchers tend to define ”good” research quality differently. The author describes how the qualitative researchers tend to reject the perception of objectivism and use a subjective approach whilst the quantitative researcher applies internal and external validity, reliability and objectivity to good research design. Seale (1999) cites the conclusion established by Cuba and Lincoln (1994): "The issue of quality in constructivism is... not well resolved, and further critique is needed". It is clear that there are many different opinions and perspectives connected to the quality of research design. Björklund & Paulsson (2003) explain the issue somewhat simplified and focus on three major aspects that are generally used by authors:

- Validity is to what extent the intended area of measurement is measured
- Objectivity is to what extent the results are affected of principles and beliefs
- Reliability is to what extent the measures are measured correctly i.e. to what extent the result would be the same if the study was conducted several times

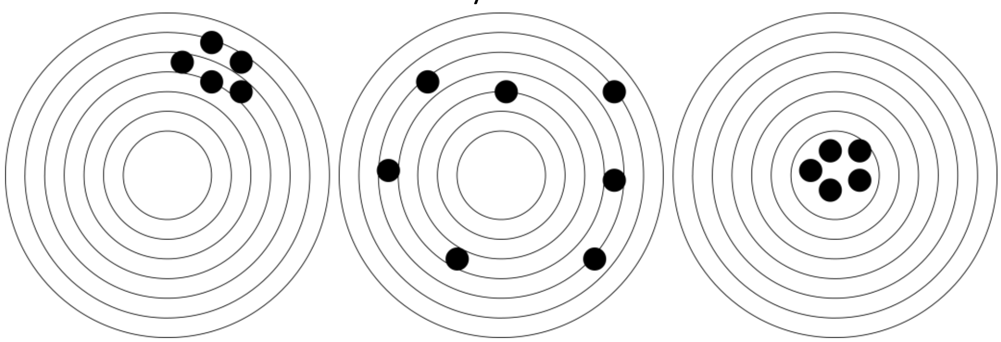


Figure 2: Circle 1 indicates high reliability and low validity, circle 2 indicates low reliability and low validity, circle 3 indicates high reliability and high validity

To enhance and secure the desired level of validity, objectivity and reliability for the data used throughout this thesis, data has exclusively been gathered for the longest possible periods of time to obtain a representative view of the organization. Further, all information gathered during interviews and from information systems have been discussed with individuals obtaining expertise within relevant fields at Scania.

3 Theoretical framework

This chapter will provide an introduction to the relevant theory used throughout the thesis. The literature concerns the understanding of efficiency, effectiveness, productivity and the relation between the concepts. A thorough understanding of Lean manufacturing and its content is necessary for understanding Scania's production system. An overview of performance measurement regarding efficiency is also presented. The chapter ends with an introduction to scientific models.

3.1 Lean manufacturing

Lean manufacturing is a world known production technique, and even an industrial philosophy. The concept is often called lean production or simply lean but the main purpose is the same. A simple description of lean would be striving to remove waste out of value streams (Lander & Liker). Waste, in manufacturing terms, is often defined as resources added to a product or service that is not appreciated by the customer, in the sense that the customer is not willing to pay for it. Numerous definitions and explanations of the lean origin have been published (Womack et al. 1990, Upadhye et al. 2010, Bicheno & Holweg, 2008), but the main characteristics are similar.

3.1.1 Background

Authors agree that lean is an extension or an evolution of the Toyota Production System (TPS), developed at Toyota during the 1950s and 1960s by among others Taiichi Ohno and Shigeo Shingo, which in turn is built upon the ideas of Just In Time (JIT) production developed mainly by Kiichiro Toyoda and Henry Ford (Womack et al. 1990). The JIT work by Henry Ford was in turn inspired by the scientific management approach, including aspects such as scientific decision making, standardization and thorough measurements, developed by Frederick Taylor in the early 1900s (Maier, 1970).

JIT

The main objective of JIT is that resources should be utilized at the exact right point in time. Excess Inventory is considered waste and should be removed if possible. When discussing JIT, the main focus is usually directed to raw material, which should arrive exactly when it is supposed to be used within the production in all parts of the process. However, the JIT concept is including numerous different aspects and to reach the true potential of the concept, managers do not just need to consider raw material inventory. One example of this would be the emphasis of the importance of flexibility among the workforce i.e. employees having the ability to operate different working stations and have knowledge in maintenance and problem solving. During the development of JIT, the majority of non-Japanese production managers believed the already well tested scientific management approach would have discovered the main benefits and that the cost of reaching additional ones would be high. This was later proven wrong by Japanese automotive manufacturers (Hitchens, 1999). As for most industrial philosophies or management techniques, there are numerous explanations of the concept. Figure 3 below shows Daugherty et al. (1994) view of JIT.

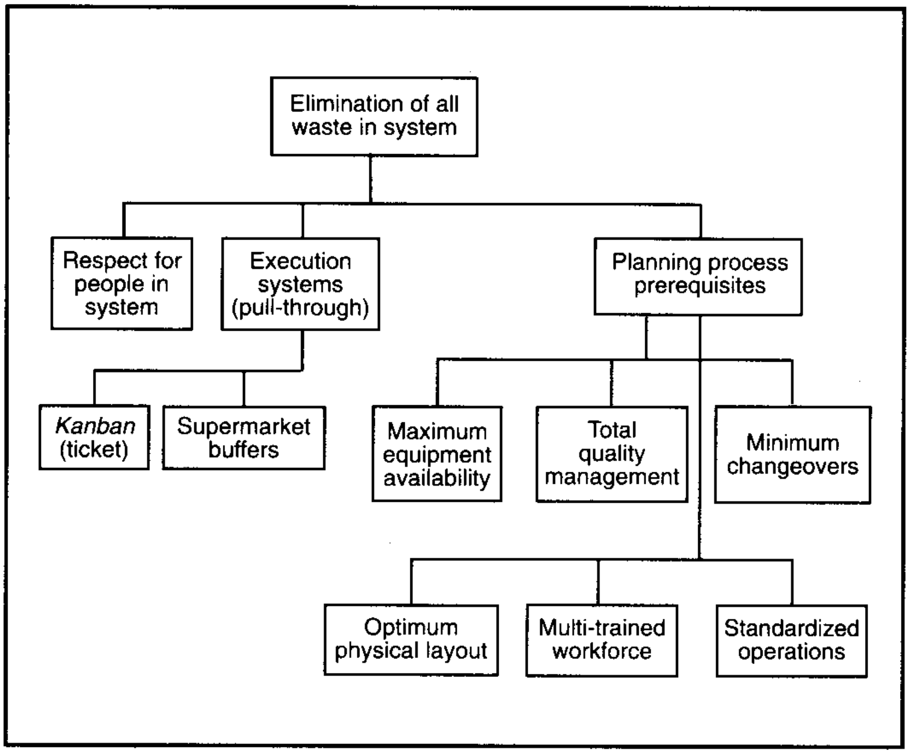


Figure 3: The JIT concept (Daugherty et al. 1994)

TPS

The main objective of TPS is to design production processes to reduce or eliminate overburden, inconsistency and waste i.e. design smoothly running processes, capable of delivering the desired results without causing the employees a stressful environment and eliminating the waste along the way. Sugimori et al. (1977), four Toyota managers, describe TPS in a simple way as to be based on two basic concepts: "Cost reduction through the elimination of waste" and "Full utilization of the worker's capabilities". This is done partially through the use of JIT procedures and a system of respect for people (Lander & Liker, 2007). The respect for people have in some cases resulted in family-like organizations and this is described by many as the main difference from earlier production systems and perhaps one of the main advantages of TPS. Flexible employees are another aspect of TPS that have evolved from the JIT concept.

TPS have, like most production systems, evolved during the years. Today, Toyota describes their production system as "The Toyota Production System empowers team members to optimize quality by constantly improving processes and eliminating unnecessary waste in natural, human and corporate resources. TPS influences every aspect of Toyota's organization and includes a common set of values, knowledge and procedures. It entrusts employees with well-defined responsibilities in each production step and encourages every team member to strive for overall improvement" (Toyota, 2014). The production system is often symbolized as the TPS house, visualized in figure 4 below.

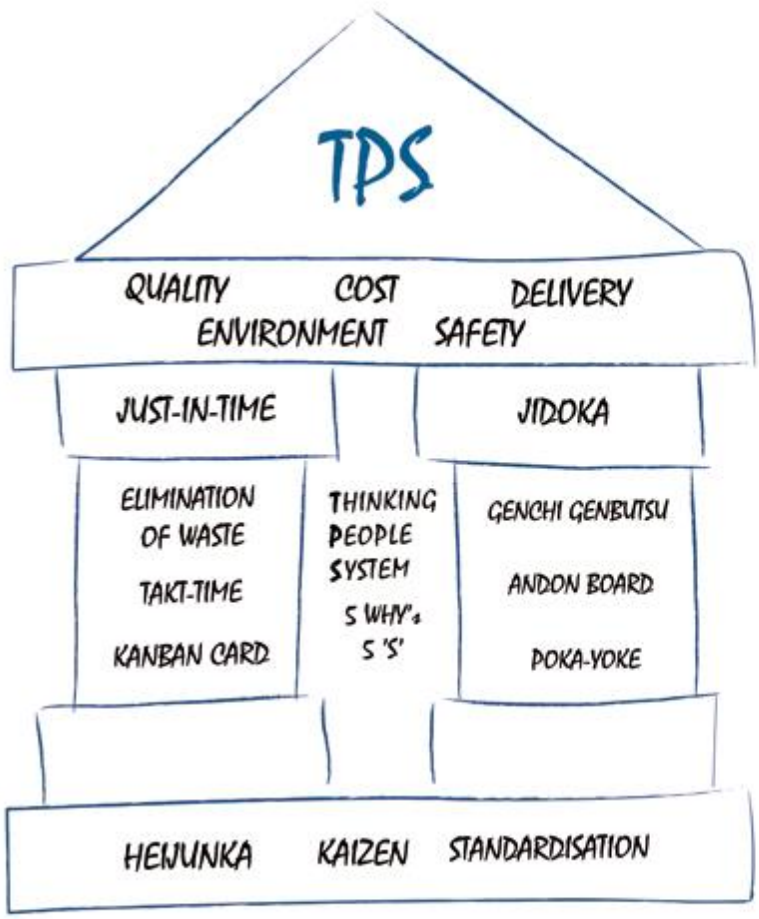


Figure 4: The TPS house (Toyota, 2014)

The Japanese terms included in figure 4 are briefly explained below.

- *Andon* is an alarm system, used by shop floor employees to notify management, maintenance or others that there is something wrong with the process. The system often includes lights or sounds to secure notification success. The centerpiece is an Andon board that covers the entire process or major parts of it. The purpose is to stop production when defects or deviations occur, study them and improve the process for the future.
- *Genchi Genbutsi* is the Toyota way of observing. The concept means that in order to solve a problem, it has to be observed in its original environment i.e. problems occurring on the shop floor have to be observed and solved on the shop floor, not from an office.

- *Heijunka* relates to leveling production and producing goods at a constant rate. By eliminating waste, the production will become more predictable and planning will become easier. This is the Toyota way of obtaining high efficiency production with predictable and high quality products.
- *Jidoka* refers to an autonomaton feature of TPS. The concept is a quality control method to prevent for producing defective products. When situations differ from the normal stage, automated robots and machines stop for an employee to investigate what went wrong, why and how to prevent this situation from occurring in the future.
- *Kaizen* is a tool for continuously improving performance. It focuses on gathering relevant people and knowledge to discuss problems and to develop solutions for improvement. The concept is widely adopted and discussed. A more thorough description is provided below.
- *Kanban* is a system for material control. Often forms of cards, called Kanban-cards, are passed along a process line to the preceding station that signals material need. A passing of a card will trigger a replenishment procedure and the entire system becomes demand driven i.e. a pull system. Signals spread across the process, which becomes agile, and lower stock levels can be obtained. During the later decades, Kanban-cards are sometimes sent electronically.
- *Poke-Yoke* relates to a mechanism that prevents errors. This means that actions are taken in order to eliminate manual errors and thereby "mistake-proof" the process. An example would be the "pick to light" picking method used in warehouses, where a light signals the right location for the picker to pick from and eliminates the possibility to pick from the wrong shelf.

3.1.2 Principles of Lean

Lean manufacturing of today builds upon the discussed systems and principles and is, as mentioned, often considered an evolution of TPS. The purpose is similar to the ones of the other concepts, focusing on making the most of as little as possible. Womack et al. (1990) describes lean as to be built upon five cornerstones, which all need to be considered in order to reach the full potential of lean. The principles in question are visualized in figure 5, as the lean cycle, and further described in table 1 (Carlborg et al. 2013).

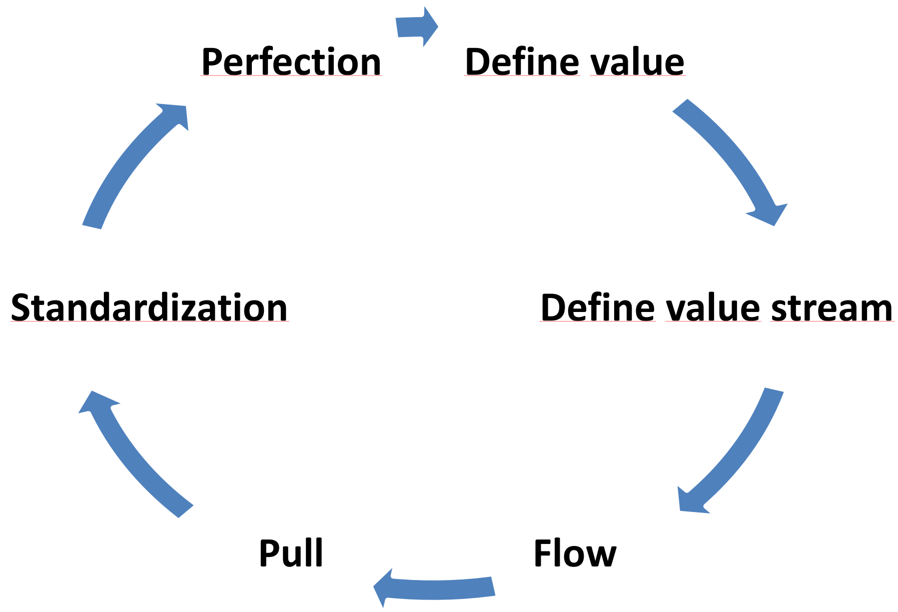


Figure 5: The lean cycle

Table 1: Principles of Lean description by Carlborg et al. (2013)

Lean principle	Literature	Meaning	Implications
Define value	Womack and Jones (2003), Pettersen (2009), Shah and Ward (2007)	Value is always created by the provider, even though value is defined by the customer	What is not adding value – waste - must be reduced by minimizing resources that do not contribute to customer value
Define value stream	Womack and Jones (2003), Pettersen (2009), Shah and Ward (2007)	Mapping every step involved in the production process	Actions are mapped into different categories – those that create value, as perceived by the customer, and those that do not
Flow	Womack and Jones (2003), Shah and Ward (2007)	Focuses on the object (such as a product, a customer, or information) running through the value stream	Instead of looking at the resources available and how to use them efficiently, flow focuses on the process and how to optimize the flow of elements through the process
Pull	Womack and Jones (2003), Pettersen (2009), Shah and Ward (2007)	Not producing prior to an order	Capacity becomes a critical issue
Standardization	Pettersen (2009)	Setting standards to achieve platforms that enable improvements	The functionality from different units can be controlled and compared with different measures
Perfection	Womack and Jones (2003), Pettersen (2009), Shah and Ward (2007)	The absolute goal of lean	The outcome of lean if all other lean principles are fulfilled

Waste

When discussing lean, the focus is mainly directed towards the elimination of waste (Womack et al. 1990, Lander & Liker, 2007). There are originally seven types of wastes connected to Lean. All are excessively described in literature (Womack et al. 1990, Liker, 2004) and explained below.

- *Transport* relates to all transports performed that are not required to perform the process as intended.
- *Inventory* relates to all inventory i.e. all material, components, products and other resources that are not processed but tie up capital.
- *Motion* relates to all movement by employees or equipment that is not required to perform the process as intended.
- *Waiting* relates to all time spend waiting for the next process step or waiting during production interruptions.
- *Over production* relates to all products that are produced but not demanded by customers.
- *Over Processing* relates to all resources added to the manufacturing process that is not required to satisfy the customer demand.
- *Defects* relates to all defected products produced and the effort required to fix them.

During recent years, additional forms of waste have been frequently discussed in literature related to lean, six sigma, kaizen and more. Aspects such as working with the wrong metrics or the wrong software as well as not allowing employees to reach their full potential have been more or less universally accepted as forms of waste, also other wastes are discussed in literature (Hines et al. 1998).

3.1.3 Lean tools

During the development of lean, numerous tools have been assigned to the lean toolbox. Different organizations use tools differently and with varying intentions. Since a complete investigation of the lean toolbox would be far too time consuming with regards to the time constraint of this thesis, a selection have been made and explained below.

Value stream mapping

As the name reveals, value stream mapping is a tool for identifying where value is added along processes. By doing this, it will become easier to identify possible sources of waste that could be eliminated in the pursuit of manufacturing excellence. Value stream mapping can be applied both to information and product flows in order to get a holistic view of the process. Value stream mapping is often explained as a step by step process. Different authors may use different steps but the main characteristics are often the same. Chen and Meng (2010) describe the value stream mapping process in the following five steps.

- *Identify product families* by categorizing products according to matrix methods and divide them into families according to the amount of work necessary to produce the specific product. In general, the total amount of work necessary to produce one product should be between 25 and 30 % of the work related to one family in total.
- *Analyze business to prioritize product families and select one for implementation* by investigating and prioritizing them according to size, business share, contribution to net profit, criticality, market position, technology outlook, growth potential, expected lean impact and more. The families with the highest potential of improvements should be prioritized for lean initiatives.
- *Draw current state map* and analyze for improvement by walking along the process to get first-hand information regarding the procedures. This will provide a solid foundation for a current state map. Questions are asked regarding the methods and alternative procedures are discussed. The flow, from the supplier to the customer, is constructed on paper to get an overview of the entire value chain.
- *Draw future state map* where the identified issues in the current state map are solved and the process works in the desired way. This step includes principles such as combining process steps, thinking parallel instead of linear layout, reduce variation, redesign processes and more, in order to create an ideal process map.
- *Implement future state map* is the fifth, final and most important step of the process. Unless the improvements are implemented, the mapping was a waste of time and resources. This step is performed by focusing on the prioritized improvements, developing a master plan to follow, developing metrics to measure the performance, monitoring the results carefully and communicating relevant information to relevant people.

Kaizen

Kaizen is a concept of continues improvements. The concept has been applied to processes within different business areas but the original focus would be the field of manufacturing. Since every activity obtains the possibility to be improved, the kaizen umbrella is connected the most of the management techniques utilized during the last 40 years (Wittenberg, 1994). Kaizen is an ongoing process of typically minor changes and improvements with a clear distinction from innovation, which include drastic changes for immediate and patent results. Wittenberg (1994) explains that both aspects are crucial for the wellbeing of many companies.

Standardization is an important aspect of kaizen. The work involves setting a standard, maintaining it and improving it. This standard is usually made up of policies, rules, directives and procedures to guide and enable employees in their work. Education and training is also crucial in the standardized work. To reach a higher standard, kaizen is an important tool (Wittenberg, 1994).

Kaizen is a long term method that focuses on benefits over time instead of immediate results. The concept is people-oriented in terms of the assumption that improvements in people's attitudes and efforts will bring greater benefits over time than changes for immediate results. Kaizen also promotes the process perspective, since the assumption is that processes have to be improved before results can be (Wittenberg, 1994).

The initial implementation of Kaizen is performed at the shop floor within the production. The main purpose is to think freely, discard conventional ideas, develop alternatives and question the current situation. Another aspect is to implement changes right away instead of over-analyzing. Another major part of Kaizen work is the focus on eliminating waste, described earlier in this thesis. When implemented on the shop floor, Kaizen is spread across the entire organization to product and production planning and design, purchasing and sales (Wittenberg, 1994).

TPM

The increasing amount of mechanization and automation has reduced the number of production personnel and increased the amount of capital tied up in production equipment (Garg & Deshmukh, 2006). This has reduced the number of employees working with and mastering maintenance of the production equipment. Garg and Deshmukh (2006) mean that maintenance costs, next to the energy costs, can be the largest part of any operational budget.

There are different ways and concepts for maintenance and scheduling maintenance. Aspinwall and Elgharib (2013) mean that companies have come to understand the importance of scheduled time for maintenance, and if not their equipment will do it for them. One way to cope with maintenance is total productive maintenance (TPM) which is an equipment management approach aimed to improve maintenance by integrating culture, proves, employees and technology (Aspinwall & Elgharib, 2013; Moore, 1997). The overall objectives of TPM are (Ireland & Dale, 2001; Pramod et al. 2006):

- To achieve zero breakdowns
- To achieve zero accidents
- To achieve zero defects and failures

As visible the objectives of TPM are mainly concentrated to enhancing the operators' roll regarding enhancing maintenance quality of the equipment. TPM is based on the seven pillars of TPM (Ireland & Dale, 2001), which are critical for the success of TPM:

- Focused improvements
- Autonomous maintenance
- Planned maintenance

- Quality maintenance
- Education and training
- Early equipment maintenance
- Safety and environment

Parmond et al. (2006) summarized the benefits of TPM as:

- Create a sense of ownership of the equipment among the operators
- Development of cross functional teams to improve individual employee and employer performance
- Increase the life of the equipment and plant
- Identification of reasons for equipment failure
- Increase in motivation level of employees

The objectives and benefits of TPM will increase productivity resulting in higher profits (Aspinwall & Elgharib, 2013). Further TPM is intended to achieve high levels of overall equipment effectiveness, OEE (Aspinwall & Elgharib, 2013) as well as overall equipment efficiency, OEE (Laugen et al. 2005). Both which are highly related to cost reductions and therefore affect the bottom line of the company.

3.2 Efficiency

When discussing efficiency there is not one trivial definition, however in general terms efficiency is described as "doing things right", which can be translated to doing something without wasting resources. Oakland and Wynne (1991) argue that efficiency is a very difficult term to define and measure. Farrell (1957) discussed the efficiency of a firm as the success in producing as large as possible output from a given set of inputs. This definition is highly related to the definition of productivity which is often denoted as the ratio of all outputs produced to all resources used (Islam & Shazali, 2011). Al-Darrab (2000) defined productivity as efficiency multiplied with the utilization i.e. a production process can be perceived as efficient though the productivity of the process is low. According to Mauri et al. (2010) there is a complex relationship among efficiency, variability and productivity. Therefore it is important to not only consider single concepts as measures of performance (Al-Darrab, 2000). Productivity, as well as effectiveness, is further described in chapters 3.3 and 3.4.

In his work, Tangen (2004) summarized numerous definitions regarding efficiency, see table 2.

Table 2: Definitions of efficiency (Tangen, 2004)

Reference	Definition of efficiency
(Sink and Tuttle, 1989)	*Efficiency is an input and transformation process question, defined as the ratio between resources expected to be consumed and actually consumed*
(Kurosawa, 1991)	*Efficiency is used for passive or operational activity, which is usually defined technically so that the system and its behavior are foreseeable in advance*
(Sumanth, 1994)	*Efficiency is the ratio of actual output attained to standard output expected, and reflects how well the resources are utilized to accomplish the result*
(Neelt et al, 1995)	*Efficiency is a measure of how economically the firm's resources are utilized when providing the given level of customer satisfaction*
(Jackson, 2000)	*Efficiency means how much cost is spent compared to the minimum cost level that is theoretically required to run the desired operations in a given system*
(Jackson, 2000)	*Efficiency = ideal system dependent time / total time*
(Jan van Ree, 2002)	*Efficiency refers to the ratio between aimed resources use and the actual resources use in order to transform and input to an output*

There are numerous aspects to consider when trying to measure the efficiency of a production process. Oakland and Wynne (1991) highlighted the importance of not only considering the utilization of a machine when measuring efficiency. The efficiency of a firm depends partially on manufacturing capabilities such as cycle time, fast delivery, flexibility etc. (Sarmiento et al. 2007; Mauri et al. 2010).

Inefficiency can be derived to numerous different scenarios, Mauri et al. (2010) divided inefficiencies throughout the production process into internal and external inefficiencies, see table 3.

Table 3: Definitions of inefficiencies (Mauri et al. 2010)

Internal inefficiencies	
Not qualified normalized time	Amount of normalized time spent in producing not sellable products
Speed losses	Difference between the actual time used to produce actual units and normalized time that should have been used
Organizational inefficiencies	Time in which the machine is either in a short stop or idle even if being available and scheduled for production
Setup time	Changeovers
Scheduled downtimes	Machine is down for preventive maintenance or validation
Unscheduled downtimes	Machine is down for a breakdown
External inefficiencies	
Blocking	Machine cannot produce due to lack of space in the following buffer
Starvation	Machine cannot produce due to lack of raw material
Not assigned	Machine has not been scheduled in production or cannot produce due to external causes

3.3 Effectiveness

Distinguishing effectiveness and efficiency can be difficult and words are frequently used in the wrong context (Lowe & Soo, 1980). The fact that the Swedish language does not separate the two makes it even more complicated when translating between Swedish and English. When describing effectiveness, the generally recognized definition is "doing the right things, at the right time and with the right quality". By defining effectiveness as a ratio, it can be defined as actual output divided by expected output (Sink and Tuttle, 1989 cited by Rolstadås, 1998). In other words effectiveness can be denoted as to what extent goals are achieved throughout an organization (Lowe & Soo, 1980). Table 4 presents different definitions of effectiveness (Tangen, 2004).

Table 4: Definitions of effectiveness (Tangen, 2004)

Reference	Definition of effectiveness
(Sink and Tuttle, 1989)	*Effectiveness which involves doing the right things, at the right time, with the right quality etc, can be defined as the ratio between actual output and expected output*
(Kurosawa, 1991)	*Effectiveness is basically used in active or innovative activity performed by a risk taker and based on a rather broad perspective*
(Sumanth, 1994)	*Effectiveness is the degree of accomplished of objectives and show how well a set of results is accomplished*
(Neelt et al, 1995)	*Effectiveness refers to the extent to which customer requirement are met*
(Jackson, 2000)	*Effectiveness in manufacturing can be viewed as to what extent the cost is used to create revenues*
(Jackson, 2000)	*Effectiveness = value added time/ideal system dependent time*
(Jan van Ree, 2002)	*Effectiveness refers to what extent the actual result (output in quality and quantity) corresponds to the aimed result*

3.4 Productivity

Similar to efficiency and effectiveness, the definition of productivity within a manufacturing industry varies widely. According to Tangen (2004) there is no such thing as a correct universal definition of productivity, instead the concept can be defined in a number of ways depending on what situation it is going to be used in. In day to day life, the conventional definition of productivity is as the total output divided by the total input (Burgess, 1990 Misterek et al. 1992). It is crucial that the term productivity is not confused with production. Although the two words often have a relationship, production is concerned with producing goods or services and productivity refers to the efficient utilization of inputs in producing agreed outputs (Stainer, 1997). In other words increased production does not necessarily mean increased productivity. Productivity is a relative concept, which means that it has to be compared with an earlier measurement in order to determine if the productivity has increased or decreased (Tangen, 2004).

In his work, Tangen (2004) summarized numerous definitions, both verbal and mathematical, regarding productivity, see table 5.

Table 5: Definitions of productivity (Tangen, 2004)

Reference	Definition of productivity
(Littré, 1883)	*Productivity = Faculty to produce*
(Japan Productivity Centre, 1958 (from Björkman, 1991))	*Productivity is what man can accomplish with material, capital and technology. Productivity is mainly an issue of personal manner. It is an attitude that we must continuously improve our selves and the things around us.*
(Chew, 1988)	*Productivity = Units of output / Units of input*
(Sink and Tuttle, 1989)	*Productivity = Actual Output / Expected Resources Used*
(Fisher, 1990)	*Productivity = Total income / (Cost + goal profit)*
(Aspén, 1991)	*Productivity = Value added / Input of production factors*
(Hill, 1993)	*Productivity is defined as the ratio of what is produced to what is required to produce it. Productivity measures the relationship between output such as goods and services produced, and inputs that include labour, capital, material and other resources.*
(Thurow, 1993)	*Productivity (output per hour of work) is the central long-run factor determining any population's average of living*
(Koss and Lewis, 1993)	*Productivity = the quality or state of bringing forth, of generating, of causing to exist, of yielding large result or yielding abundantly*
(Bernolak, 1997)	*Productivity means how much and how well we produce from the resources used. If we produce more or better goods from the same resources, we increase productivity. Or if we produce the same goods from lesser resources, we also increase productivity. By 'resources', we mean all human and physical resources, i.e. the people who produce the goods or provide the services, and the assets with which the people can produce the goods or provide the services.*
(Kaplan and Cooper, 1998)	*Productivity is a comparison of the physical inputs to a factory with the physical outputs from the factory*
(Jackson and Petersson, 1999)	*Productivity = Efficiency * Effectiveness = Value adding time / Total time*
(Al-Darrab, 2000)	*Productivity = (Output / Input) * Quality = Efficiency * Utilisation * Quality*
(Moseng and Rolstadås, 2001)	*Productivity is the ability to satisfy the market's need for goods and services with a minimum of total resource consumption*
(Jan van Ree, 2002)	*Productivity refers to the ratio between the actual result of the transformation process and the actual resources used*

There are basically five different relationships regarding improvement in productivity (Misterek et al, 1992). These are presented below.

1) *Managed growth* relates to when the output increases faster than input i.e. the increase in input is proportionately less than the increase in output.
2) *Working smarter* means more output from the same input.
3) *The ideal* relates to more output with a reduction in input.
4) *Greater efficiency* means the same output with lesser input.

5) Managed decline is connected to when the output decreases, but input decreases more i.e. the decrease in input is proportionately greater than the decrease in input.

From the definitions above regarding efficiency, effectiveness and productivity as well as the relations between them, the belief is that the confusion between the concepts has been sorted out. To summarize and once again clarify the relation between the concepts, the triple-P model by Tangen (2005) is presented in figure 6.

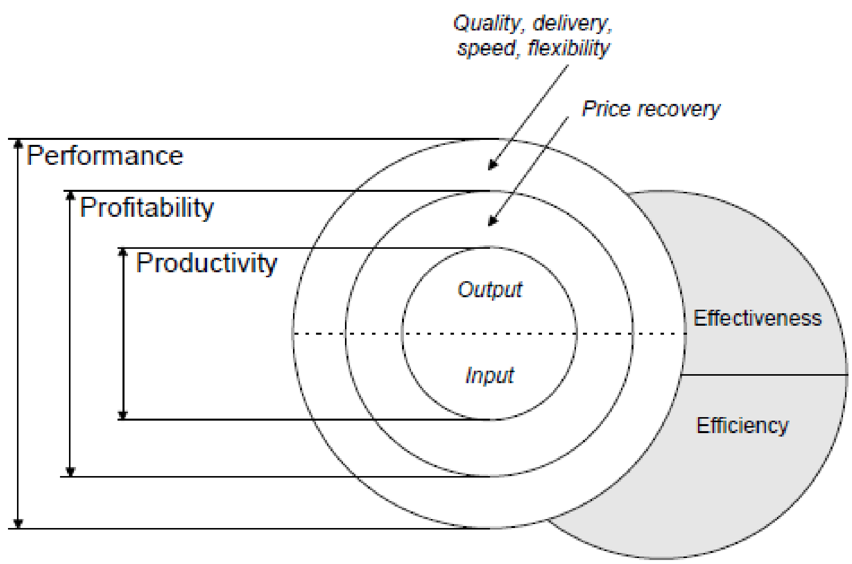


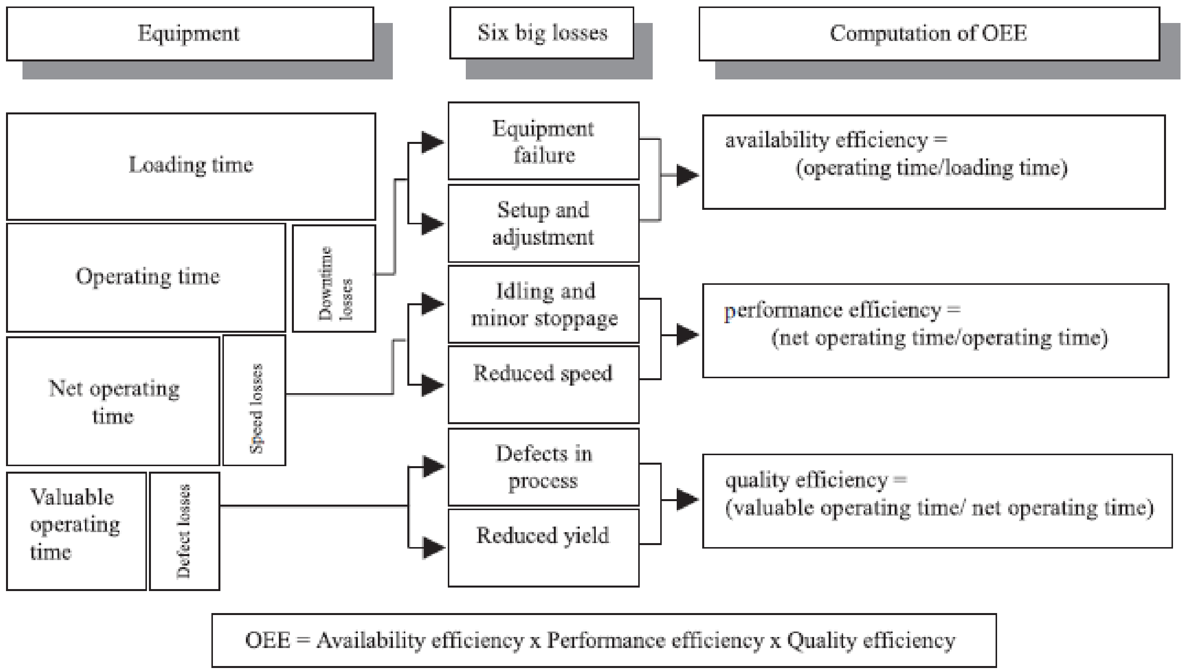
Figure 6: The triple-P model by Tangen (2005)

The triple P-model includes all discussed and relevant concepts. In the model, productivity is the central part and is defined as the relation between output quantity and input quantity. Efficiency and effectiveness are defined as cross functional terms with one major dissimilarity; efficiency relates to internal performance i.e. an input oriented concept, and is defined as how well the utilization of resources is carried out. Effectiveness relates to external performance i.e. an output oriented concept, and is defined as how well the desired results are achieved.

3.5 OEE and OPE

There are several ways to measure the efficiency and effectiveness of a production facility. Overall equipment efficiency, overall equipment effectiveness and overall process efficiency are examples of performance measurements. The exact definition of the concepts differs regarding area of application and authors (Bamber et al. 2003).

OEE is a measure of overall index regarding the operating efficiency by the time loss structure for the processing type equipment (Kwon & Lee, 2004). Nakajima (1988) divided the time loss structure into six big losses, displayed in figure 7.



Source: Nakajima (1988)

Figure 7: The six big losses according to Nakajima (1988)

The six big losses can be divided into three categories, explained below.

- *Downtime losses* relates to the time losses when the productivity is reduced and quantity losses caused by defective products. Downtime losses are also the set-up and adjustment losses as a result from downtime and defective products that occur when adjusting the equipment production from production of one item to another.
- *Speed losses* relate to the Idling and minor stoppage losses occurring when production is interrupted by a temporary malfunction or when a machine is idling. Speed losses are also losses referring to the difference between equipment design speed and actual operating speed.
- *Quality losses* relates to quality defects and reworks caused by malfunctioning production equipment. Quality losses are also yield losses that occur during the early stages of production, from machine start-up to stabilization.

Jeong and Phillips (2001) divide time losses into ten classification areas for a capital-intensive industry:

1) *Non-scheduled time* is connected to the time when the equipment is not scheduled to operate
2) *Scheduled maintenance time* is the time for preventive maintenance
3) *Unscheduled maintenance time* relates to the time spent during breakdowns

4) *R&D time* is the time spent for the purpose of research and development
5) *Engineering usage time* relates to the time spent for an engineering check up
6) *Setup and adjustment time* is the time spent for setup and adjustment for operation
7) *Work In Process (WIP) starvation time* is the time while equipment is operating when there is nothing to process
8) *Idle time without operator* relates to the time while equipment is ready, however there is no operator available
9) *Speed loss* is the time loss due to equipment that is operating slower than standard speed
10) *Quality loss* relates to the time while equipment is operating for unqualified products

Kwon and Lee (2004) defined the overall equipment efficiency as equation [1] below. This definition can however be confused with the definition of overall equipment effectiveness, which proves the statement of (Bamber et al. 2003) regarding the variation in definitions depending on situation and author, defined as equation [2] below (Bamber et al. 2003; Sohal et al. 2010).

$$OEE = \frac{theoretical\ cycle\ time\ x\ good\ products}{loading\ time} \quad [1]$$

$$OEE = Availability\ [A]\ x\ Performance\ rate\ [Q] x\ Quality\ rate\ [Q] \quad [2]$$

Where,
A = Operating time (h) / Loading time (h)
P = Theoretical cycle time (h) x Actual output (units) / Operating time (h)
Q = [Total production (units) – Defect amount (units)] / Total production (units)

3.6 Scientific models

There are numerous examples, explaining the importance of using models in scientific contexts. Several of them have changed the ways of science and enabled the learning of a broader audience. Examples of these are the Bohr model of the atom, the Lorenz model of the atmosphere and the evolutionary model of social science (Frigg & Hartmann, 2012). The absolute main characteristic that is alike between the mentioned models, and others as well, is that they are simplified versions of complex situations and therefore allow for analyzing factors that in their natural stage would be too complex to grasp i.e. models allow for surrogative reasoning (Swoyer, 1991). Scientists spend a large amount of time developing these models and authors of scientific journals spend a lot of time interpreting those (Frigg & Hartmann, 2012). Models and reasoning based on models have been widely accepted in literature and authors claim that the subject has given rise to a new approach of reasoning called “model based reasoning” (Magnani & Nersessian, 2002).

There are three main types of models. *Models of phenomena* and *models of data* are representational models. These types of models represent a target system i.e. a selected part of the world. *Phenomena* is used as an umbrella term of relatively stable and scientifically interesting aspects of the world. Examples of *phenomena models* are the Bohr model of the atom and the Lorenz model of the atmosphere. *Data models* are corrected, restructured and in some cases idealized versions of raw data. The standard procedure is to remove errors form the raw data and present it in a pedagogical way. The third type of models is *theoretical models*. This type of model interprets the laws of a specific theory. The models are not mutually exclusive but can be of both representative and theoretical nature at the same time (Frigg & Hartmann, 2012).

Models are usually used as a reference to a wide range of things. These things can be physical objects, such as miniature models of bridges, planes or ships. Models can also be fictional objects, such as the earlier mentioned Bohr model of the atom. These kinds of models are however often referred to as physical models with regards to the possibility of manipulating the model (Morgan, 1999, cited by Frigg & Hartmann, 2012). Aside from objects, models can refer to equations or set-theoretic structures or even combinations of all mentioned things above.

Since computers have been developed to be perhaps the single most important tool for scientific discoveries, the nature of models has developed as well. Simulations are becoming more important when discussing issues like this one. Even though some authors claim that there is a distinct difference between models and simulations, the concepts are closely related (Hartmann, 1996). Simulations could be described as dynamic models that often are used with involvement of time. The main purpose of simulations is to imitate a real process over a specific time period (Hartmann, 1996). Even if there are different opinions of the issues associated with models, there is no doubt about the practical significance of simulations (Frigg & Hartmann, 2012).

4 Empirical data

This chapter will provide an overview of Scania worldwide, Scania Production System and the production site in Oskarshamn. Further the topcoat paint shop is thoroughly described from numerous perspectives such as cost, production history, disturbances, energy consumption and performance measurement. The information and data presented throughout this chapter is gathered through interviews with employees from several functions of the company and from numerous information systems.

4.1 Company description

Scania is a major automotive industry manufacturer of commercial vehicles, mainly producing heavy trucks, buses and industrial as well as marine engines. Furthermore, Scania is also a provider of services, such as financial and after sale services. The company has production sites in Sweden, Netherlands, Poland, Argentina, Russia and Brazil. Scania employs approximately 41 000 people and annually produces around 74 000 trucks, 6 800 buses and 6 800 engines resulting in a turnover of SEK 87 billion (Scania annual report 2013).

The entire global organization is built upon three core values, described below (Scania's strategic platform).

- *The customer first* means that by truly understanding their customer, Scania can to a larger extent offer the customer desired and additional value. The aim is to apply a customer perspective from research and development, throughout the entire production process to sales and after sales services.
- *Respect for the individual* relates to taking care of the Scania employees, using every individual's knowledge and experience to continuously improve the organization. By nourishing innovation, Scania aims to enhance personnel development and satisfaction, quality and efficiency.
- *Quality* relates to only offering customers the absolute highest level of qualitative products in order to secure a long term customer satisfaction. Deviations in quality are treated as areas for improvement.

To reduce development- as well as production costs, without compromising the customers' customization options, Scania has developed a modular system for production. By limiting the number of different parts a more competitive production system has been obtained, which has resulted in decreased production lead times and reduced costs throughout the supply chain. This modular system is a major part of the Scania Production System, described below.

The production site in Oskarshamn, Sweden, produces cabs that are further shipped to additional production sites where they are assembled to complete trucks. The site in Oskarshamn mainly consists of four workshops: press shop, body shop, paint shop and assembly shop. The Oskarshamn production facility in general and the paint shop in particular, are further described in chapter 4.4.

4.2 Scania production system

The Scania Production System (SPS) pervades all activities throughout Scania. The system was first introduced as a copy of the Toyota Production System (TPS), as Scania recognized the positive impact it had on Toyota. The result was not as expected and Scania introduced a modified version of TPS which resulted in the SPS house, see figure 8. The main focus of SPS is to work according to standardized methods and continuous improvements (SPS, 2007).

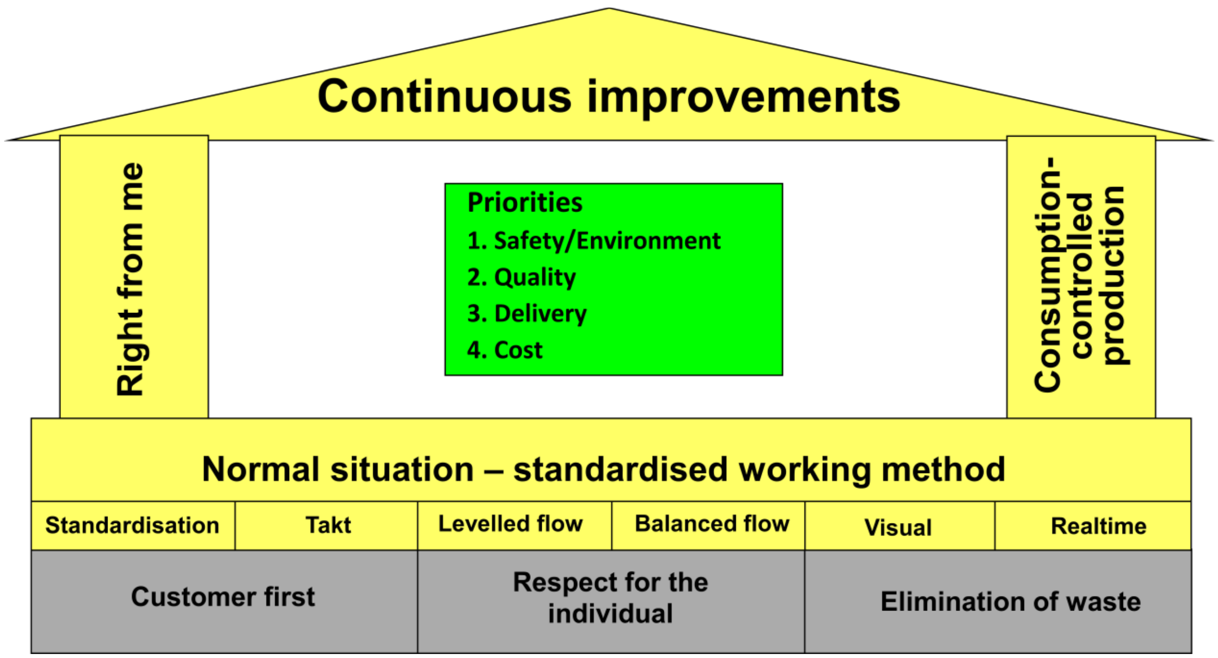


Figure 8: Scania Production System

Values

SPS is built upon three core values, customer first, respect for the individual and elimination of waste. The values reflect the culture of the company and all activities performed.

Customer first: Focus is put on the customer when working and when decisions are made. The goal is to always exceed the customers' expectations.

Respect for the individual: All personnel should feel respected by managers and colleagues. Further every individual should have the opportunity to development, based on personal presumption, and the opportunity to influence.

Elimination of waste: Activities that are not requested from the customer or value adding should not be performed. All form of waste should be eliminated to increase the competitiveness of the company.

Principles

The intention of Scania is to work according to a normal situation which inquires standardized working methods. By doing this, deviations can be identified. The normal situation consists of six principles: standardization, takt, leveled flow, balanced flow, visual and real time (SPS, 2007).

- *Standardization:* By standardizing the production process Scania is able to achieve the following:
  1) Create conditions for high safety and quality
  2) Secure that the work can be done within the production rate
  3) Create basis for improvement work
  4) Visualize waste
  5) Create a tool for training new employees
- *Takt:* The production rate is determined by the customer demand. This facilitates the work of detecting deviations and none value-adding operations, it also shows how the production process works according to customer demand.
- *Leveled flow:* By leveling the time consuming cabs throughout an entire day Scania is able to utilize their resources optimally.
- *Balanced flow:* The goal for the production is to have a high and even degree of utilization. By doing this Scania can optimize their capacity and realize efficiencies.
- *Visual:* It is crucial to have simple, straightforward, visual and transparent flows throughout the operations. This is done in order to detect deviations from the normal situation and to be able to act immediately, so called real time.
- *Real time:* Scania works with real time information, by doing this Scania is able to act immediately with recent and relevant information. All parties involved should be informed as quick as possible.

Further Scania has three main principles which are intended to provide guidance regarding how the employees should think and act, which includes what methods that should be used. The three main principles are: right from me, consumption controlled production and continuous improvements (SPS, 2007), all explained below.

- *Right from me:* All employees must ensure that their work is done correctly and that no fault or problem is forwarded in the value chain. This is done by using knowledge, methods, tools and instructions.
- *Consumption controlled production:* The production is controlled by customer orders, i.e. Scania only produces to order. The production system is based on never producing more than the next production step requires. By doing this waste such as over production can be eliminated.

- *Continuous improvements:* Continuous improvements are part of constantly challenging and improving the current normal situation, this is essential to stay competitive. Scania intends to improve their quality and work environment while increasing productivity and efficiency.

Priorities

Throughout Scania and during operations the following priorities are followed:

1) Safety/environment
2) Quality
3) Delivery
4) Economy

The priorities should be seen as "both" where Scania priorities safety while producing high quality, delivering in time and having a competitive cost structure. The priority is only seen as controlling during an abnormal situation or when the priorities stand in opposition to each other.

4.3 Performance measurements

4.3.1 Jobs per hour (JPH)

The number of cabs produced is of course an important measure for the Scania production facility in Oskarshamn. This number is measured in different contexts such as the number of cabs produced per employee and the number JPH. Further, JPH is closely related to the production rate which is displayed in the amount of cabs that are to be produced per day. The number of cabs produced per hour is frequently discussed during real time management in order to evaluate the performance of the production in relation to the production goals. This implies that the performance of each production sector is evaluated on a daily basis, considering the long term goal of the number of cabs produced per hour, in order to reach the long term goals of increased production rate. If the desired amount of cabs is not achieved, initiatives are taken in order to improve the production process.

There are numerous ways to consider JPH when evaluating and planning the production process. Purchased JPH is a number regarding the JPH that the machinery was indented to achieve when purchased or the highest measured JPH for the machinery during operations. Target JPH is the required JPH by the machinery to cope with future production demand, this is a number that is ever challenged and numerous projects are initiated in order to reach the target. The actual JPH achieved during production is normally slightly below the purchased JPH, this due to different form of disturbances throughout the production. JPH is measured and calculated according to equation [3].

$$JPH = \frac{Number\ of\ cabs\ produced}{Available\ time} \quad [3]$$

Where available time is the total amount of time excluding breaks, startup/showdown and production disturbances.

4.3.2 Cost per cab

One of the economic key measurements is the cost per cab. This cost is measured by all costs that are related to intangible production applications divided by the number of cabs produced, in other words all costs that are related to material attached to the cab are not included in this measurement. The reasoning behind this approach is that all material attached to the cab is necessary for the customer satisfaction, but costs related to other factors, that is not visible for the end customer, are considered waste and are therefore measured to be minimized. The cost per cab is measured and calculated on a monthly basis, see equation [4].

$$Cost\ per\ cab = \frac{Costs\ (intangible\ production\ applications - primary\ energy)}{Number\ of\ cabs\ produced} \quad [4]$$

When defining intangible production costs, major costs allocated to oil, heat and electricity are not included in the equation. The reason for this is that these costs are difficult to relate to specific production sectors and are therefore measured in a greater perspective, e.g. energy consumption per production site etc.

4.3.3 Overall process efficiency (OPE)

Throughout Scania's production OPE is a performance indicator used to describe how well the production process is utilized during the time period it is planned to be used. The measurement is affected by availability, performance efficiency and quality rate.

The mathematical definition of OPE used throughout the paint shops is described in equation [5].

$$OPE = \frac{number\ of\ approved\ cabs\ \times cycle\ time}{scheduled\ production\ time - occupancy\ shortage} \quad [5]$$

Where,

- *Number of approved cabs* = the number of cabs that are delivered from the paint shop during the specific time period, scrap cabs are excluded
- *Cycle time* = purchased cycle time, the cycle time that the machinery was indented to achieve when purchased or the highest measured capacity
- *Scheduled production time* = available time – planned stoppage time, such as spare shifts, weekends, holidays and breaks
- *Occupancy shortage* = time when the following buffers are fully occupied

OPE is measured and analyzed in other to understand how well the process is utilized. In order to increase the workshop's OPE the underlying reasons for the losses have to be identified, analyzed and corrected.

4.4 Cab production process Oskarshamn

There are five major steps throughout the cab production plant located in Oskarshamn, see figure 9. Sheet metal is received and is pressed to different components of the cab throughout the press workshop. Further, the parts are combined and welded into a cab in the body workshop. The cab then acquires paint through two paint shops, the primer coat paint shop and the top coat paint shop. Finally the cab is processed in the assembly workshop where the interior and parts of the exterior are assembled. The five different workshops are described briefly below, followed by a thorough description of the top coat paint shop.

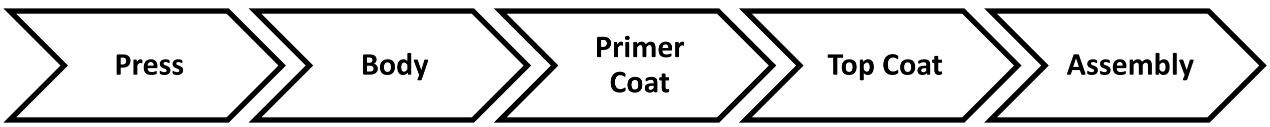


Figure 9: The different workshops throughout the production plant in Oskarshamn

Press workshop

The sheet metal is received as large rolls which are cut into various sizes. The pieces are pressed and molded into different parts of the cab such as roof, front, doors etc. Theses standardized parts are thereafter stored before entering the body workshop.

Body workshop

Throughout the body workshop the metal pieces from the press workshop are welded, glued and bolted together into a shell that will be further processed into a cab. The cab shell is stored within a buffer before entering the primer coat paint shop.

Primer coat paint shop

The cab shell is degreased and cleaned from various dirt particles when entering the primer coat paint shop. The cab is further phosphate and painted with a primer before be hardened in an oven. Finally the cab is treated with a paste in order to join and treat seams throughout the cab.

Top coat paint shop

The top coat is applied to the cab in one of three painting lines depending on color and type of color. The cabs are also treated with anti corrosion oil in various spaces of the cab. A more thorough process description is presented in chapter 4.4.1.

Assembly workshop

Finally the cab is finished in the assembly workshop where the cab is processed through nine lines. Each line adds numerous parts of interior and exterior such as seats, steering wheel and windshield. Further, the cab is transported to one of Scania's chassis workshop in Södertälje, Zwolle or Angers.

4.4.1 Top coat paint shop

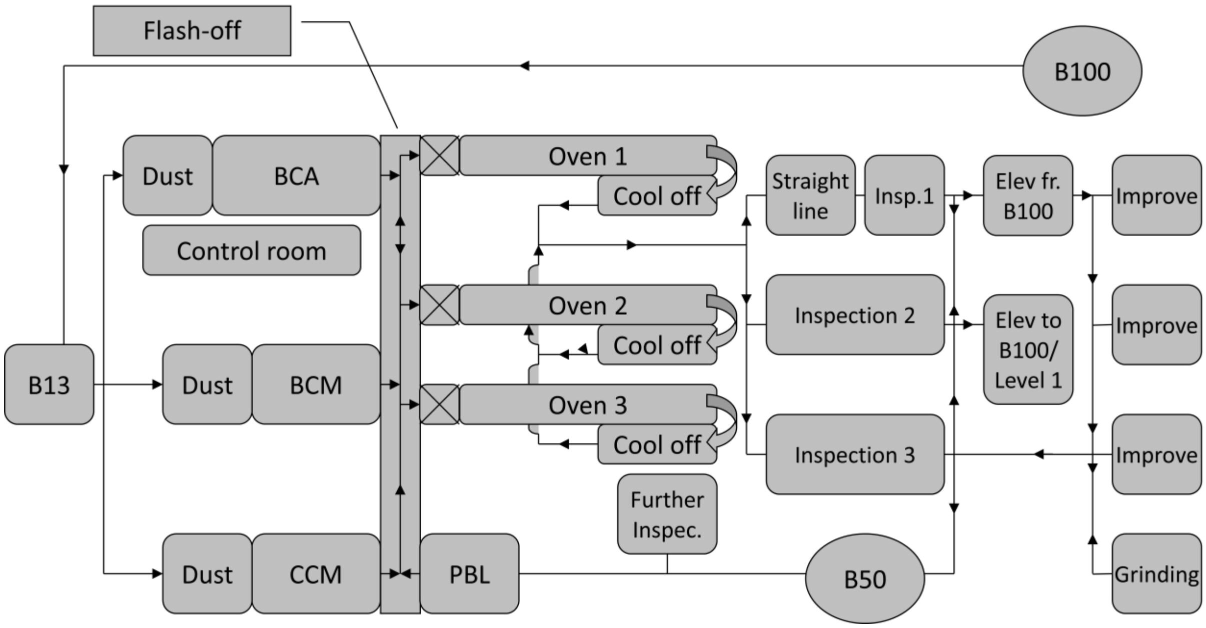


Figure 10: The top coat paint shop

Painting lines

After the cabs have undergone the primer coating process and been placed on skids, it arrives at the top coat paint shop, displayed in figure 10, via buffer B13. Historically the cabs have arrived according to the distribution 45%/45%/10% from the primer coat paint shop during the three shifts. The cabs are directed to one of three available painting lines with regards to the type of paint and color that is to be used for the specific cab. Before entering the actual painting stations, all cabs will undergo a dusting procedure to remove dust, which is a major factor for discrepancies during painting. The dust is removed manually by wiping the cabs with a dust cloth.

BCA

BCA is a fully automatic painting line where the cabs are painted by robots. The paint type used throughout BCA is water based (1K) and the colors used are the so called high runner colors, meaning the most frequent used colors. Before the paint is applied, the cab arrives at a booth where sensors identifies that it is the right cab in terms of ID and model by a comparison with the information system. The color that is supposed to be used is detected and the information is further sent to the paint kitchen, which automatically pumps the color to the painting equipment (see paint kitchen below). The cab is moved forward to the painting box where the painting is performed in three steps:

1. Two robots, one on each side of the cab, paint the Interior doors, door frames, tool box hatch (if existing), the lower cab and the front and back seams. When painting the interior, the robots are assisted by two additional robots for opening the cab doors.
2. Two robots, one on each side of the cab, paint the first complete, external layer of paint onto the cab by electrostatic painting.
3. Two robots, one on each side of the cab, paint the second complete, external layer of paint onto the cab by electrostatic painting.

The final step of the BCA line is an additional painting box which is intended for manual painting. This booth is called "Touch-up" and is mainly used for additional painting for transparent colors or when a problem regarding the robots in any of the previous painting boxes is detected.

During all steps of the BCA line, the cab is monitored from a control room. From there the monitoring, communication and alarming connected to ventilation, conveyors and robots is handled. The control room is staffed at all times to stay in control of the processes and to be able to act quickly if an emergency occurs. The primary responsibilities of the employees within the control room are divided into three categories and the responsibilities are divided between the painting lines and the control room employees:

- IT
- Robotics/Equipment
- Touch-up/Colors

BCM

BCM is a partially manual and partially automatic painting line. The average cycle time is longer than for BCA based on one painter in the painting box. However, the cycle time could be reduced by approximately 50% with two simultaneous painters. The paint type used is 1K and the line is mainly used for low frequency colors. The base painting of all metallic cabs is also subject of this line. As for BCA, BCM starts with a control booth with sensors to secure that it is the right cab in terms of ID and model. The paint kitchen is notified through the information system and the color is controlled and pumped to the painting equipment (see paint kitchen below). The painting in BCM is performed in two steps:

1. Interior doors, door frames and tool box hatch (if existing) are painted manually as well as the back and side window seams for some of the transparent colors. The procedure differs from the BCA line partially due to the ergonomic situation of the employees.
2. Two robots, one on each side of the cab, paint a complete, external layer of paint onto the cab including the lower cab by electrostatic painting, this step is performed twice.

CCM

CCM is, as BCM, semi automatic. This line is used for cabs with clear coat paint and for solvent based colors (2K). As for BCM, the cycle time for CCM is longer than BCA, based on one painter. If two painters would be allocated to CCM the cycle time could be reduced by approximately 35%. The cabs are controlled in the control booth in the same way as for the other two lines and the paint is pumped to the painting equipment in a similar manner as for the BCM line, however via a somewhat different distribution system (see paint kitchen below). The painting is performed in two steps:

1. Interior doors, door frames and tool box hatch (if existing) are painted manually as well as the back and side window seams for some of the transparent colors. The procedure differs from the BCA line partially due to the ergonomic situation of the employees.
2. Two robots, one on each side of the cab, paint a complete external layer of paint onto the cab by electrostatic painting, this step is performed twice.

Personnel

The personnel working on the painting lines is divided into three shifts, day, evening and night. The staff is relatively flexible in their working procedures and a large portion of the staff is capable of performing different tasks. However, the painting procedure is more complex than dusting which makes it easier to move a painter to the dusting station than the other way around. Employees of the control room are capable of performing production tasks as well. The number of employees and their primary areas of responsibility are displayed in table 6 below.

Table 6: Number of employees per area of responsibility throughout the painting lines

Area of responsibility	# of employees shift 1	# of employees shift 2	# of employees shift 3
Dusting	4	4	1
Painting	7	7	0
Control room	4	4	3
Programming	1	0	0
Painting maintenance	1	0	0
Total	**17**	**15**	**4**

Paint kitchen

The area where all paint is either produced or distributed to the painting equipment on the painting lines is called the paint kitchen. The paint that arrives is stored in a warehouse and brought to the paint kitchen when needed at a painting line. Frequently used colors are ordered while not so frequently used colors are mixed by the paint kitchen employees. The mixed colors are tested thoroughly within a lab to secure the exact characteristics of the paint to match the customer demand. The paint is then distributed to the painting lines via various distribution systems, depending on what painting line to be applied to.

BCA

The BCA distribution system is primarily automatic and consists of seven different pumps containing the five most frequently used colors, cleansing liquid and water. The paint within this system circulates and the colors that are to be used are automatically chosen by the production system connected to the painting robots on the BCA line. Batching is done automatically for this line, this procedure is explained in more detail below. Before paint runs out, they are refilled manually. If for some reason the line would benefit from a manual system, this possibility exits. When switching colors, the painting equipment is automatically flushed with cleansing liquid and water before the upcoming paint is pumped to the robots. The paint within the system is seldom switched which makes it unnecessary to flush the entire system. The water and cleansing liquid is pumped to a water treatment facility, where paint particles are separated from the water through a chemical procedure. The cleansing liquid is once again used for flushing the painting equipment and the paint particle waste is transported to an external facility where it is disposed in a environmentally friendly way.

BCM

The paint distribution system for the BCM line is manually supplied with paint. There are three pumps that are manually loaded with the three upcoming colors that are to be used on the painting line. The paint is applied to the system from barrels containing approximately three cabs worth of paint. The staff within the paint kitchen is also responsible for batching cabs on this line according to colors in order to minimize the switching of paint and thereby the resources used. This procedure is explained further below. The system also consists of another pump, dedicated to the base paint of metallic cabs. When switching colors, the employees first attach a cleansing liquid that is pumped through the system to clean it. After this procedure the paint can be reloaded. Every flush will waste approximately one liter of paint that is still in the system. The cleansing liquid and the water are reused and disposed by the same procedure as for the BCA line.

CCM

The CCM distribution system works in a similar manner to the manual BCM system. Paint is replaced manually by the paint kitchen staff and pumped up to the CCM line. The pumps are however different for this line, with regards to the 2K colors that are to be pumped through the system. The paint is initially placed in lockers to reduce the odor and the splashing of 2k-paint. This procedure is both technically and environmentally suitable for the CCM line. The procedure of switching colors is the same as for the BCM line. However, the cleansing liquid and the flushed water is treated somewhat different. Due to the different characteristics of the CCM line, the procedure used in BCA and BCM cannot be applied. Instead, liquid particles are transported through the venturi, located below the painting box, where the paint particles are separated from the liquid. However the largest amount of color and thinner waste is transported through pipes to a waste tank. This procedure is further explained below, throughout the ventilation and energy consumption part of this thesis.

Batching

The batching procedure differs between the lines. As other functions, the batching procedure for BCA is automatic. With a 60 minute interval all cabs that currently are located in buffer B13 or that are scheduled to arrive in buffer B13 during the next 60 minutes are batched by color to minimize the number of color changes and thereby the resources used. When one batch has been painted, the cab with the earliest shipment date will be transported to the painting line. The batching procedure for BCM and CCM is however performed manually by the paint kitchen employees. This procedure is performed in a similar way to the automatic batching procedure on BCA but there are no actual time constraints. Since the majority of cabs are painted on BCA, it is not uncommon that there is a limited amount of cabs for the other lines in the B13 buffer. This results in the paint kitchen employees using their experience to batch cabs for this line i.e. cabs that are to be painted with frequently used colors can be stored in the buffer for a short period of time, and therefore be batched with another cab.

Personnel

The personnel working in the paint kitchen is divided into three shifts, day, evening and night. The work tasks of the personnel in this part of the process differ from other areas of the company since the majority of the staff is not directly employed by Scania, but hired consultants. The current number of employees and their primary areas of responsibility are displayed in table 7.

Table 7: Number of employees per area of responsibility throughout the paint kitchen

Area of responsibility	# of employees shift 1	# of employees shift 2	# of employees shift 3
Materials planning	1	0	0
Color production	2	2	1
Color distribution	4	4	1
Water treatment	1	1	1
Total	**8**	**7**	**3**

Ovens

All cabs move along conveyors from the painting lines, via an elevator, into the ovens in order for the paint to harden. Before entering the elevators the cabs are placed in the "Flash-off" zone for approximately eight minutes. The cabs that have been improved due to deviations will also arrive at the flash of zone via the PBL station, described below. The purpose of this procedure is to allow the water or solvent in the paint to evaporate in order to prevent the paint from boiling in the ovens. The "Flash-off" zone is tempered at 27-28 °C. The cabs are redirected to one of three elevators, each connected to one of three ovens, depending on what type of paint that is applied to it.

Oven 1 & 2
Ovens one and two, or BCA and BCM, have the same characteristics. The ovens are reserved for cabs either painted with 1K-colors directly from the painting lines, cabs from the PBL or for the cabs completely recoated with 1K-colors. Both ovens can hold six cabs each. All cabs will undergo the following procedure within the ovens:

- A minimum of 130 °C in 20 minutes
- A maximum of 130 °C in 60 minutes or 145 °C in 45 minutes

The average time spend in the ovens is approximately 55 minutes.

Oven 3
Oven three, or CCM, differs from the previous two. Cabs are directed to oven three if they are either clear coated or base coated metallic colors. Cabs that are either painted with 2K-colors directly from the painting line or from the PBL or if they are completely recoated with 2K-colors are also subjects for this oven. Oven three can hold six cabs all which will undergo the following procedure:

- A minimum of 80 °C in 30 minutes
- A maximum of 100 °C in 45 minutes

The average time spend in oven three is the same as for the other two ovens i.e. approximately 55 minutes.

Inspection
Before reaching the inspection, cabs that leave the oven have to cool off. An elevator transports the heated cabs from the oven to the cooling zones. The cabs are placed in these zones for approximately 10 minutes. During this time, the temperature of the cabs from oven one and two will drop from 140 °C to 25 °C and the temperature of the cabs from oven three from 100 °C to 20 °C. Each cooling zone has the ability to accommodate two cabs. The purpose of the cooling zone is for the inspection employees to be able to perform their working procedures with regards to the temperature of the cabs. When cooled off, the cabs are loaded onto a conveyor that transports them to the inspection lines. The cabs are directed to one of three possible lines depending on the type of paint that is applied to it.

Straight line
All cabs, except for the base painted metallic cabs, are directed to inspection line one via the straight line. The straight line consists of two polishing stations, where defects are removed manually by employees using air driven polishing equipment, if possible. Special lighting is applied in order to facilitate the detection of defects. The focus is directed to areas of the cab that are considered most important i.e. the areas that are most visible to the driver. Employees

of the first station focus on the top half of the cab. This includes the upper parts of doors, window frames, upper part of side plates, roof and external back panel. The employees in this part of the process have access to lifting equipment to reach all mentioned areas. In the second part of the polishing station, employees focus on the lower half of the cab. This includes the lower parts of doors and side plates.

Inspection line 1

In inspection line one, the cab is visually controlled in daylight in order to detect additional defects or color mismatches. The cab is elevated to the exact height it will attain when applied to a chassis further on in the manufacturing process. A special procedure regarding the positioning of the employees and pattern of investigation is used. These standards are developed so that defects that are not detected by inspection are acceptable to pass along the process. All defects are recorded into the information system so that stations later on in the process can obtain the data and take actions accordingly. Approved cabs are transported by an elevator to the first floor for anti corrosion treatment or to the buffer B100 to be transported to the Anti Corrosion Line (ACL) when possible.

Inspection lines 2 & 3

All cabs that have been partially repainted in the PBL and the base painted metallic cabs are directed to either inspection line two or three. The procedure is the same as for the visual control in inspection line one, but these lines are not preceded by a straight line or any other station. Instead, it is possible to polish cabs in the inspection station on lines two and three.

Personnel

The personnel working on the inspection lines is divided into three shifts, day, evening and night in a similar manner as the employees within the painting lines. The staff for this section is relatively flexible in their working procedures as well and most of the staff is capable of performing different tasks. Some of the employees of the inspection lines are capable of performing tasks within the painting lines. The employees are able to rotate between the different inspection lines depending on what type of paint the current cabs have. The number of employees and their primary areas of responsibility are displayed in table 8 below. During shift 3, only inspection lines 2 and 3 are employed.

Table 8: Number of employees per area of responsibility throughout the inspection lines

Area of responsibility	# of employees shift 1	# of employees shift 2	# of employees shift 3
Polishing	4	4	1
Inspection	2	2	1
Final polishing	1	1	1
Secondary line employees	1	1	0
Total	**8**	**8**	**3**

Improvement

Cabs that need further improvement are transported to the improvement stations, grinding stations or to the area of further inspection if additional investigation is required. In the area of further inspection, production managers and engineers discuss appropriate actions to take for the specific case. If these stations are full, the cabs are temporarily stored in buffers B50 or B100.

Improvement stations

Cabs with small defects which do not require recoating are sent from the inspection lines to one of the improvement stations, depending on the situation possibly via a buffer. The employee within the improvement booth collects the data regarding defects from the information system and performs necessary actions. The improvement process consists of grinding the defect and spray painting the area. The paint is ordered manually from the paint kitchen. Instead of resending the cab to the ovens, the operator uses a infrared lamp to quickly harden the paint. This process will last for approximately 30 minutes. Lastly, the finishing touch is performed by additional grinding in order to make the painted area blend in with the rest of the cab. The cab is then either transported to the first floor for anti corrosion treatment or to the B100 for temporary storage.

Grinding station

If the defects are too substantial to be improved within the improvement booths and instead need repainting, the cabs are sent to the grinding station. Information regarding the defects are retrieved from the information system and the operator uses grinding equipment to improve the defect. Depending on the amount of repainting work required, the cab is sent to either the beginning of the painting lines via the B100 buffer for a complete repainting or to the PBL for smaller areas of painting, such as a door.

PBL

PBL is the destination for cabs leaving the grinding station and are not subjects for complete repainting. Within this station, the cabs undergo a two step process:

1. Masking: all areas of the cab that are not to be painted are covered.

2. Painting: the grounded parts of the cab are painted manually with the correct color, ordered from the paint kitchen.

The painted cabs are sent to the flash off station before once again entering the ovens.

Personnel

The personnel working on the improvement section is also divided into three shifts, day, evening and night in a similar manner to the employees of the painting lines and the inspection. The number of employees and their primary areas of responsibility are displayed in table 9 below.

Table 9: Number of employees per area of responsibility throughout the improvement area

Area of responsibility	# of employees shift 1	# of employees shift 2	# of employees shift 3
Team leader	1	1	0
Improvement	2	2	1
Grinding	1	1	1
PBL	2	2	0
Total	**6**	**6**	**1**

Buffers

In order to attain a certain level of flexibility and security, buffers are located in different locations throughout the production. The main purpose of the buffers is the same, but there are some characteristics that differ between each one. All buffers are described further below.

B13

All cabs arrive to the top coat paint shop from the prime paint shop via an elevator from B13, before they are assigned to one of the painting lines. B13 is connected to another buffer, B100, to allow the cabs in B100 to be delivered to the painting via the same elevator lines. However, cabs from B100 cannot enter B13. The capacity of buffer B13 is 79 cabs.

B50

Buffer B50 is used as a temporary storage for cabs waiting for the improvement stations or the PBL to be available.

B100

Buffer B100 is used for cabs that have been grinded and are waiting for a complete repaint and for the metallic cabs that have undergone their base coating process and are to be clear coated. The approved cabs that cannot be sent to the anti corrosion treatment on floor one due to sequencing issues are also stored in B100 as well as the ones that need further improvements in the improvement stations or grinding station. The combined size of buffers B100 and B50 is 31 cabs.

4.4.2 Anti corrosion line

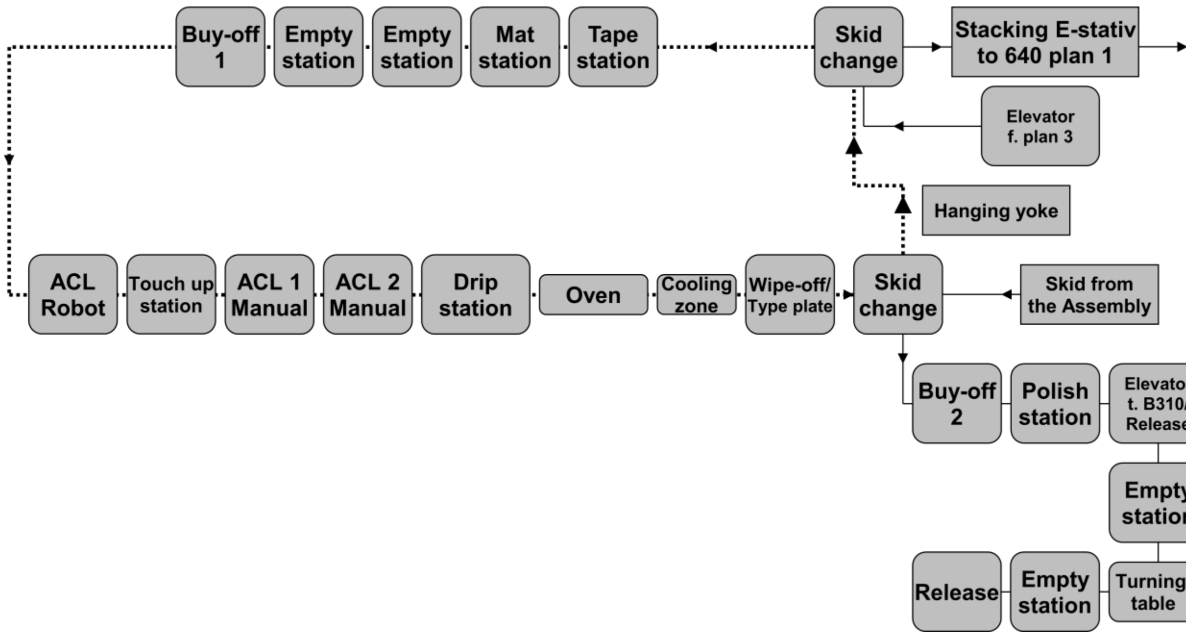


Figure 11: The anti corrosion line

Approved cabs are to the anti corrosion line, displayed in figure 11, on the first floor via an elevator. Some cabs have been temporarily stored in B100. When arriving at the ACL, the skids transporting the cabs are replaced by hanging yokes attached to another conveyor. This makes it possible to treat the bottom of the cabs later on in the process. The yokes are sent back to the primer paint shop.

Tape station

To prevent water leakage on finished cabs, the area where the door meets the roof is taped and the area by the defroster duct is treated with a rubber strip. Employees at the tape station uses lift tables in order to reach the areas where the work is performed manually.

Mat station

To prevent noise due to vibrations in the cab, vibration absorbing mats are placed throughout specific areas within the cab which are melted in order to stick. Thin magnetic mats are applied to areas such as the inside door and side plates and thicker mats are placed on the floor and the hood for optimal noise prevention. Rubber plugs are applied to all holes in the floor to prevent water and dirt from entering the cab and causing rust. During this entire procedure, the cab is fixed with a floor fixture in order for the operators to be able to climb onto the cab if necessary.

Buy-off 1

The cabs are transported along two empty stations before arriving to the first “Buy-off” station. This is an inspection station with the same procedure as the inspection in the top coat painting process. The purpose is to identify defects that either have been missed or caused since the last inspection.

ACL stations

Cabs that are approved in the first buy-off station are transported to the first station in the lower part of the ACL. This station consists of an automated robot which applies anti corrosion oil into the beams and holes under the cab to avoid future corrosion issues. The procedure is initialized when a vision system i.e. cameras recognize the cab's position and directs the robot with regards to this information. If a cab is recognized as scrap in the previous buy-off station, no anti corrosion oil is applied.

Next in line is the touch up station. Here an operator can perform the same operation as the robot in the previous section. This station is used when the mentioned robot malfunctions.

The first manual ACL station is employed by one operator, who applies anti corrosion oil into cavities such as those in the firewall and the ones in the rare cab brackets. These areas are covered manually because they are hard to reach for the robot. The operator finishes the work of this station by drying of any excessive oil with a cloth. The second manual ACL station works in a similar manner to the first. There are however two employees applying anti corrosion oil to the cab and the areas of treatment are cavities such as the ones on the inside of the doors. Excessive oil is once again removed before the cab is transported along the line.

The drip station is an unemployed station where the cabs hang for one takt time in order for any excessive oil to be drained before the cab is transported into the oven.

Oven

The next step of the anti corrosion treatment process is the oven. The oven is tempered at 154°C and holds a total of five cabs. During time throughout the oven, the anti corrosion oil will reach 80°C and become drip free. The mats and plugs melt and will thereby stay in the proper positions.

For the benefit of the process operators next in line, the cabs are cooled in the "cooling zone" before they are transported along the line. Within this station the cabs temperature fall from around 130°C to approximately 30°C. This zone holds two cabs.

Wipe-off/Type plate station

The cabs move along the process and arrive at the wipe-off/Type plate station, employed by two operators. Here excessive oil, which eventually splashed onto the cabs in the oven, is removed and a sticker, containing information such as the cabs ID, is attached onto the defroster duct. When a cab arrives at the second cooling zone, a signal is sent to an engraving robot in the wipe-off/type plate station that manufactures a badge to be attached to the cab.

One operator compares the badge with another ID badge, which was preliminary attached in the body shop. If the badges comply, the preliminary one is removed and the newly manufactured is attached to the boarding step unit at the right side of the cab. For some specific types of cabs, an additional badge is attached to the left side as well.

Next, the cabs are once again placed on skids instead of hanging yokes. The skids are transported from the assembly line, stacked, split, placed onto a lift table and elevated to match and dock the specific cab. The yoke releases the cab and is transported back to its original position at the same time as the cab is moved forward to the second buy-off station.

The final ACL stations

In the second buy-off station an operator makes sure that there are no defects in the paint, that the type plates are properly assembled, that the welded screws are in place and that the mats are properly melted in the right locations.

Approved cabs are sent by an elevator to the buffer B310 via a polishing station, where minor defects can be removed by polishing. The cabs that have been flagged as defected, development cabs and other cabs that are not to be assembled are transported to the release track via the same elevator and a turning table which turns the cab to the desired direction. From the release track, the cabs are transported by a lifting truck to either the “final improvement” station or the development center.

Personnel

The manual working stations within the ACL line is not as time consuming as the ones on the third floor. Therefore only one employee is positioned at each manual station during the day-time shifts. The number of employees and their primary areas of responsibility are displayed in table 10 below.

Table 10: Number of employees per area of responsibility throughout the ACL

Area of responsibility	# of employees shift 1	# of employees shift 2	# of employees shift 3
Manual ACL stations	8	8	1
Robot operator	1	1	1
Team leader	1	1	1
Reserves	2	2	0
Total	**12**	**12**	**3**

4.4.3 Process ventilation

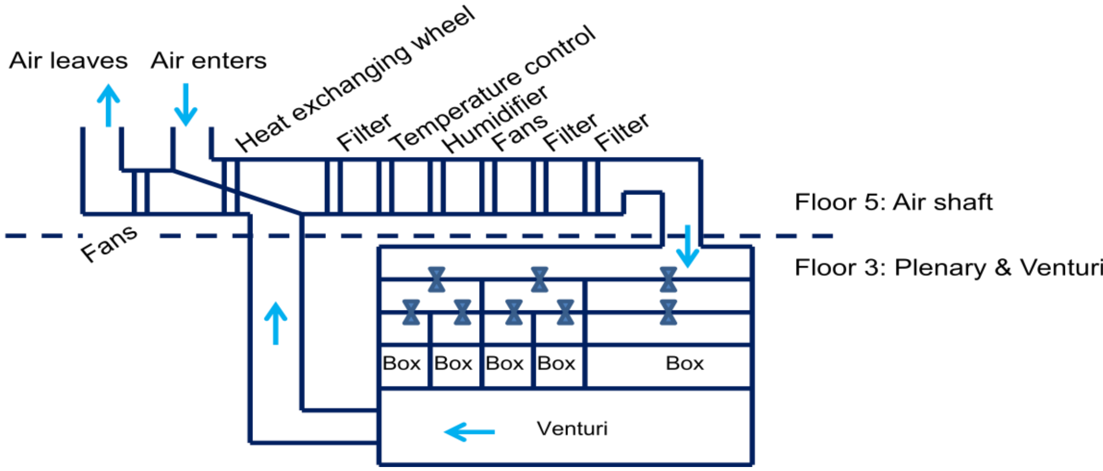


Figure 12: The ventilation and energy conservation process

To reach the desired product and process quality, a well-functioning environment for the employees and to reduce the environmental impact, process ventilation is required. The main purpose of the ventilation is to:

- Remove particles from the air before entering the process
- Remove process sensitive gas from the air before entering the production process
- Keep the right air level of humidity to perform the production process
- Keep the right air temperature to perform the production process
- Keep the right speed and flow of air through the production process

The ventilation, displayed in figure 12, covers an area of approximately 6000 m^2. Each painting line is equipped with a separate ventilation system, as well as the PBL. Each hour, approximately 150 000 m^3 of air flows through each ventilation facility.

Air shaft

Air from outside is brought into the facility through three airshafts located on top of the roof. One shaft is dedicated to BCA and one to the PBL, while BCM and CCM shares the last shaft. When the air enters the shaft it is transported through a heat exchanging wheel that evens out the temperature of the entering and the exiting air. This way, heat from the inside air is reutilized to heat the cold air from outside during the winter. In the summer, the process works the other way around. The air is transported through a filter that removes the largest particles, such as pollen. Depending on the temperature of the air after the heat exchanging wheel, the temperature of the air is controlled by a cooling facility, consisting of a compressor, condenser, evaporator, expansion valve and an electronic engine. The cooling facility tempers the air to 21°C and cooperates with a humidifier, which adds water to the air if necessary, to make sure the air has a humidity of 61%. This is possible since temperature and humidity is strongly correlated. The systems need approximately two hours to secure the right temperature and humidity within the painting booths on the third floor, when rebooted. Finally a ventilator pushes the right amount of air through two additional filters that remove the smaller particles.

Plenary

The air leaves the shaft at high speed and needs to be slowed down and distributed properly before entering the painting booths. The purpose of the plenary is to distribute the air at the correct speed. The speed of air entering manual painting booths is set to 0,3 m/s and the air entering automatic painting booths is set to 0,3 m/s. Finally the air enters the painting booths after it has passed three levels of plenary.

Venturi

Before the used air is transported back to the roof it will pass through a venturi. The purpose of this process is to remove the paint particles from the air to be able to discharge the used air outside with reduced environmental impact. The air is transported through a layer of water that will absorb the particles and release pure air that is transported to the airshaft on the roof. The water will turn into a thick layer of solid waste that will be transported to a facility where it is disposed in an environmentally friendly way.

Personnel

There are no regular personnel on the ventilation floor for every day work. This section of the paint shop is more self sufficient than other areas and the daily work is managed by one engineer. The maintenance employees adjust settings for heat, air pressure and similar to secure the right production environment within the paint shop on the third and first floor as well as other issues in this section of the paint shop.

4.4.4 Maintenance

The maintenance performed throughout the production process and facility is done by Dynamate AB, an external maintenance service provider and a cooperating partner to Scania. There are two types of maintenance, preventive maintenance and emergency maintenance. The preventive maintenance required within the production is planned for a broad time period ahead, for the complete schedule regarding year 2014 see appendix C. The majority of the preventive maintenance activities and the total time of maintenance are not affected by the current production rate. However the actual time when the maintenance is performed varies depending on the current production planning and production disturbances. It can be difficult to identify suitable time periods during production for maintenance. Therefore a large number of the preventive maintenance activities are currently planned during weekends, so called off production, in order to cope with the list of activities. The amount of prescheduled time for preventive maintenance during production, on prod, and the amount of prescheduled time during weekends, off prod, is presented in figure 13. The graph represents week 9-52 year 2014. The cost for maintenance is further explained in chapter 4.8.

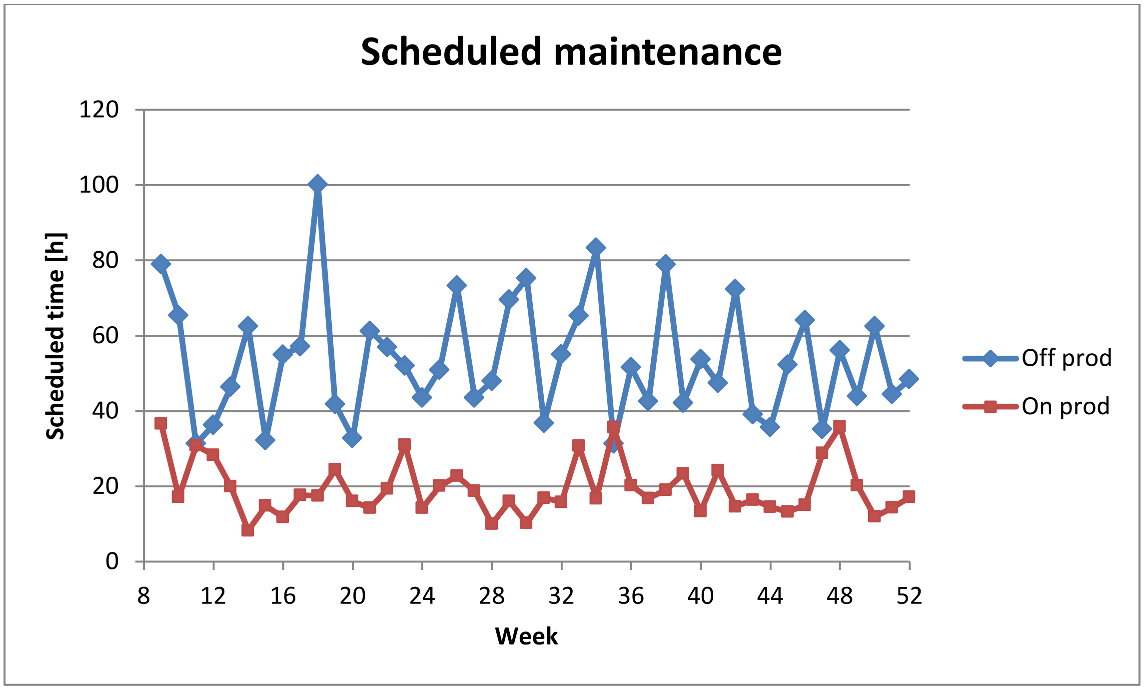


Figure 13: Amount of time scheduled for preventive maintenance on production and off production

4.5 Production data

4.5.1 Production rate

The production throughout Scania's production facility is determined by a fixed production rate. The production rate is measured in the number of cabs manufactured per day. Figure 14 shows the production rate during the years 2011, 2012 and 2013. The production rate has been varied to comply with the customer demand during this period.

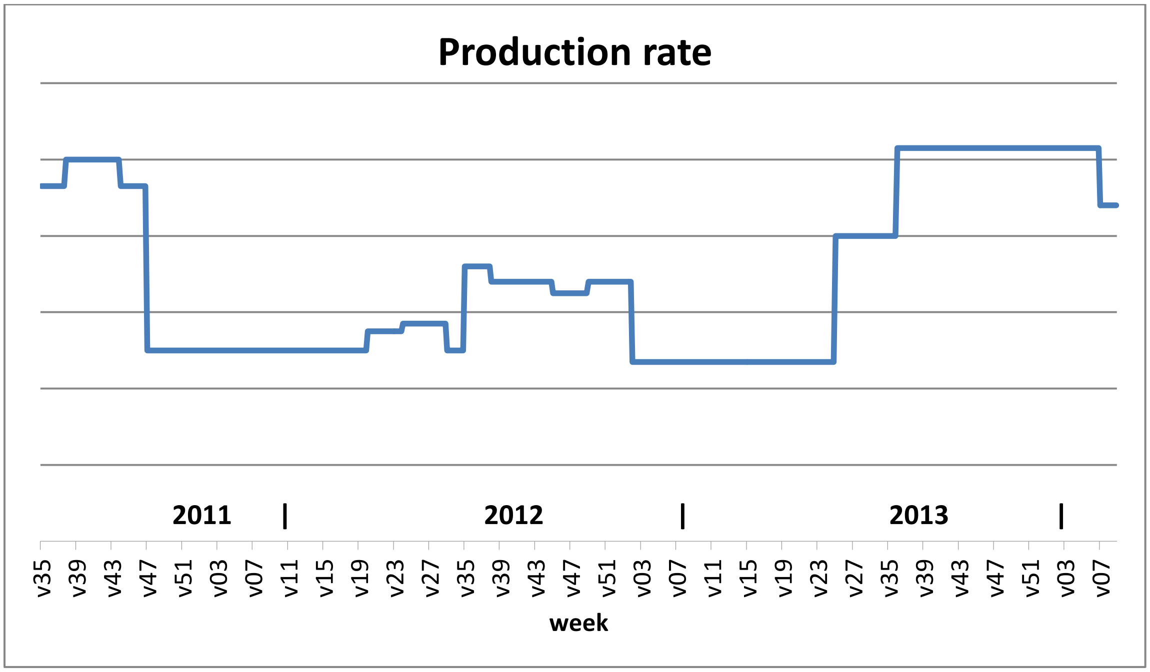


Figure 14: The production rate during the years 2011, 2012 and 2013

Figure 15 shows the actual number of manufactured cabs during this period. The number of cabs is measured in delivered cabs, i.e. cabs that are approved throughout inspection per day and delivered to the following production step. The actual number of produced cabs occasionally varies from the production rate since external factors affect the production process.

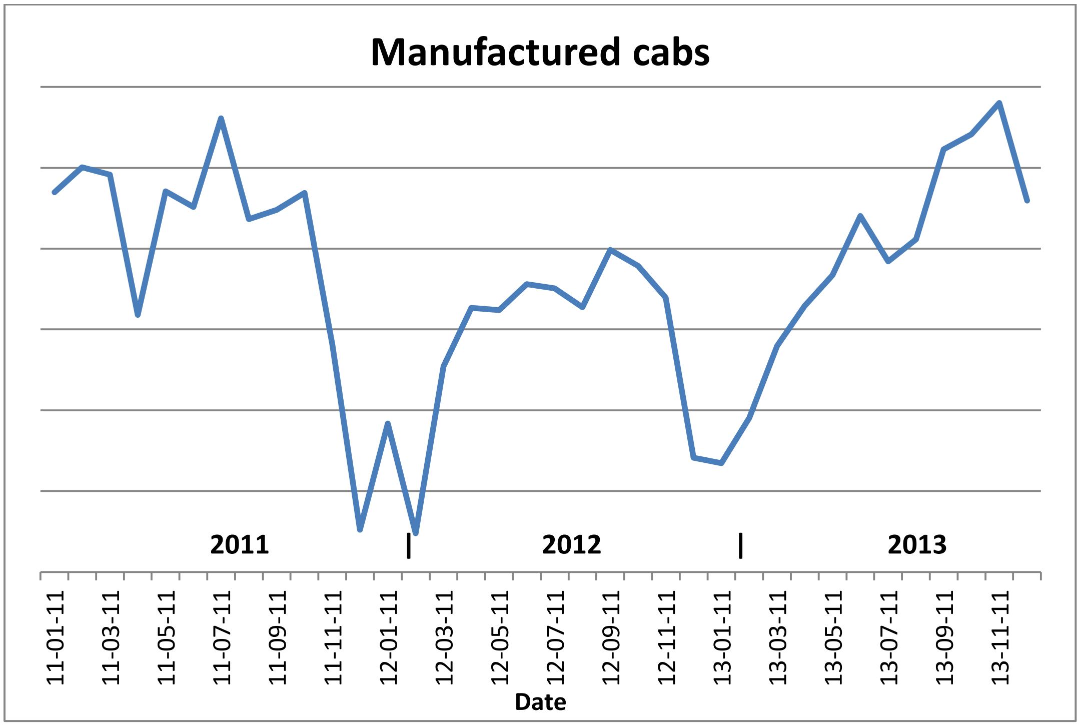


Figure 15: The number of manufactured cabs during 2011, 2012 and 2013

4.5.2 Cost per cab

The cost per manufactured cab is considered an important performance indicator for Scania. Figure 16 illustrates the cost per manufactured cab for the time period 2011-2013. During the industrial vacation in July and August, the data for the graph is not accurate due to economic aspects such as invoice operations, as well as production aspects differs from the normal. This implies a greater cost per cab than other time periods.

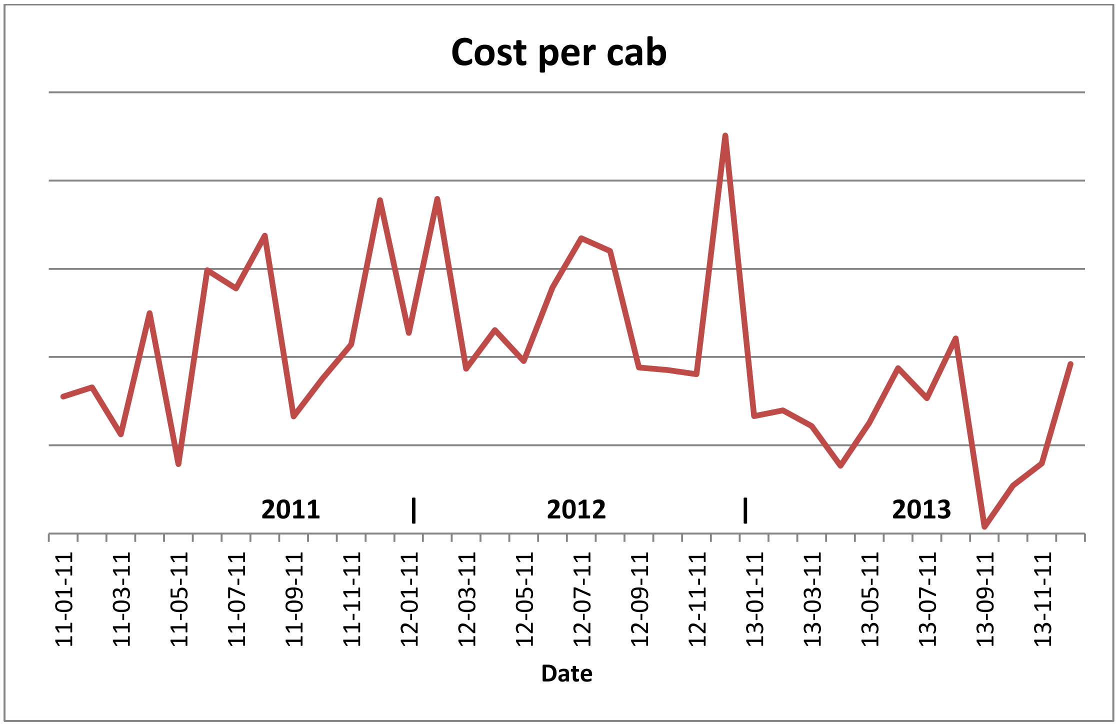


Figure 16: The cost per cab during the years 2011, 2012 and 2013

4.5.3 Production distribution

The total amount of cabs produced per week day varies due to the fact that the number of shifts varies between Monday – Thursday and Friday. During Fridays, the night shift is not utilized which result in less cabs produced. The distribution per line and week day during the time period of 10/26/13-02/06/14 is presented in table 11. The historical distribution has been calculated to 80%/15%/15% for BCA/BCM/CCM.

Table 11: The number of cabs produced per day and line, resulting in a distribution

Average distribution	BCA	BCM	CCM	Total
Monday - Thursday	65%	15%	20%	100%
Friday	70%	12%	18%	100%

4.5.4 Color distribution

The amount of cabs produced per day is allocated to the different painting lines regarding the color that is to be applied to the cab and to the capabilities of each line. The color distribution regarding the total cab production for 2011, 2012 and 2013 is presented in figure 17 and table 12. As illustrated the colors and the distribution is relatively constant over time.

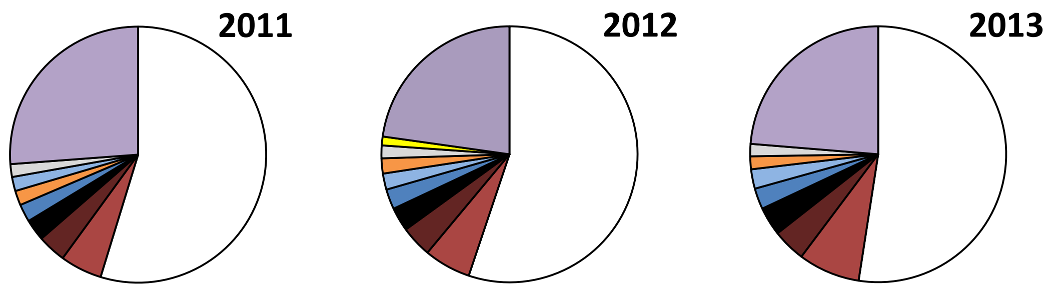


Figure 17: Color distribution for the years 2011, 2012 and 2013

Table 12: Color distribution for the years 2011, 2012 and 2013, presented in percentage of total production

Color	Color ID	2011	2012	2013
White Ivory	1366386	52,45	55,16	54,74
Red Chilli	1433004	7,79	5,91	5,28
Red Cherry	1546014	4,16	3,94	3,59
Black Ebony	1396114	3,61	3,01	2,72
Blue Mediterranean	1435812	2,65	2,53	2,24
Blue Baltic	1396147	2,45	2,03	1,84
Orange Amber	1546011	1,63	1,91	1,79
Silver Arctic	1516942	1,55	1,62	1,62
Yellow Savanna	1546010	-	1,11	-
Rest < 1%	-	23,7	22,77	26,18

As shown in table 12, a limited amount of colors represent the largest amount of production. These colors, high runner colors, are mainly applied on the BCA line. Less frequent colors are applied on the BCM line and, as explained in chapter 4.4.1, the 2K-colours are applied on the CCM line. Figure 18, 19 and 20 below presents the color distribution for each painting line. These figures are based on data during the same period as presented above, color distribution painting lines.

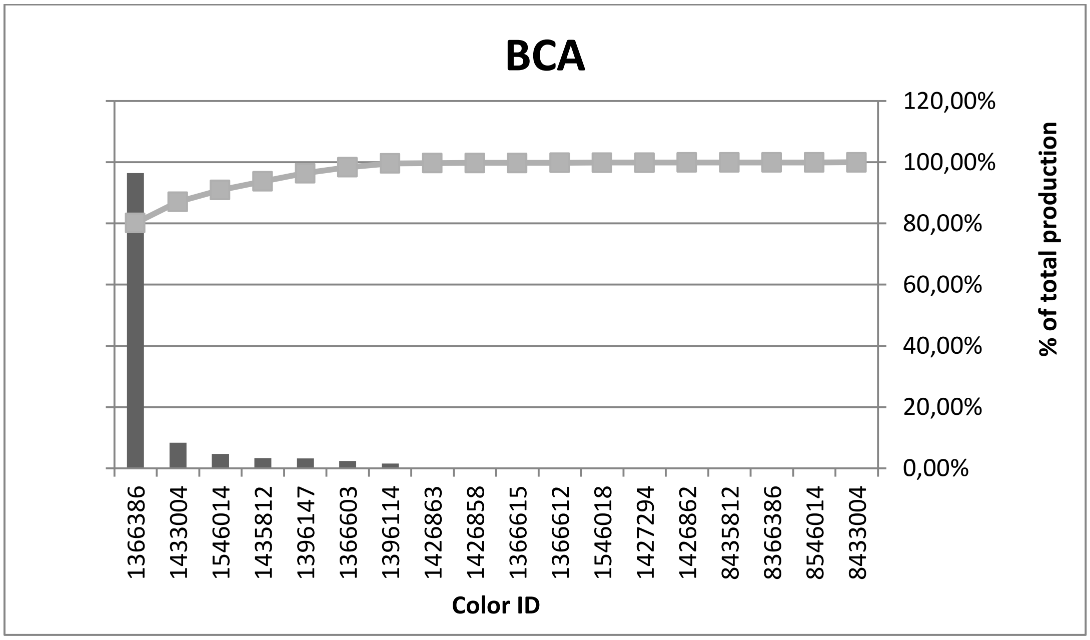


Figure 18: Pareto diagram for the distribution of colors within BCA

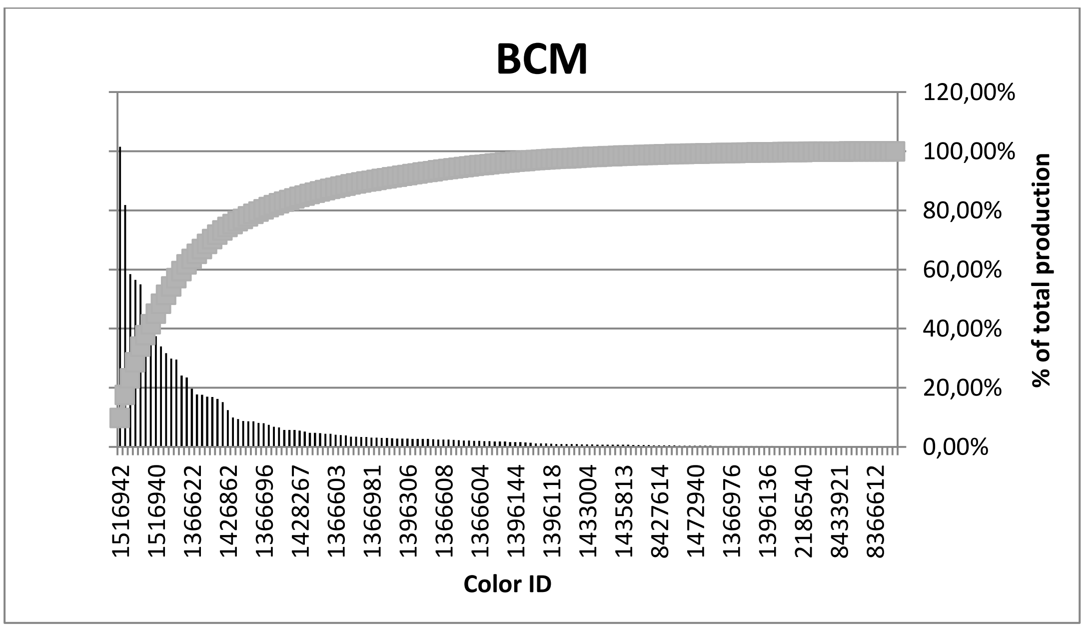


Figure 19: Pareto diagram visualizing the distribution of colors within BCM

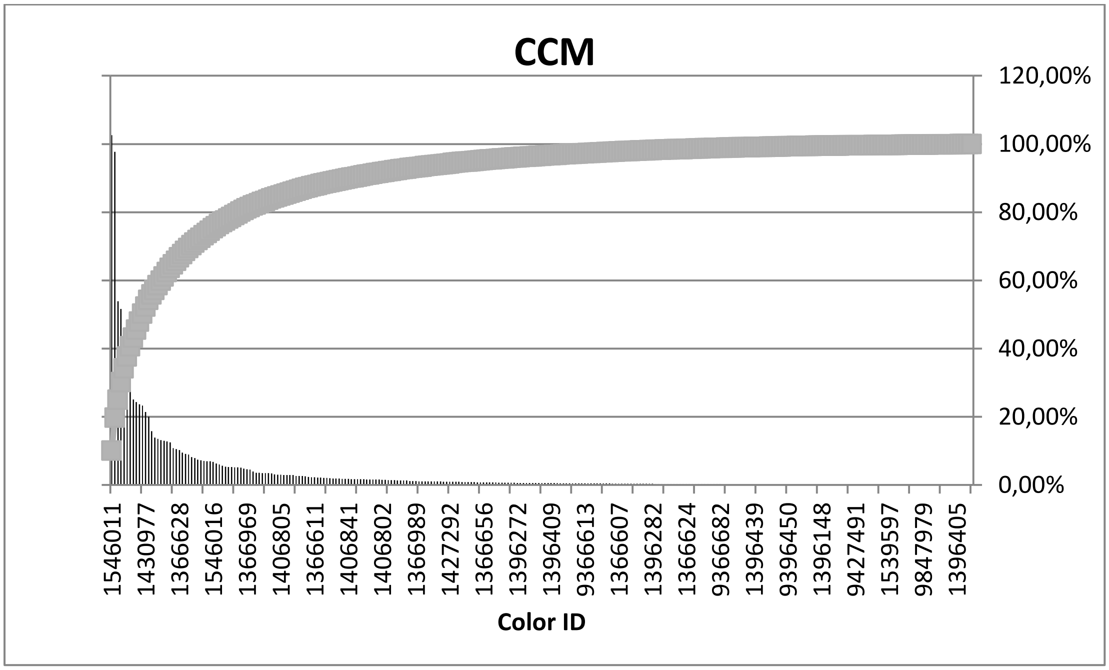


Figure 20: Pareto diagram visualizing the distribution of colors within CCM

4.6 Production disturbances

For the three painting lines, there are numerous disturbances that occur during production and therefore prevent the production of cabs. There are both internal disturbances, such as machine breakdowns or lack of staff, and external disturbances, such as shortage from the previous process step or full forward. The data collected and summarized below represents two different production rates, 1,06X and X, meaning that 1,06X is 6% higher than X. The production rate of X accounts for the time period of 10/20/13 – 02/07/14, thereafter the production rate was reduced to Y for the time period of 02/07/14 – 03/14/1 i.e. the two production rates represent a different number of production days. The data is collected from disturbance lists that are currently filled out manually by operators.

For each line there are a number of disturbance topics to allocate the disturbance to. These are predetermined to simplify the work and monitoring of the production. Currently the disturbance lists are not filled out during night shifts. This is due to the fact that the production targets are not representative compared to the day and evening shifts. The night shifts are also reduced in terms of employees, therefore the employees are forced to rotate between different workstations during the shift. For example, after painting a cab the employees can be required to inspect cabs at the inspection lines. This implies that the disturbances are not denoted and monitored as during day and evening and therefore negligible.

4.6.1 BCA

The total time of disturbances for the two different production rates has been summarized in table 13. The disturbances are also illustrated by shift. For top disturbances throughout BCA during the two time periods see appendix A.

Table 13: Disturbances throughout BCA during 1,06X takt (10/20/13 – 02/07/14) and X takt (02/07/14 – 03/14/1)

Production rate	1,06X (72 days)				X (24 days)			
Cause of error	**Day**	**Evening**	**Night**	**Total**	**Day**	**Evening**	**Night**	**Total**
Facility	12,4	10,2	4,8	27,4	4,9	1,9	0,1	6,9
BCA Robot 1	1,9	0,3	0,5	2,7	0,0	0,3	0,0	0,3
BCA Robot 2	4,4	0,6	2,2	7,2	0,3	0,3	0,0	0,7
BCA Robot 3	0,5	0,4	0,0	0,8	0,0	0,0	0,0	0,0
BCA Robot 4	2,2	0,6	0,7	3,5	0,2	0,5	0,0	0,6
BCA Robot 5	3,1	0,1	0,0	3,2	0,0	0,1	0,0	0,1
BCA Robot 6	2,2	0,5	0,0	2,7	0,0	0,0	1,5	1,5
BCA Robot 7	0,8	0,2	0,6	1,5	0,2	0,0	0,0	0,2
BCA Robot 8	0,1	0,7	0,3	1,1	0,0	0,7	0,0	0,7
Lost takt, dusting	62,3	53,7	0,0	116,0	21,5	19,1	0,0	40,6
Full forward	49,3	45,1	0,0	94,3	13,2	7,0	0,0	20,2
Shortage 640	35,0	34,0	0,0	69,0	6,1	8,8	0,0	14,8
Shortage facility	4,7	4,7	0,0	9,4	0,5	0,2	0,0	0,7
Planned stop	8,3	18,7	0,0	27,0	7,9	9,9	0,0	17,9
Cleaning	15,1	24,1	0,0	39,2	8,4	9,2	0,0	17,6
Other faults - test cabs	5,0	3,3	0,0	8,3	0,4	0,3	0,0	0,7
Total [h]	**207,2**	**196,9**	**9,0**	**413,1**	**63,5**	**58,3**	**1,6**	**123,3**

The three major causes of disturbance during both production rates are lost takt due to dusting, full forward and shortage from 640, i.e. the primer coat paint shop. Lost takt due to dusting only occurs throughout the BCA line which operates according to a fixed takt. If the dusting, which is done manually, is not completed during a takt an empty location will occur throughout the line. In other words a painting location within the painting line will not be utilized during the upcoming takt. Full forward occurs when the inspection lines and improvement boxes are occupied. This results in full ovens and buffers between the ovens and inspection lines which implies that the cabs are not able to proceed from the painting lines. Shortage 640 occurs when the previous production step, the primer coat paint shop, is not able to deliver cabs to buffer 13.

4.6.2 BCM

The total time of disturbances for the two different production rates has been summarized in table 14. The disturbances are also illustrated by shift. For top disturbances throughout BCM during the time two periods, see appendix A.

Table 14: Disturbances throughout BCM during 1,06X takt (10/20/13 – 02/07/14) and X takt (02/07/14 – 03/14/1)

Production rate	1,06X (72 days)				X (24 days)			
Cause of error	**Day**	**Evening**	**Night**	**Total**	**Day**	**Evening**	**Night**	**Total**
Facility	7,5	1,5	0,0	8,9	8,6	0,0	1,2	9,9
BCM painting gun right	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
BCM painting gun left	0,5	0,0	0,0	0,5	0,0	0,0	0,0	0,0
BCM Robot 1	2,3	1,0	0,0	3,3	2,6	6,6	0,0	9,2
BCM Robot 2	0,4	0,7	0,0	1,1	0,0	0,5	0,0	0,5
Full forward	13,5	10,7	0,0	24,2	5,0	0,0	0,0	5,0
Shortage 640	58,1	98,5	0,0	156,6	40,1	64,4	0,0	104,4
Shortage facility	0,8	1,5	0,0	2,3	0,0	0,0	0,0	0,0
Planned stop	10,9	26,4	0,0	37,4	8,3	15,7	0,0	23,9
Other faults - test cabs	1,8	3,3	0,0	5,0	3,4	0,0	0,0	3,4
Total [h]	**95,6**	**143,6**	**0,0**	**239,2**	**68,0**	**87,1**	**1,2**	**156,3**

For BCM shortage 640 and planned stops are significantly larger than any other error cause. As mentioned earlier BCM represents approximately 15 % of all production, i.e. occasionally the line will be starved due to customer demand and consequently previous steps in the production process. The planned stops is also a result of the limited production throughout the line, this allows time to be allocated to e.g. maintenance.

4.6.3 CCM

The total time of disturbances for the two different production rates has been summarized in table 15. The disturbances are also illustrated by shift. For top disturbances throughout CCM during the two time periods, see appendix A.

Table 15: Disturbances throughout CCM during 1,06X takt (10/20/13 – 02/07/14) and X takt (02/07/14 – 03/14/1)

Production rate	1,06X (72 days)				X (24 days)			
Cause of error	**Day**	**Evening**	**Night**	**Total**	**Day**	**Evening**	**Night**	**Total**
Facility	10,6	1,3	0,5	12,5	4,8	1,9	0,0	6,7
CCM painting gun right	0,5	0,1	0,0	0,6	0,1	0,0	0,0	0,1
CCM painting gun left	1,4	0,2	0,0	1,6	0,2	0,1	0,0	0,3
CCM Robot 1	2,1	0,9	0,0	3,0	5,6	2,3	0,0	7,8
CCM Robot 2	2,8	10,0	0,0	12,8	0,7	0,8	0,0	1,5
Full forward	18,7	11,2	0,0	29,8	1,6	0,2	0,0	1,8
Colour delivery	18,2	12,3	0,0	30,5	4,8	4,5	0,0	9,3
Shortage 640	34,6	41,0	0,0	75,6	14,6	7,1	0,0	21,7
Shortage facility	0,9	1,7	0,0	2,6	0,0	0,0	0,0	0,0
Planned stop	17,8	9,3	0,0	27,1	12,8	10,4	0,0	23,2
Cleaning	0,0	2,1	0,0	2,1	0,0	0,6	0,0	0,6
Other faults - test cabs	6,8	4,8	0,0	11,6	5,9	0,7	0,0	6,6
Total [h]	**115,1**	**100,1**	**0,5**	**215,7**	**51,2**	**28,5**	**0,0**	**79,7**

The main disturbances for CCM are the same as for BCM, the CCM line occurs for approximately 15% of all production and therefore the line will occasionally be starved due to the current customer demand.

4.6.4 Variation in disturbances

It is generally recognized throughout Scania that the amount of disturbances is affected by the actual production rate. To later be able to analyze the connection between the two, disturbances for higher and lower production rates, than 1,06X and X, will be presented below. Since the production rates of 1,06X and X are rather adjacent, there is a risk that the connection between the production rate and disturbances will be neglected.

BCM and CCM

Time periods where the production throughout BCM and CCM has been high and low have been identified and illustrated in table 17. It is assumed that BCM and CCM follow the same variation in disturbances for different production rates, due to the similarities of the painting lines. To identify the production rate, a "Theoretical production rate", the actual production throughout the lines has been divided with the historical distribution for the lines, approximately 15%, presented earlier in chapter 4.5.4. This generates a "theoretical production rate", in other words during what production rate the lines can be expected to produce the actual measured outcome. As illustrated in table 16 time periods that represent production rate between 0,8X and 1,6X cabs per day have been identified.

Table 16: Numerous time periods with varying production rates throughout BCM and CCM

	P1	P2	P3	P4	P5	P6	P7	P8	P9
Theoretical production rate	0,8X	0,9X	0,94X	1,03X	1,21X	1,24X	1,43X	1,53X	1,6X
Disturbances day shift [h]	3,52	3,27	3,97	3,62	2,37	2,44	1,38	1,78	0,21
Disturbances evening shift [h]	4,02	2,42	2,73	2,10	1,29	1,70	1,01	0,58	1,65
Total disturbance per day [h]	7,54	5,69	6,71	5,72	3,66	4,14	2,39	2,36	1,86

Figure 21 shows how the total disturbances per day varies regarding to the identified production rates for the nine time periods.

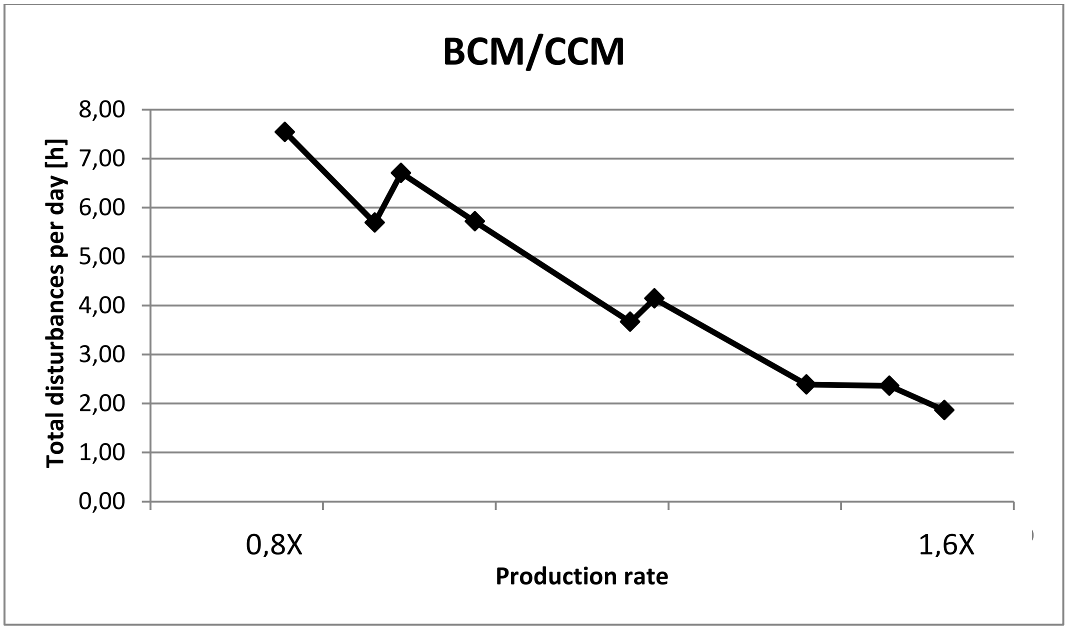


Figure 21: The relationship between production rate and total time of disturbances per day for BCM and CCM

BCA

As for BCM and CCM, data regarding a relation between the total amount of disturbances and the production rate has been gathered for BCA. Table 17 illustrates the average production per day for twelve periods, resulting in a theoretical production rate. The theoretical production rate is calculated by dividing the average production per day with the historical distribution of amount of cabs produced throughout BCA, 80%, presented in the empirical data chapter 4.5.3.

Table 17: Numerous time periods with varying production rates throughout BCM and CCM

	P1	P2	P3	P4	P5	P6
Theoretical production rate	0.9X	0,96X	0,97X	0,99X	X	1,01X
Total disturbance/day [h]	5,6	5,8	5,7	5,2	4,7	5,0
	P7	**P8**	**P9**	**P10**	**P11**	**P12**
Theoretical production rate	1,02X	1,03X	1,04X	1,05X	1,11X	1,17X
Total disturbance/day [h]	4,3	5,0	5,0	4,1	4,0	2,0

Figure 22 shows how the total disturbances per day varies regarding to the identified production rates for the nine time periods.

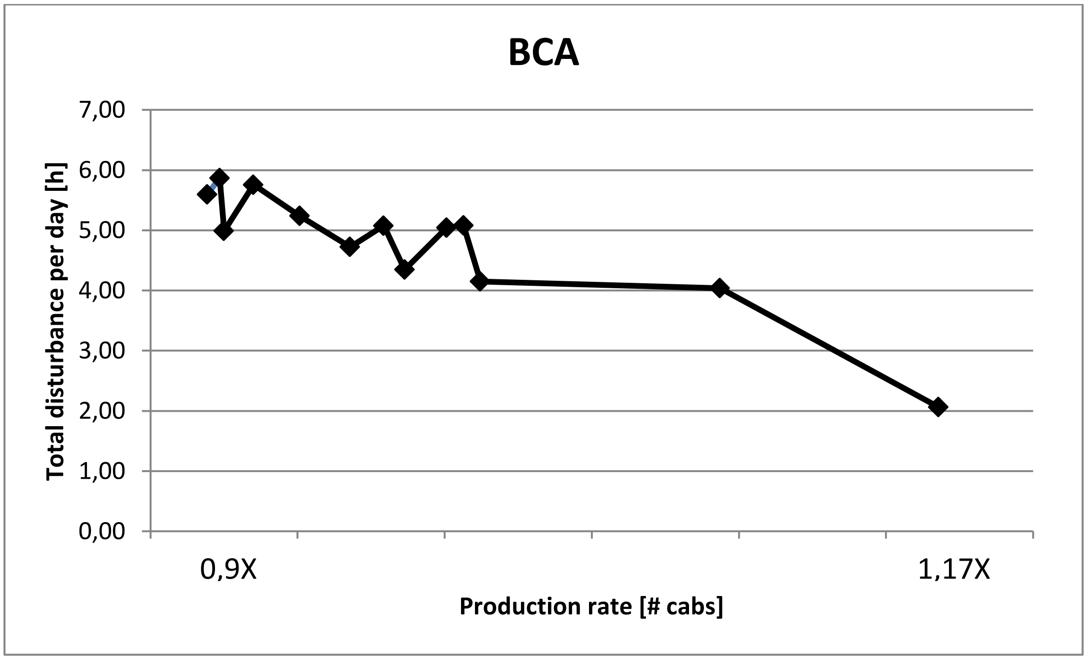


Figure 22: The relationship between production rate and total time of disturbances per day for BCA

4.7 Energy consumption

The paint shop in general and the top coat paint shop in particular, are energy intensive areas of the production process. The major energy sources are electricity, oil and heat related to production. The overall energy consumption for the paint shop per month is presented in figure 23 and table 18 and more thorough in appendix B.

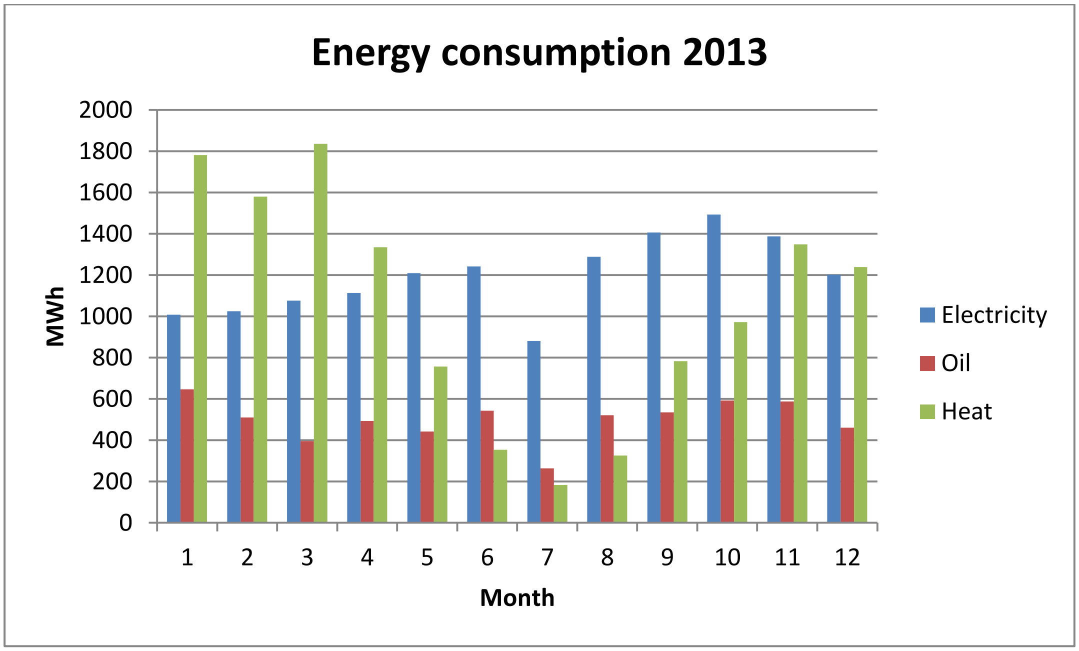


Figure 23: Energy consumption per month during 2013

Table 18: Total energy consumption in numbers during 2013

Energy source	2013 [MWh]
Electricity	14 332
Oil	5 998
Heat	12 501
Total	**32 831**

Since oil is used as fuel to heat up the ovens for drying the paint, these costs are simple to trace and understand. This means that the entire oil consumption can be connected to the four ovens dedicated to the painting line and ACL. All ovens are similar from a technical perspective however since they are used for somewhat different purposes and are tempered differently, the ovens consume a different amount of oil. The consumption is relatively stable during production but will fluctuate during startups. The ovens are currently operating 24 hours a day from Monday to Thursday. On Fridays, the employees of the evening shift shut down the ovens when the shift ends and the employees of Friday's night shift start the ovens during their shift on Sunday nights. The average oil consumption for all ovens is presented in table 19 below. The consumption during startups is based on the average value for the first two hours of production.

Table 19: The average oil consumption per oven during production and startups

Average oil consumption (Liters/hour)				
	BCA	**BCM**	**CCM**	**ACL**
During production	28,25	27,21	22,50	42,24
During start ups	47,96	49,33	36,98	49,17

Further, figure 24 shows how the temperature within the ovens of BCA and BCM varies during a shut down and startup of the oven.

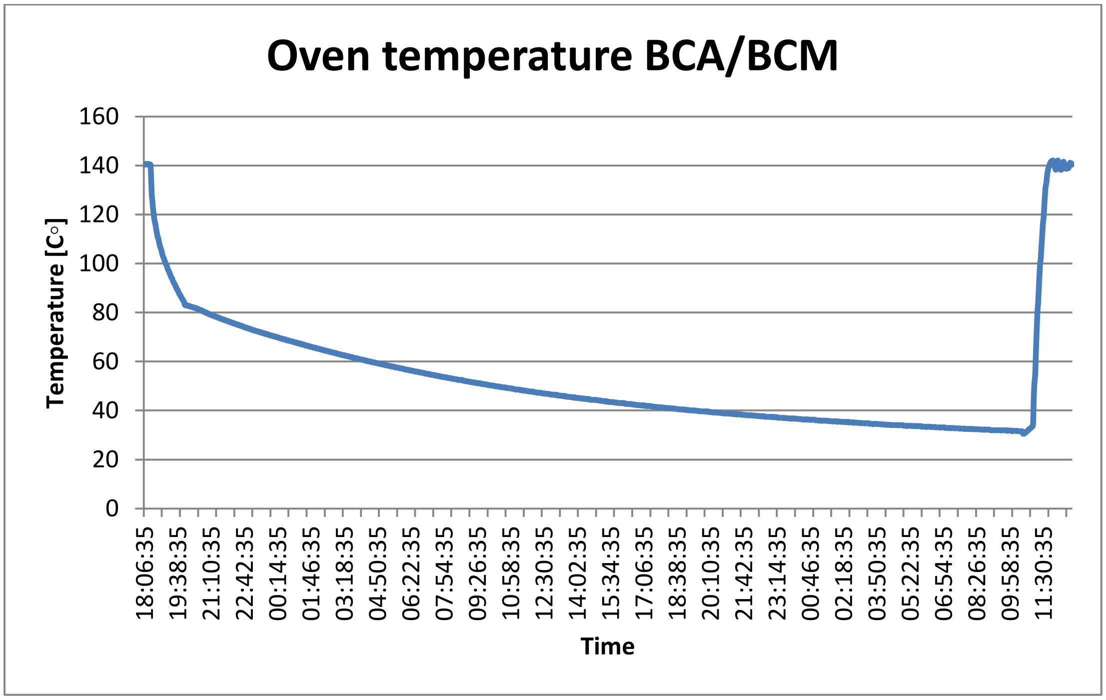


Figure 24: Temperature within the ovens during shut down and start up

Electricity and heat are however more difficult to trace since these energy sources are used in a large number of locations throughout the production and not all areas have been subject of evaluation in the past. In order to obtain an increased understanding of how the energy is consumed within the top coat paint shop, standard values have been used. These values are estimates based on calculations performed by Dynamate AB. These values cover the heat consumption for each painting line and are presented in table 20 below.

Table 20: Total heat consumption for each painting line during 2013

Location of heat consumption	Average MWh/year
BCA	2085,3
BCM	1522,2
CCM	1167,7
MCC	1649,6

Since there are no exact figures regarding momentarily heat consumption or heat consumption per shift, estimates have been made in order to obtain a more thorough understanding of the heat consumption per shift and hour. These estimates are listed below and the resulting figures are presented in table 21.

- There are approximately 230 working days during one year.
- Every working day is divided into three, approximately equally long, 8 hour shifts.

Additional costs associated with energy consumption are currently not traceable to specific production sectors and can therefore not be further presented.

Table 21: Average heat consumption for each painting line per shift and hour

Location of heat consumption	Average MWh/shift	Average MWh/hour
BCA	3,02	0,38
BCM	2,20	0,27
CCM	1,69	0,21
MCC	2,39	0,29

4.8 Cost distribution

Figure 25 shows the cost distribution for the top coat paint shop during 2013, 2012 and 2011. The figures are based on the average costs per month, excluding the period of industrial vacation in July and August as well as December for the same reason as explained earlier in this thesis. The costs are divided into four major categories and are presented in a similar manner as they are within the company. Worth mentioning is that the costs for energy are not included in this cost distribution, but presented separately. The cost distribution is presented below and the costs associated with energy are presented in this chapter.

- Personnel costs include employee wages, including social costs, and additional costs associated with personnel.
- Freight and transportation costs include costs associated with incoming and outgoing goods, customs and other costs associated with freight and transportation.
- Additional costs include operating costs, maintenance costs, quality costs, administrative costs, facility costs and other costs related to any of these.
- Capital costs include costs of deprecations, impairments and other capital costs.

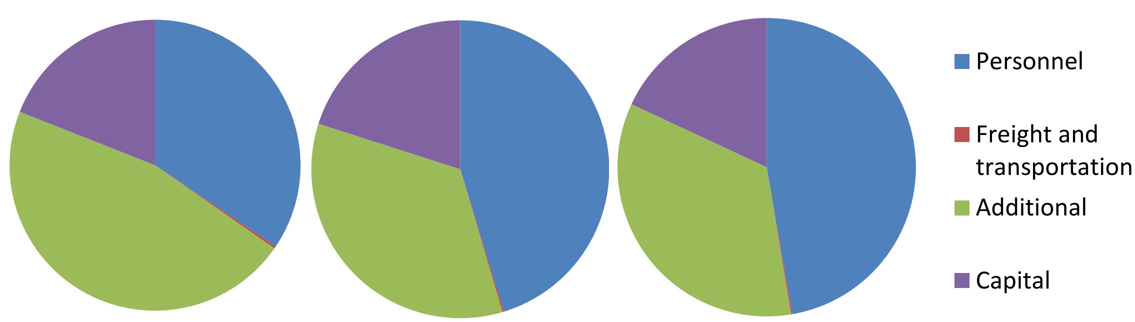


Figure 25: Average cost distribution per month for 2013, 2012 and 2011

Dividing each cost category into smaller ones, a more thorough cost break down is obtained and visualized in figure 26.

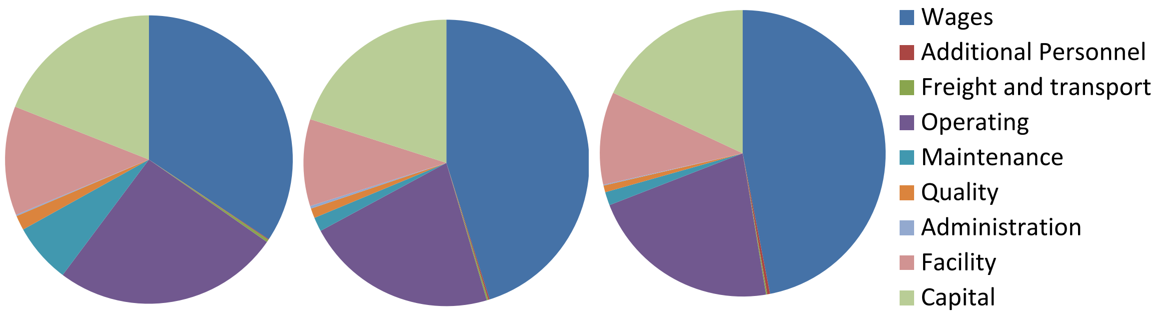


Figure 26: A more thorough average cost distribution per month for 2013, 2012 and 2011

In addition to the costs presented above, costs associated with energy are, as mentioned, stored separately. The major costs for this area are related to the consumption of oil, heat and electricity. Since the costs for these sources vary and not all have been subject for evaluation in the past, estimates have been made in order to get an increased understanding of the costs connected to energy within the production.

- The price for electricity within the top coat paint shop is assumed to be equal to the average price for electricity within the entire paint shop for 2013, 0,15SEK/kWh.
- The price for oil is assumed to be equal to the current average market value 13SEK/liter (SPBI, 2014).
- The price for heat is assumed to be equal to the current average market value 0,45SEK/kWh.
- The cost of maintenance is 490SEK/h during week days and 980SEK/h during weekends.

The distribution of costs regarding energy consumption per month, based on assumptions above, is presented in figure 27.

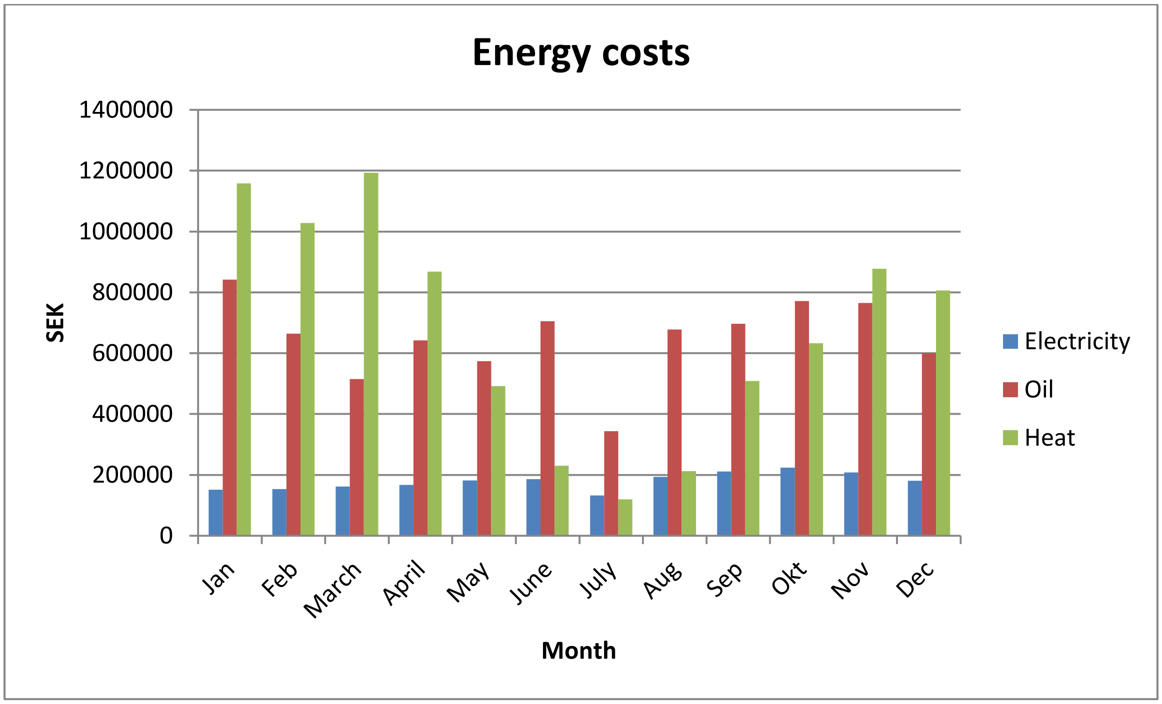


Figure 27: Distribution of energy costs per month during 2013

4.9 Production planning model

Since the top coat paint shop is highly influenced and impacted of variations in customer demand and unforeseen production disturbances, it is difficult to determine production targets regarding the number of cabs that are to be produced throughout each part of the production. Numerous factors need to be considered in order to create an as accurate forecast as possible.

Currently the production planning is supported by a model, covering the production flow through the entire paint shop during each shift. Since this thesis is delimited to only consider the top coat paint shop, the focus regarding the mentioned model will be on this production sector. This part is, within the model, divided into three separate parts, one for the painting lines, one for inspection and one for ACL. The painting lines' part of the model is further divided into three parts, one for BCA, one for BCM and one for CCM. This implies that these parts are not by any means connected in the current model.

The model is built upon, among other aspects, multiple input parameters. The input parameters are fixed factors that are relatively constant in practice, even if they in theory are easy to vary. The values of these input parameters are easy to obtain. The input parameters are complemented by a number of factors that in this thesis will be called production parameters. The production parameters differ from the input parameters since these are based on historical and present data and are therefore more difficult to obtain and keep relevant. For the model to work properly, the production parameters need to be accurate. The model also contains various variables which are the experimental values of the model. By altering these variables, the purpose of the model is to, by considering the variables and parameters, generate useful production values. The parameters, variables and production values are presented in table 22 below.

Table 22: Parameters, variables and productions values for the production planning model

Input parameters	Production parameters	Variables	Production values
Time per shift	Compensation factor	Production rate	Operating time
Time for breaks	Metallic distribution	Target JPH	Production target
Time for meetings	Repaint distribution		JPH per shift
Time for startups and turn offs	Improvement distribution		Theoretical takt time
Cycle time			Actual takt time
			Maximum allowed time for disturbances
			OPE

Figure 28 shows the layout of the current model and the placement of all parameters presented in table 22. The input parameters are highlighted in blue, the production parameters in black, the variable in orange and the production values are highlighted in red.

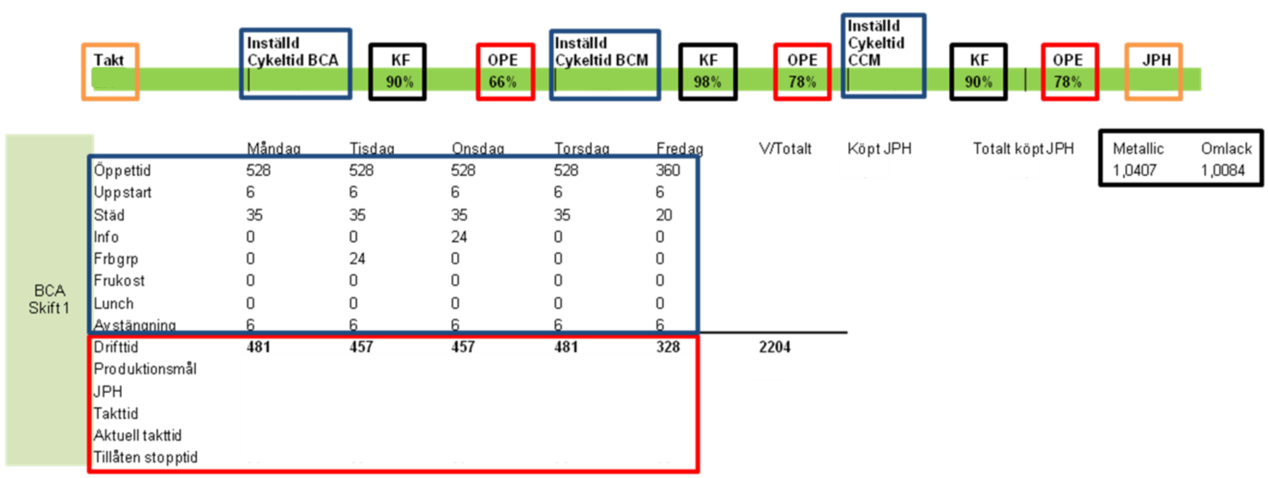


Figure 28: Print screen of the current model, illustrating BCA shift 1

Note that all production parameters are not used throughout all parts of the model. The parameter for improvement distribution is only used within the inspection part of the model, where the cabs are actually sent to improvement. The reason for this is that the parameter would not add any value to the model in other parts, since the parameter only affect the specific production sector. For the same reason, the production parameters for metallic and repaint distribution are not used within the ACL part of the model. Finally, the time for breaks are not included into the BCA part of the model, this due to the fact that the line is automated and breaks are not necessary. Further presentations of the parameters, variables and values follow below.

Input parameters

As mentioned, the input parameters are relatively constant with regards to the working routines and shift form used. The values for these parameters are seldom changed in the model. If the parameters were to be altered, the new figures would not be time consuming to develop. This due to the fact that the parameters only depend on the shift forms used and therefore easy to apply into the model. The input parameters and their characteristics are listed and further explained below.

- *Time per shift* is strictly determined by the shift form used. The values are the same for all production sectors during the same shift. However, the time per shift differs from day to day since the working routine during shifts connected to weekends i.e. Mondays and Fridays are somewhat different.
- *Time for breaks* relates to all breaks during each shift. The total time of this parameter is set to one hour during day shifts, 42 minutes during evening shifts and 18 during night shifts. These figures are determined with regards to the shift form used. As explained earlier, the BCA part of the model is not affected by this parameter.
- *Time for meetings* is the total time for discussions and presentation regarding production control and improvement initiatives. This parameter differs between the production sectors with regards to the necessity of meetings for the specific sector.
- *Time for startups and shut downs* are strictly determined by the capabilities of the production equipment for each sector.
- *Cycle time* is, similarly to time for startups, strictly determined by the capabilities of the production equipment for each sector.

Production parameters

The production parameters are more complex than the input parameters. This means that the parameters, as mentioned, are built upon large amounts of data and are time consuming to analyze and keep relevant. The parameters are ultimately dependent on customer demand and production capabilities, even if the parameters to some extent can be manipulated by production planning decisions within the company. The production parameters including characteristics are listed and further explained below.

- *Compensation factor* is a parameter that is intended to compensate for unexpected happenings within the production sectors. This parameter is based on historical and current figures regarding the average time of disturbances and planned stops during each production sector. The inspection and ACL parts of the model obtain one factor each and the painting line part of the model obtains three, one for each painting line.

This parameter is determined as the percentage of total available production time excluding the disturbances. The current value for each compensation factor is presented in table 23 below.

Table 23: Compensation factors for each production section

Production section	Compensation factor
BCA	90%
BCM	98%
CCM	90%
Inspection	90%
ACL	95%

- *Metallic distribution* is a parameter that is supposed to compensate for the amount of cabs that circulate through the production process two times i.e. the cabs that are painted with metallic colors. This factor is, similarly to the compensation factor, based on the historical and current data and is presented as the percentage of the total amount of cabs, including the second process lap of the metallic cabs as additional production. This parameter is currently set to 104,07%, i.e. 4,7% of all cabs are expected to undergo the painting process two times.
- *Repaint distribution* relates to a figure that is supposed to compensate for the amount of cabs that will need to undergo repainting. This figure is based upon historical data of relevant cabs and is presented as the percentage of the total amount of cabs, including the amount of cabs that will need repainting as additional production. Currently, this figure is set to 100,84%.
- *Improvement distribution* is a parameter with the purpose to compensate for the amount of cabs that will need to undergo improvements. This factor is, similarly to the repaint distribution parameter, based on historical data of relevant cabs and is presented as the percentage of the total amount of produced cabs, including the cabs that are going to need improvements as additional production. This parameter is currently set to 110%.

Variables

The variables of the model are, for this thesis and the original intention of the model, the experimental values. By altering these values, the user is supposed to obtain an increased understanding of how the production planning will be affected with regards to the production capacity. Since the target JPH is determined with regards to a target production rate which is an important aspect of this thesis, the variables is a crucial part of the model. The variables and their characteristics are presented below.

- *Production rate* is, as explained earlier in the empirical data chapter 4.5, the amount of cabs that are to be produced each day. This factor is varied within the model to see how the current production facility will act during different production rates, and to determine how the production planning should be carried out during these rates.

- *Target JPH* is, as explained earlier in the empirical data chapter 4.3.1, the amount of cabs that are to be produced each hour in order to reach the target production rate.

Production Values

The production values are the results of the model when other parameters and variables are entered to the model, i.e. the actual figures that will serve as a basis for the production planning. It is crucial that the input parameters and variables are accurate in order to obtain useful production values for successful production planning. The production values are further explained below.

- *Operating time* is the amount of time available for production when planned stops are excluded, calculated according to:

$$time\ per\ shift - time\ for\ breaks - time\ for\ start\ ups\ and\ shut$$

- *Production target* is the maximum amount of cabs that can be produced during the operating time in order to reach the target JPH :

$$\frac{target\ JPH * metallic\ dist * repaint\ dist * improvement\ dist}{Operating\ time * 60}$$

- *Takt time* is the maximum amount of time available for production of each cab, not considering any disturbances:

$$\frac{production\ target}{target\ JPH}$$

- *Actual takt time* is the maximum amount of time available for production of each cab, considering disturbances

$$takt\ time * compensation\ factor$$

- *Maximum allowed time* for disturbances is the total amount of time available after produced the production target at the actual takt time:

$$(takt\ time - actual\ takt\ time) * production\ target$$

- *OPE* is, as mentioned earlier in the empirical data chapter 4.3.3, a measurement of the overall process efficiency and how well time is utilized:

$$\frac{sum(\frac{operating\ time - \max time\ allowed\ for\ disturbances}{operating\ time})}{Number\ of\ days\ and\ shifts}$$

5 Analysis

This chapter will analyze the relation between efficiency, mainly in terms of costs and time losses, and production rate. Further the chapter will present several strategies to cope with the efficiency losses and the impact of the strategies. To finally identify when the strategies are feasible, a production planning model will be presented.

5.1 Understanding the problem

Initially the analysis is to evaluate how the issue at hand appears i.e. answering the question of how the reduction in production rate affects the efficiency of the production process and how it is visualized.

5.1.1 The theoretical perspective

As presented in the theoretical framework of this thesis, "efficiency losses" is not a clearly defined statement. Authors refer to efficiency in different manners and it is not always apparent what aspects the concept includes. However, when analyzing literature on the subject numerous conclusions can be stated. The theoretical perspective of efficiency often includes how well resources are utilized in order to reach a specific output. Another aspect related to efficiency, or even more relevant; inefficiency, is the inclusion of time losses such as down-time, blocking and starvation within a production process. All inefficiencies established by Mauri et al. (2010), presented in the theoretical framework, are clearly based on wasting time on non-value adding activities.

This statement is further strengthened when analyzing how efficiency is measured. The six big losses for measuring overall efficiency by Nakajima (1988), presented in the theoretical framework of this thesis, are all related to wasting time in different ways. This is even more evident when investigating the ten losses for a capital intensive industry by Jeong and Philips (2001), also presented in the theoretical framework. It is therefore relevant to assume that the ten losses can be considered in this case, due to the fact that Scania's manufacturing process is a highly capital intensive industry.

A final argument to support the correlation between efficiency and wasting time is the relation between efficiency and Lean manufacturing. This aspect is perhaps most visible when considering the seven types of lean waste described by, among others, Womack et al. (1990) in the theoretical framework. Similar to the inefficiencies, mentioned above, the majority of lean wastes can be related to wasting time on non-value adding activities.

5.1.2 The empirical perspective

As concluded when analyzing the problem from a theoretical perspective, efficiency losses are closely related to wasting time on non-value adding activities, which are perhaps most visible in time losses throughout the production. This phenomena will evidently result in increased costs due to the fact that time is spend on non-value adding activities, and additional time will have to be used for actual production. Costs are of course always important to consider since cost reductions will directly affect the bottom line of the company. Both time losses and costs are aspects of the problem that are recognized from an empirical perspective as well through discussions with Scania employees. Both aspects are analyzed below.

Production disturbances

As presented in the empirical data chapter 4.6, production disturbances i.e. time losses are highly noticeable throughout the top coat paint shop. Table 24 is a summary of the disturbances presented in the empirical data and shows the average disturbance per shift for each painting line during two production rates.

Table 24: Total disturbance per line and shift for 1,06X and X takt

Average disturbance/shift [h]	BCA (1,06X)	BCA (X)	BCM (1,06X)	BCM (X)	CCM (1,06X)	CCM (X)
Day	2,88	2,64	1,33	2,83	1,60	2,13
Evening	2,73	2,43	2,08	3,63	1,45	1,19
Night	0,13	0,07	0,00	0,05	0,01	0,00

The data collection shows that for BCA the amount of disturbances does not vary significantly depending on day or evening shift, however for BCM and CCM the time varies more. As shown in table 24, BCM has been affected by disturbances to a greater extent during the evening shift and CCM is affected by disturbances to a greater extent during the day shift. This number can however vary significantly during different time periods as a result of current customer demand, therefore conclusions regarding the distribution of occupancy throughout the day for the painting lines are difficult to state and can be incorrect for an upcoming time period.

When analyzing data regarding two different production rates, see table 24, the disturbances remain rather constant for BCA. The largest disturbances for the different production rates are also similar, see appendix A. This indicates that for surrounding production rates the disturbances can be assumed to act similar. For CCM and BCM the amount of disturbances seem to increase when reducing the production rate, see table 24. As mentioned earlier, only a small amount of cabs are processed through CCM and BCM. It is therefore a risk that the data presented in table 24 shows a situation where the current production throughout these lines is not representative for upcoming time periods. It is therefore difficult to assume how the disturbances will act during variations in production rate for BCM and CCM. However, by identifying periods with high, respectively low utilization and using the historical disturbance of total amount of cabs throughout each line theoretical production rates were identified. The relations for BCM/CCM and BCA are presented in figure 29 and 30 below, including an approximated equation representing the relation for each relation.

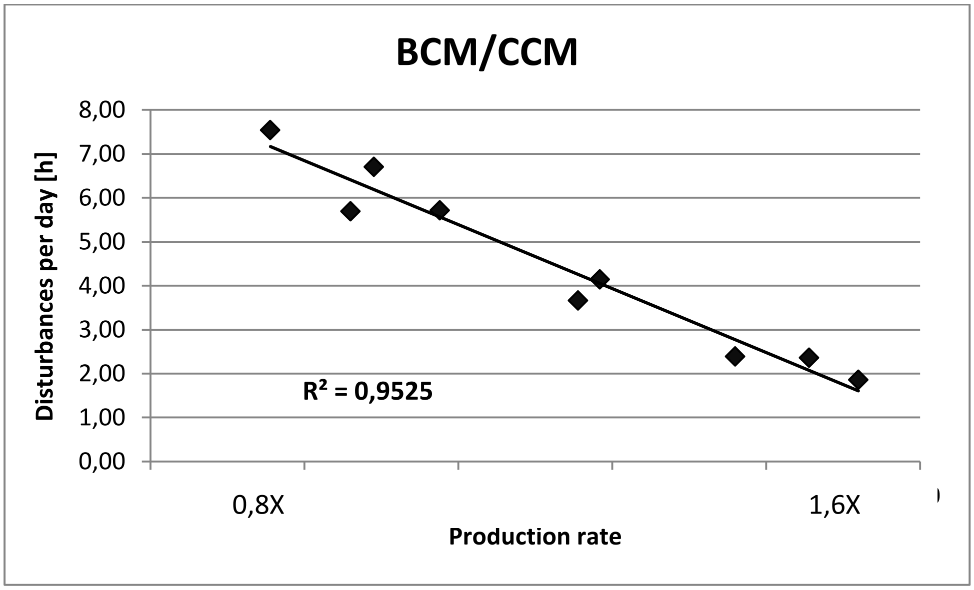


Figure 29: Correlation between disturbance and production rate for BCM/CCM

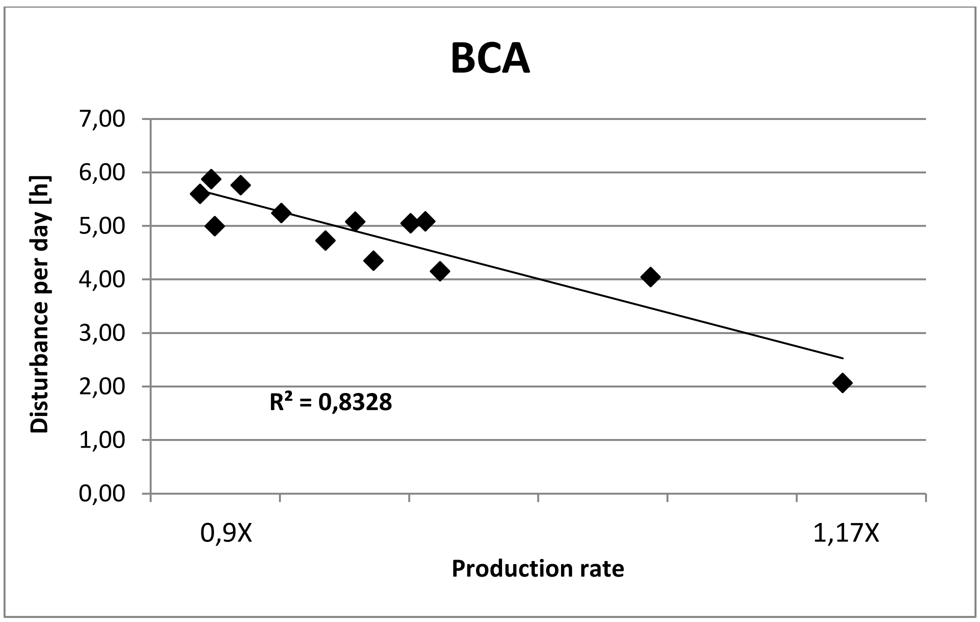


Figure 30: Correlation between disturbances and production rate for BCA

The figures above show a clear correlation between the total time of disturbances per day and the production rate, with a R^2 value of 0,9525 for BCM/CCM and 0,8328 for BCA. As a result of the steady production throughout BCA there were difficulties with identifying time periods with varying production rates, or theoretical production rates. Therefore the interval of production rates for figure 30 is quite narrow. As mentioned earlier in this thesis, the production facility has undergone extensive modifications and improvements since 2013 and it is therefore not relevant to search for production rates during time periods prior to the current.

In order to draw further conclusions regarding the relation, the disturbances have been divided into five categories, see figures 31 and 32. The relation shows that the total time for the different categories varies significantly in relation to the production rate with no apparent trend. Conclusions regarding the separate categories are therefore difficult to identify. The lack of correlation between certain categories and production rate can in addition to natural variation be derived to the fact that the reporting of disturbances are currently filled out manually and the process currently lack standardization. An example of this situation is presented in table 25, which illustrates a disturbance during the production rate of 215 cabs where shortage 640 has been declared as planned stop and can therefore to some extent explain the patterns of “Shortage 640” and “Planned stop” in figure 30.

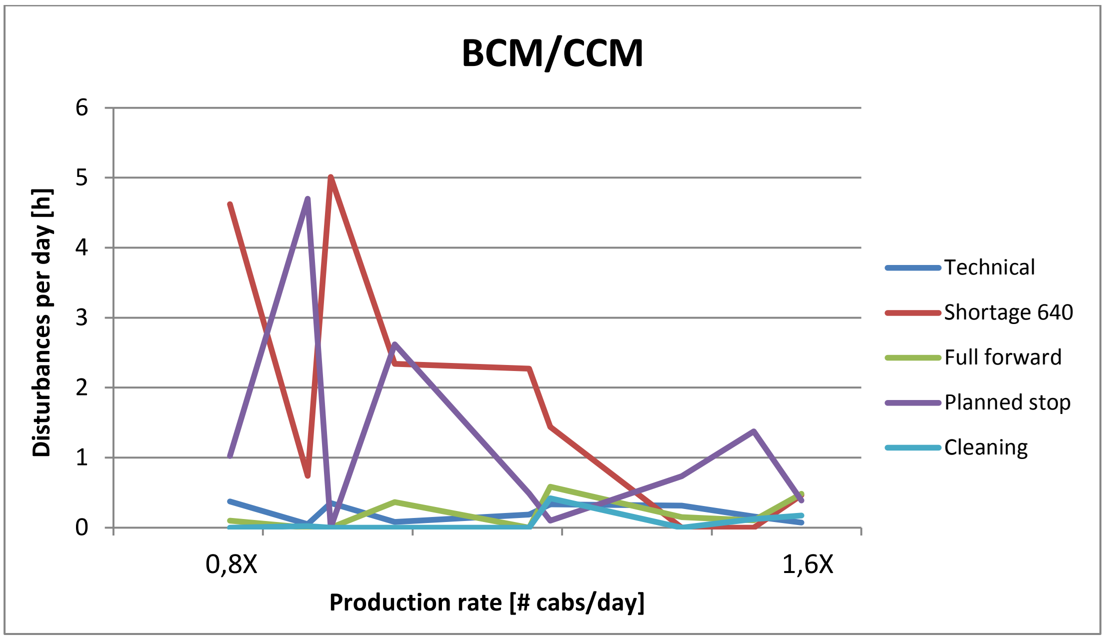


Figure 31: Breakdown of disturbances for BCM/CCM

Table 25: An example of a disturbance

Production rate	Category	Manual description disturbance	Time [h]
0,9X	Planned stop	"Shutting down BCM due to shortage 640, instead staffing CCM"	4,77

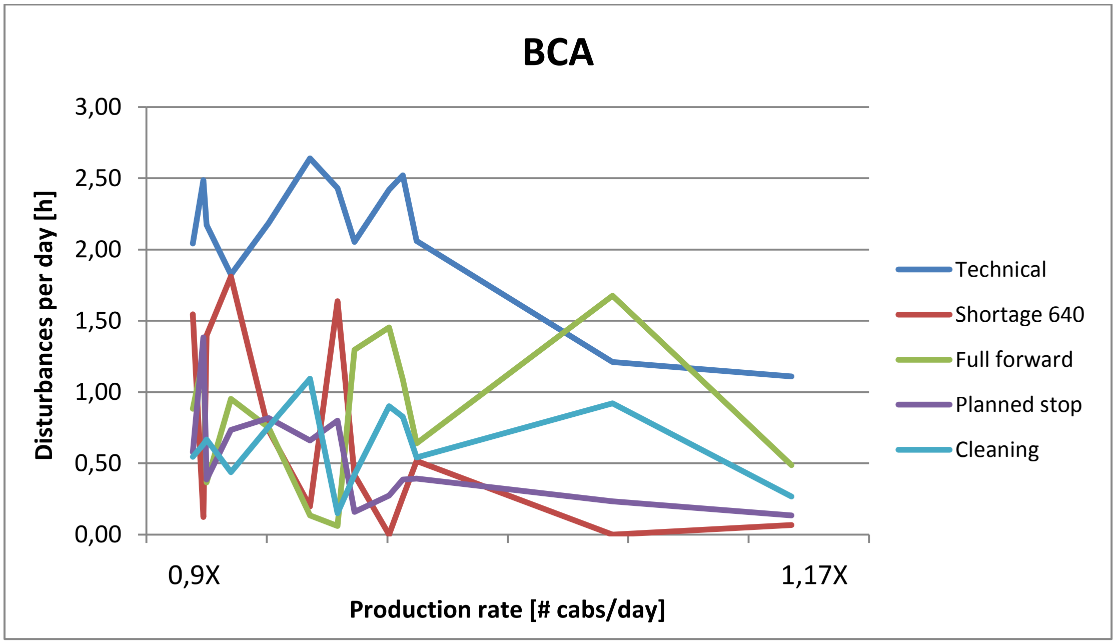


Figure 32: Breakdown of disturbances for BCA

Overall process efficiency is a measurement that describes how well the production facility is utilized. As the calculation of OPE implies, explained in the empirical data chapter 4.3.3, the measurement is affected by the disturbance within the production facility. As visualized in figures 29 and 30, the total amount of disturbances decreases within an increasing production rate. Therefore the OPE of the facility will increase within an increased production rate and decrease with a decreasing production rate.

Cost drivers

During interviews and discussions with Scania stakeholders regarding the subject of this thesis, the expected result has often taken the form of cost reductions and as mentioned above, time losses will indirectly result in increased costs. This aspect indicates that costs are closely related to efficiency and production rate. By analyzing the trends, presented in the empirical data chapter 4.8, a deeper understanding of this correlation can be obtained. Figure 33 shows the cost per manufactured cab, the number of manufactured cabs and the relationship between them. During the industrial vacation period during July and August, the statistics for the graph are not accurate since economic aspects as well as production aspects differ from the normal.

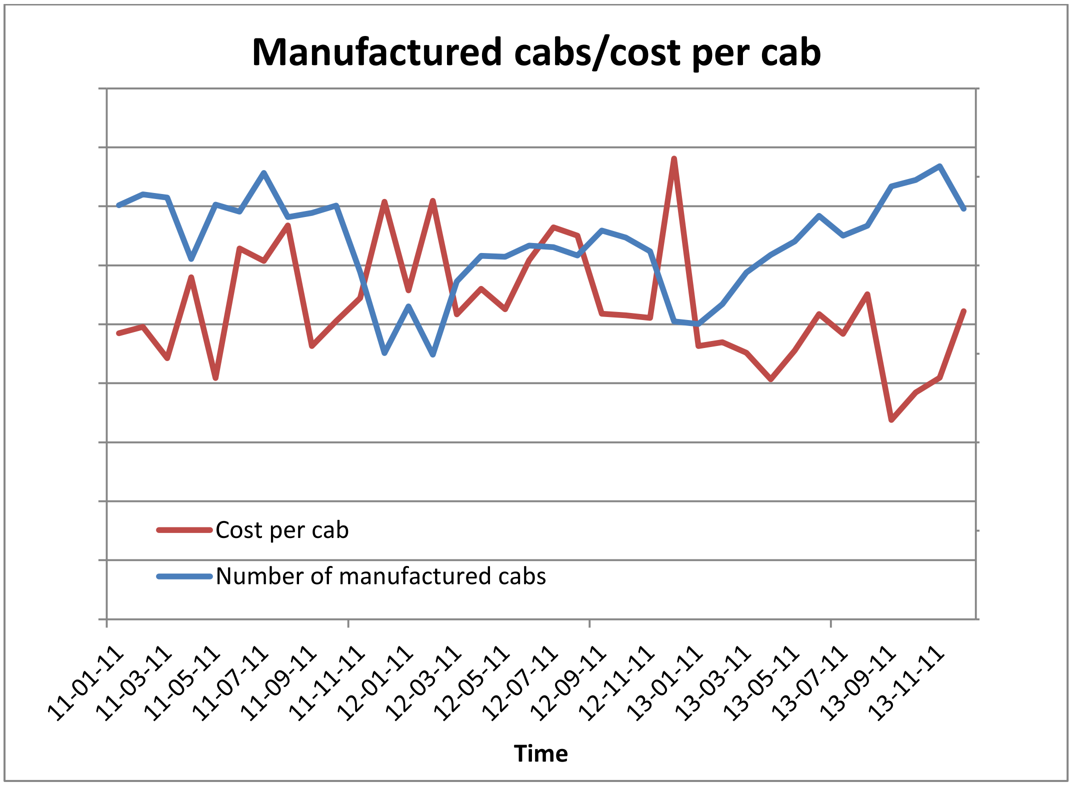


Figure 33: Relation between cost per cab and number of manufactured cabs during 2011, 2012 and 2013

The graph clearly shows that there is a correlation between the number of manufactured cabs/production rate and the cost per manufactured cab in the sense that when the one aspect increases the other one reduces and vice versa. This correlation can seem trivial since there are numerous costs that are not affected by the number of cabs produced. For example when the cost of the facility will be divided upon a smaller number of cabs, the cost per cab will of course be larger assuming other aspects are constant. Since fixed costs cannot be varied with the production rate without demanding a far too complex and time consuming analysis as well as potentially large investment plans. This results in not considering fixed costs as efficiency losses during production rate reductions. However, there is a possibility to experiment with the variable costs during changes in production rate and thereby possibly reduce the negative correlation between the number of produced cabs and the cost per manufactured cab. This results in considering variable costs, which could potentially be reduced, as losses in efficiency during production rate reductions.

When analyzing the holistic cost break downs for the years 2013, 2012 and 2011, presented in the empirical data chapter 4.6, it is evident that the major source of costs are the same each year. Even though the distribution differs somewhat between each year, the main overall cost categories are the same. Due to this fact, and to simplify further analysis, costs drivers will be analyzed only during one year. The costs for 2013 was chosen for this purpose, mainly because they are more relevant and represents the current organization and production system better than the previous years.

Further, not all costs are relevant to consider when developing strategies to cope with efficiency losses during production rate reductions i.e. depending on the nature of the cost, it will be more or less relevant. When focusing on small costs, the potential gains when implementing strategies will be insignificant. When focusing on fixed costs, the strategies will have to contain complex investment plans or restructuring of the additional facility which would demand a more thorough analysis and more time than is available. Costs that are considered important for this thesis are large and variable costs that have high savings potential and vary with production rate. When analyzing a holistic cost break down of the top coat paint shop, presented in the empirical data chapter 4.6, two initial conclusions have been made, listed below.

- Freight and transportation costs are insignificant when compared to other cost categories. There the costs regarding freight and transportation are not considered during the continued analysis.
- Capital costs, such as deprecations and impairments, are fixed and will not be affected by variations in production rate. This results in neglecting capital costs from further analysis.

With these conclusions in mind, the further analysis was conducted to investigate the impact of personnel costs and additional costs. The basis for this analysis is the thorough cost break down per month, presented in the empirical data chapter 4.6. The cost distribution used, excluding freight and transportation as well as capital costs, is displayed in figure 34. The breakdown of major cost categories into minor enables additional conclusions, these conclusions are listed below.

- Facility costs, such as rent, are fixed costs and will not be affected by the variations in production rate. Therefore, these costs are neglected from further analysis.
- Administration costs and additional personnel costs are insignificant compared to other costs, which results in neglecting these costs from further analysis.
- Quality costs as well as other aspects connected to quality demands complex and time consuming investigations and this thesis has, as explained in the introduction, been delimited from quality. This cost category is also small compared to other categories and therefore these costs will be neglected from further analysis.

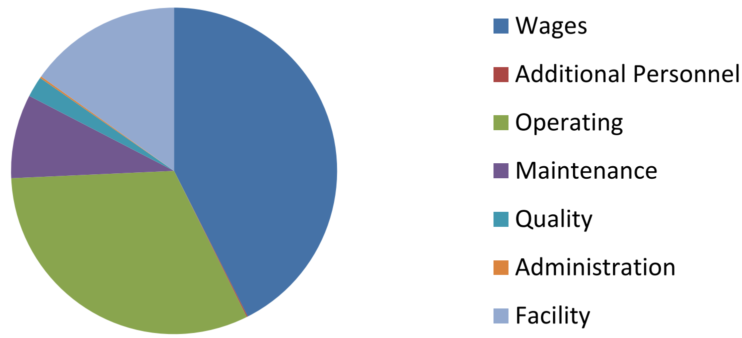


Figure 34: Average cost distribution per month, covering relevant costs, for 2013

To further improve the understanding of the cost distribution throughout the top coat paint shop, the remaining cost categories are again divided into smaller categories. This approach allows for further conclusions regarding the relevance of each cost with regards to developing strategies to cope with efficiency losses.

The conclusion of this analysis is that the costs associated with personnel, wages and social costs for operators in particular, are important to consider when developing strategies to cope with efficiency losses. Since these costs are variable and represent a large part of the total annual cost, these costs are considered areas of great savings potential. This argument is further strengthened by the fact that cleaning of machinery and equipment and coloring production capacity. These costs are also to a great extent represented by wages for cleaning personnel and employees within the paint kitchen.

Except for the costs mentioned above, it is important to consider costs linked to energy consumption. As described in the empirical data chapter 4.6, costs for energy consumption and particularly oil and heat are major cost drivers for the top coat paint shop and will therefore be further analyzed. Costs associated with electricity are also part of the energy costs but these costs are difficult to trace and evaluate since there is a clear lack of data, both historical and current, as well as a large number of consumption locations. The costs for electricity are also small compared to the costs of the other two energy sources, approximately 10% of the total costs for energy within the top coat paint shop. As a result the costs regarding electricity will be neglected.

Most likely, potential strategies for reducing efficiency losses during production rate reductions will affect numerous areas within the production facility and thereby affect numerous costs. Even if costs not previously mentioned are smaller than the ones discussed, the development of strategies will consider them in a secondary perspective. Costs related to maintenance, particularly repairs and maintenance of machines and tools but also preventive maintenance of machinery and equipment, are examples of costs to be considered during strategy development, but from a secondary perspective.

5.2 Generating strategies

To cope with efficiency losses during production rate reductions, numerous actions can be performed. These actions are not well defined and there is a clear lack of theory regarding the subject. Solutions to the issue will instead be perused by generating alternative actions and investigating the impact on the top coat paint shop. Strategies are developed with the perspective of, in this thesis established, relevant definitions of efficiency losses which result in distinct areas of focus. These areas are primary aspects to consider when developing strategies and are listed and further explained below.

- Consider time losses i.e. production disturbances and how they affect the development of strategies.
- Consider personnel costs and how the costs could be reduced during production rate reductions.
- Consider energy costs, more specifically costs for oil and heat, and how they could be reduced during reductions in production rate.

Considering time losses

Since time losses are major parts of the issue at hand, it will be an important aspect for the development of strategies to cope with efficiency losses during production rate reductions. However, this thesis has been primarily delimited from quality aspects of the problem and will focus on time losses during production rate reductions instead of time losses in general.

Time losses occur in most parts of the production facility. Since production is carried out in a continuous flow, time losses in specific production sections will affect other sections as well. This makes it important to consider time losses in all parts of the production process. However, since the painting lines are divided into three separate lines, it is recognized that there is greater potential to reduce time losses within this section than for other parts of production. This makes the painting lines an important area to consider for further analysis and inclusion in the strategy generation, from a time-loss perspective.

Considering personnel costs

It is trivial that the necessary amount of labor will be reduced if the production rate decreases. Personnel costs are therefore another important aspect to consider when developing strategies to cope with efficiency losses.

As presented in the empirical data chapter 4.6, the most labor intensive parts of the production facility are the painting lines, and more specifically BCM and CCM. The painting lines account for twice the amount of labor compared to the second most labor intensive sector, the inspection lines. This makes the painting lines an important area for further analysis and inclusion in the strategy generation, from a personnel perspective.

Considering energy costs

The final aspects of primary consideration are the energy costs associated with oil and heat, explained earlier in the analysis chapter 5.1.2. In resemblance to the reasoning regarding the amount of personnel necessary, the amount of energy necessary will be reduced with lower production rates.

The relevant energy sources are, as mentioned in the empirical data chapter 4.7, simple to trace. Oil is used for heating the three ovens in connection to the painting lines, and the oven connected to the ACL process. Heat is used in numerous areas of the production facility, the major energy consumption is connected to heating the air within the painting lines. This reasoning makes it important to consider the painting lines, ACL and the respective ovens for further analysis and inclusion in the strategy generation, from an energy perspective.

As mentioned earlier, the generation of strategies will most likely affect numerous areas and aspects of the production, in addition to the aspects presented above there are also aspects to consider from a secondary perspective. An additional aspect that will be considered during the strategy development is the flexibility and the potential to perform changes throughout the specific production sector. This aspect once again directs focus towards the painting lines since this sector includes three separate production flows, which enhances the possibilities for variations in the working routines.

5.2.1 Strategy 1 - Closing the night shift

By shutting down the night shift when production decreases, numerous costs could be reduced and the production efficiency could be enhanced. As explained above, the primary reason for implementing this strategy would be to reduce the costs associated with energy consumption, more specifically oil and heat, and costs associated with personnel and their wages. It is important to include the disturbances and time losses into the analysis in order to obtain an accurate estimate of the impact and feasibility of the strategy. Further, the distribution of the production between the painting lines is a parameter that highly influences the feasibility of the strategy. If the disturbances would be neglected in such an analysis, the production would not be able to cope with the customer demand which in the long run could lead to dissatisfied customers. However, if an accurate estimate of the feasible breakpoint in production rate for shutting down the night shift could be attained, there are numerous benefits that can be realized. The potential economic outcome per week for this strategy is presented in table 26 and explained below.

Table 26: Economic outcome per week for strategy 1

Source of savings	Cost savings per week [SEK]
Employees	157 080
Oil	38 818
Heat	15 750
Total	**211 648**

To further evaluate the savings related to strategy one, it is of interest to evaluate the cost saving per cab when implementing the strategy. Figure 35 shows the saving per cab when implementing the strategy at different production rates.

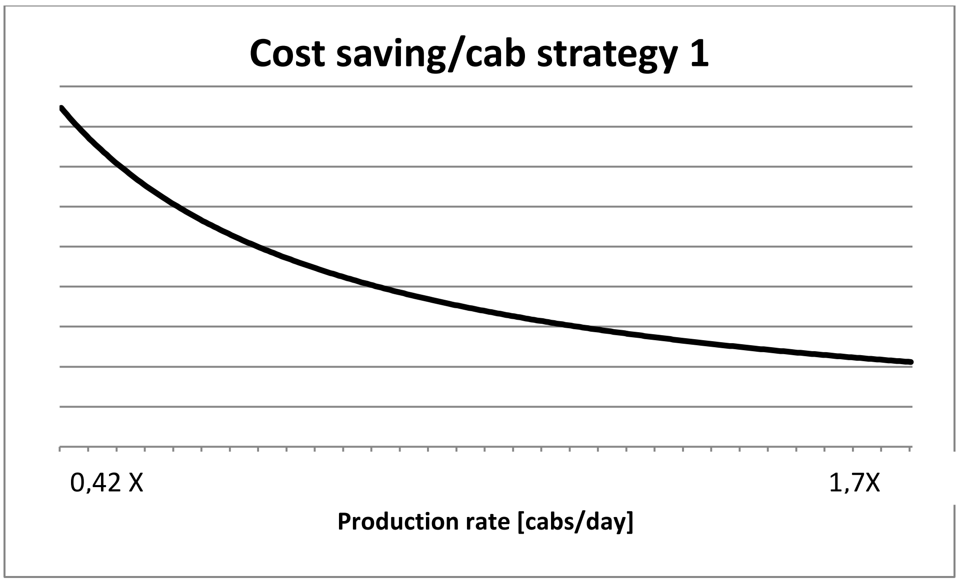


Figure 35: Cost saving per cab when implementing strategy 1 at different production rates

Strategy one, with the resulting economic outcome presented in table 32, is constructed with the assumption that the night shift for the entire top coat paint shop is closed. Potentially, this strategy could include only shutting down the night shift for specific production sectors but there are aspects that need to be considered in this case. First, since the majority of the production is distributed to BCA and since BCM and CCM are currently not staffed at night, the strategy implies that the night shift will be eliminated completely when terminating the night shift for BCA. This could of course change in the future depending on customer demand or reconstructions in the current facility. Furthermore, since there is no buffer in between the painting lines and inspection decks, when closing the night shift for a production sector upcoming production sectors will have to close the night shift as well. This aspect could also change with a reconstruction of the production facility. Theoretically, cabs could be stored in the buffer between inspection, improvement and the ACL. However, since the buffer is relatively small, compared to the production volume, and since the fill rate within this buffer is strongly dependent on the current production quality, great caution must be taken if this alternative would be considered.

Personnel costs

All personnel costs, including wages and social costs, linked to the night shift employees would be eliminated if implementing the strategy. Table 27 shows a summary of the average number of employees during a standard night shift for each production sector within the top coat paint shop, presented in the empirical data chapter 4.4.

Table 27: Average number of employees during a standard night shift

Area of responsibility	Average number employees during night shifts
Painting lines	4
Paint kitchen	3
Inspection	3
Improvement	1
ACL	3
Total	**14**

Since a significant amount of all employees within the production are hired as consultants with two weeks' notice, shutting down the night shift is an action that needs to be planned some time in advance. Excess personnel could be used to cover up for the momentarily not present, due to sickness or similar reasons, day and evening personnel. Another approach would be to use the night shift employees in other areas of the production if needed. The total costs associated with 14 employees would reach 157 080 SEK per week, based on 34 hours of operating time during night shifts per week and an estimated personnel cost of 330 SEK/ hour.

Energy costs

The second aspect of reducing costs with regards to closing the night shift would be the potential savings in energy consumption. As explained earlier, the major costs associated with energy consumption are the costs for oil and heat. By closing the night shift, the majority of both the energy used for heating the painting lines as well as the oil used for heating the ovens would be eliminated during nights.

Oil

Since the oil consumption ends abruptly when turned off, there would be immediate savings when the night shift originally would have started. However, there would be an increased oil consumption during the two hour start up each morning compared to if the ovens would have been in constant production mode and only turned off during weekends. The total oil consumption per week during nights, based on the figures of average oil consumption presented in the empirical data chapter 4.7, is presented in table 28. Note that the total time of all night shifts for a week reaches 34 hours per week.

Table 28: Average oil consumption during nights when using and when not using a night shift

Average oil consumption/week, during night shifts [Liters]			
	During production	**During startups**	**Total**
Current production	4088	367	4454
Implementing strategy 1	0	1468	1468

The difference between the alternatives, which is equal to 2986 liters, is the total amount of oil saved when shutting down the night shift. When using the average market value for heating oil, presented in the empirical data chapter 4.7, 13 SEK/liter, the total amount of reduced oil consumption would equal 38 818 SEK/week.

Heat

Since the heat consumption within the painting lines currently cannot be momentarily traced, it is more difficult to estimate the energy consumption for shorter periods of time. By assuming that the heat consumption ends abruptly and requires two hours to start, as for the oil consumption, further analysis will be simplified. Another assumption made is that the startup process will require no additional heat than during normal production. This assumption is based on the fact that increase in temperature is small. Based on these assumptions and the figures regarding the average heat consumption per shift, presented in the empirical data chapter 4.7, the average heat consumption per night shift for strategy one is presented in table 29.

Table 29: Average heat consumption during nights when and when not using a night shift

Average heat consumption/shift during nights [MWh]	
Current production	9,3
Implementing strategy 1	2,3

The difference between the alternatives, which is equal to 7 MWh, is the total amount of energy saved per shift in terms of heat when shutting down the night shift. When using the average market value for heat, which is presented in the empirical data chapter 4.7, 45 SEK/kWh, the total saving regarding heat would equal 3150 SEK/shift, i.e. 15 750 SEK/week.

Additional gains

This strategy serves Scania, not only from a financial and operative perspective, but also from an environmental. By shutting down the night shift, Scania's CO_2 footprint would be reduced. This aspect is not an immediate gain for Scania as a company, but the entire society will gain from this in the long run which includes Scania and their employees as well.

Using standard values for CO_2 emissions, 0,28 ton CO_2/m^3 oil, the amount of oil saved by shutting down the night shift would equal approximately 0,84 ton CO_2/week.

Impact on buffers

Reviewing the strategy from the perspective of buffers is essential due to the limited space in between production sectors. How the buffers are affected by this strategy is presented below.

B13

As mentioned earlier, the total production throughout the primer coat paint shop is currently divided 45%/45%/10% during the day, evening and night shifts. Strategy one would imply that the theoretical maximum amount of cabs being stocked in buffer 13 before the beginning of the day shift would be 10% of the current production rate. This conclusion is also based on the fact that the production throughout BCM and CCM is limited to the day and evening shifts, as it currently is. Since B13 has a capacity of 79 cabs, theoretically the buffer would hold the entire night shift production of cabs for production rates up to 790 cabs per day, assuming that all other production related aspect are constant. However, this relation is not considered valid for production rates that vary far from the current with regards to the variation in disturbances and quality aspects. During times of production rates, similar to the current, the buffer is however considered to manage the impact of strategy one.

B50 & B100

By the reasoning earlier in chapter 5.2.1, the buffers B50 and B100 will not be affected by strategy one. However, if the strategy would be altered to include only shutting down the night shifts for specific production sectors, the buffers will have to be carefully considered with regards production quality and buffer size.

5.2.2 Strategy 2 - Closing one shift throughout BCM/CCM

Another strategy that could potentially increase the efficiency in terms of reduced costs regarding personnel and energy is the strategy of closing BMC and CCM during one shift of the day. When reviewing production data regarding BCM and CCM there are two aspects that enhance the feasibility of the strategy, the lines account for only a small amount of the total production and the lines are historically highly affected by disturbances. In order to operate the painting lines in a more efficient way, the strategy of shutting down one of the two lines during a time period of the day will be evaluated. Currently, both lines are operating during the day and evening shift.

The strategy is highly affected by the distribution between the lines. This distribution is not constant, it varies depending on customer demand and active configurations regarding the production process. For example, decisions such as transferring the painting of a specific color from one line to another can affect the distribution. The small amount of production throughout the lines currently implies a large number of disturbances such as shortage from 640. If instead one of the lines would be shut down during one shift, the amount of cabs allocated to the certain line would increase in the previous buffer, B13, during that time period. In other words the primer coat paint shop would have the night shift and the unutilized shift, day or evening, to increase the buffer for the upcoming day. Therefore the amount of disturbance time connected to shortage from 640 would decrease. Further, as presented earlier in the analysis chapter 5.1.2, the total time of disturbances tend to decrease with higher production rates.

If shutting down one of the two painting lines, the employees from the line that is shut down can be allocated to the second line. Tests show that the cycle time for both lines can be reduced significantly by reallocating the employees. This reduction is realized mainly due to the fact that the manual painting throughout the lines can then be done by two painters instead of one.

When shutting down a painting line there are several savings that can be realized, mainly costs of energy and maintenance which are presented in and below table 30. Note that the total saving per day, with restrictions to the costs for maintenance which is further explained below, for implementing the strategy is the sum of total savings for BCM per shift and CCM per shift, which is equal to 15 007 SEK.

Table 30: Economic impact of strategy 2

Closing BCM	
Source of savings	**Cost saving per shift [SEK]**
Oil	1 547
Heat	743
Maintenance	5 390
Total	**7 669**
Closing CCM	
Source of savings	**Cost saving per shift [SEK]**
Oil	1 378
Heat	570
Maintenance	5 390
Total	**7 338**

To further evaluate the savings related to strategy two, it is of interest to evaluate the saving per cab when implementing the strategy. Figure 36 shows the saving per cab when implementing the strategy at different production rates.

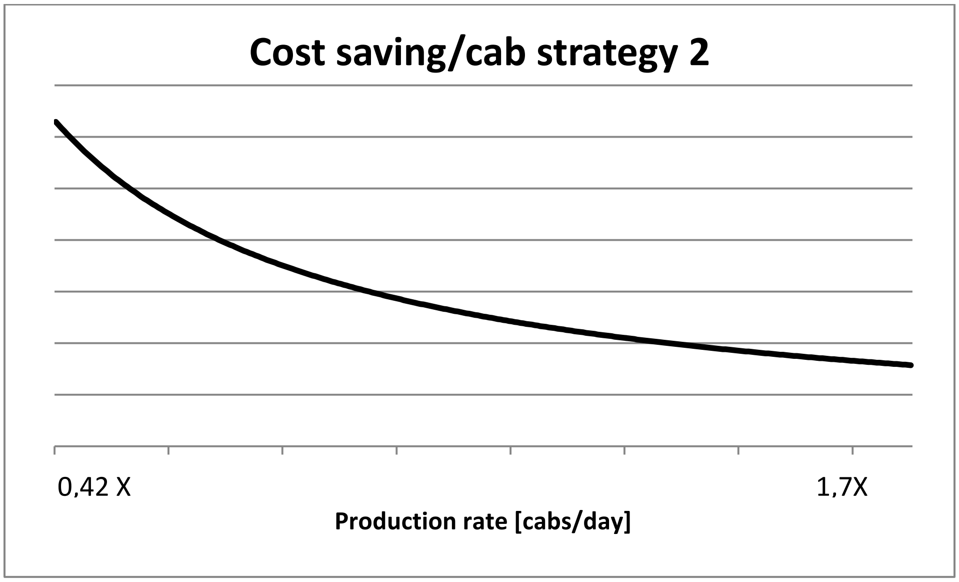


Figure 36: Cost saving per cab when implementing strategy 2 at different production rates

Personnel costs

When closing BCM or CCM all employees for the two lines are allocated to the line operating, this in order to maintain and achieve the total amount of cabs produced per day. Therefore, there are no savings regarding employees when implementing strategy 2. However, this is only the case for higher production rates when the takt throughout one shift for each line has to be increased in order to fulfill the production target per day. For lower production rates there is however a possibility that the employees for the closed line do not have to be allocated to the remaining line and therefore savings regarding employees could be realized.

Energy costs

The savings related to energy is divided into oil and heat. Currently the painting lines in terms of oil and heat consumption are in operation during the entire day. In other words, the energy consumption is constant during the day, independent of production rate and disturbances. By only operating one of BCM and CCM during a shift the energy consumption can be reduced significantly, increasing the efficiency throughout the production and reducing the cost per cab.

Oil

By the reasoning regarding oil consumption for strategy one above, the average oil consumption for shutting down BCM or CCM is displayed in table 31 below. The numbers are based on the figures of average oil consumption for each painting line, presented in the empirical data chapter 4.7.

Table 31: Average oil consumption during production and startups for BCM and CCM

Average oil consumption [Liters/hour]		
	BCM	**CCM**
During production	27,21	22,50
During start ups	49,33	36,98

The net savings regarding oil for strategy two is denoted as production during 8 hours minus start up for two hours. When using the average market value for heating oil, which is presented in the empirical data chapter 4.7, the total reduction oil consumption would equal 1 547 SEK/shift when shutting down BCM and 1 378 SEK/shift when shutting down CCM. The total cost saving, for closing both painting lines during one shift each during the day, is equal to 2 925 SEK.

Heat

Savings can also be realized in terms of heat expenses. The average heat consumption during a shift is calculated from an annually estimated value for the specific line. As denoted in the empirical data chapter 4.7, the number for BCM is 2,2 MWh/shift and 1,69 MWh/shift for CCM. Considering the two hour start up time and the average cost per MWh, 450 SEK/MWh, the cost reduction for shutting down BCM and CCM is calculated. The resulting saving for BCM equals 743 SEK/shift, and the respective number for CCM equals 570 SEK/shift.

Maintenance

By shutting down BCM and CCM during a shift benefits in terms of maintenance can be realized. As noted in the empirical data chapter 4.4.4, a large number of activities regarding preventive maintenance are performed during weekends, i.e. off production. By implementing the strategy, the freed time during weekdays can be scheduled for maintenance and therefore avoid performing maintenance during weekends, when it is more expensive.

The prescheduled time for preventive maintenance solitarily dedicated to BCM and CCM during weekends is approximately 10 hours. The total amount of time is however difficult to calculate due to the fact that the activities, presented in appendix C, are difficult to allocate to only one single part of the production process. One example is the production ventilation which is directed to the entire top coat paint shop. Therefore the time for preventive maintenance allocated to BCM and CCM, respectively, is assumed to be 1/5 of the total amount of preventive maintenance during weekends. This due to the fact that there are five large areas within the production: BCA, BCM, CCM, inspection and ACL. As presented in the empirical data chapter 4.4.4, the average amount of time dedicated to preventive maintenance during weekends is 55 hours resulting in 11 hours per area of interest throughout the top coat paint shop.

With the assumption above and the cost for maintenance being 490 SEK/hour during week days and 980 SEK/hour during weekends the saving realized would reach up to 10780 SEK per week, 5390 SEK/line, calculated by saving 22 hours during weekends. Note that the saving for maintenance is calculated per week and not per day as for the other savings. This is due to the fact that the number of hours dedicated to preventive maintenance is calculated per week. The calculation also assumes that the 22 hours of maintenance that would be performed during a weekend can be performed if the strategy was to be implemented at least one day during a week.

Additional gains

As mentioned in the strategy above there are also other benefits by shutting down BCM or CCM during a shift throughout the day. The reduced amount of oil, 0,316 m^3 for BCM and 0,254 m^3 for CCM, would result in reducing $C0_2$ emission by 0,088 respectively 0,071 ton/day.

Impact on buffers

As for strategy one, it is important to consider how the buffers between production sectors will be affected by strategy two. This aspect is further described below.

B13

When evaluating strategy two it is important to consider how the previous buffer, B13, would be affected and if the strategy would be feasible. As mentioned earlier when producing throughout one line, the buffer connected to the remaining line will be able to be restocked. This relation is illustrated in figure 37, where line X is operating during the day shift and line Y during the evening shift. Therefore the buffer for line X will increase during the evening and night, and the buffer for line Y will increase during the night and day.

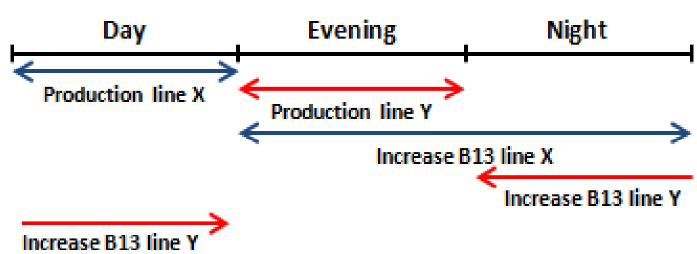


Figure 37: Illustration of the restocking aspect for strategy 2

As illustrated in figure 37 above, strategy two implies that the total buffer allocated to BCM and CCM within B13 will be at its highest after the night shift. The number of cabs dedicated to BCM and CCM at the beginning of the day shift for the strategy described in figure 37 is described by equation [6].

$$PR \cdot \left((dist\ PPS\ shift\ 2 + dist\ PPS\ shift\ 3) * dist\ line\ X\right) + \ (dist\ PPS\ shift\ 3 * \ dist\ line\ Y)) \quad [6]$$

Where,
PR – production rate
dist PPS shift 2 – the production distribution for shift 2 in the primer coat paint shop
dist PPS shift 3 – the production distribution for shift 3 in the primer coat paint shop
dist line X - the distribution of total production in the topcoat paint shop allocated to line X
dist line Y - the distribution of total production in the topcoat paint shop allocated to line Y

If assuming the current production distribution per shift, the production distribution per line and the historical respective for the prime coat paint shop, presented in the empirical data chapter 4.4, the relation described above would in theory result in a maximum of 0,1X cabs, stored in B13 for the upcoming BCM shift. The respective figure for the upcoming CCM shift would be 30. If the same reasoning would be applied to the BCA line, assuming that the BCA line would not use a night shift, the buffer would hold an additional 0,06X cabs. Strategy two would imply the maximum amount of cabs stored in B13 would reach 0,16X cabs, during the assumed conditions. This would not be an issue since the capacity of the buffer is significantly higher. This reasoning is, as described in strategy one, not valid for production rates that strictly differ from production rate X. However, during current conditions, the reasoning is considered applicable.

B50 & B100
Since the total amount of cabs produced per day is independent of implementing strategy two or not, buffers B50 and B100 are not affected in any particular way. This assumes that the distribution between the lines is rather equal, as currently. However if the distribution varies significantly, the amount of cabs produced during shift 1 and 2 would vary as well. This could potentially be a problem for buffers B50 and B100, however with a significantly varying distribution it is likely that the strategy would not be considered at all from a production planning perspective.

Impact on ovens
When implementing strategy two there is an additional aspect to consider, how the strategy affects the ovens. As mentioned in the empirical data chapter 4.4.1, the cabs that are base painted with metallic colors are processed through BCM. The metallic coated cabs also require a lower temperature when drying and are therefore directed to oven three. Since oven three is mainly dedicated for 2K-colors painted throughout CCM the oven is currently shutdown when CCM is closed. If the strategy would be implemented and CCM is shutdown during one shift the metallic cabs that are painted throughout BCM will not be able to be dried due to the fact that the temperature within the remaining ovens in operation is too high. There are two solutions to resolve this situation:

1) When strategy 2 is feasible, BCM should be operating during the day shift and CCM during the evening shift. By doing this the metallic cabs can be processed through BCM

during the final time of production during shift 1 and thereafter be dried in oven three during the beginning of shift 2. This would imply that the CCM oven would have to be started earlier.

2) If instead CCM is operated during shift 1 and BCM during shift 2, the temperature of oven two can be decreased during the final production time of shift 2 and the metallic cabs can be processed during this time.
3) By the same reasoning as 2), base painted metallic cabs could be processed during the initial production time of shift 2 on BCM if the oven was kept at a lower temperature during initial production.

5.2.3 Strategy 3 – Oven standby mode

Previously discussed strategies would clearly generate numerous benefits if implemented. Strategy one and two are highly affected by the production rate and disturbances, therefore there are uncertainties when these strategies are feasible. Considering the criteria for developing strategies, described in chapter 5.2, there are actions that could be implemented disregarding the production rate. By implementing a standby mode for the ovens to reduce the temperature and oil consumption during periods with less frequent production, energy costs would potentially decrease i.e. efficiency losses would be reduced. This strategy could be implemented disregarding of the current production rate but the strategy still serves the purpose of this thesis since the benefits of the strategy would increase with reduced production rate.

Currently, there is a standby mode applied to the ovens. This is called “break-mode” and is activated automatically when there is a disturbance in front of the ovens, for example full forward. The purpose of this mode is however not energy savings, but preventing cabs from extensive heat. The break-mode implies that the valves above the ovens switch direction and heat is transported past the ovens and up to the roof, where the heat is released to the outside air. The break-mode serves its purpose well but does not in any way reduce the energy consumption or costs related to energy. Therefore, an alternative standby mode could be developed for this purpose. By turning off the flow of oil instead of redirecting the valves, a new standby mode would still prevent the cabs within the oven from extensive heat, but also reduce the oil consumption and thereby the energy costs.

The main issue associated with this suggestion is regarding when the strategy would be feasible. Since there is a lack of necessary data, and the timeframe for this thesis is limited, the strategy will have to be based upon assumptions, listed below.

- The temperature within the ovens is assumed to increase linear in the interval of room temperature to production temperature during startups.

- The temperature within the ovens is assumed to decrease with a constant and exponential pattern during turn offs.

By using these assumptions when analyzing the temperature within the ovens, presented in the empirical data chapter 4.7, further analysis regarding the strategy can be conducted. The estimated equations for the temperature during shutdowns and startups are displayed in figure 38 below and further described in appendix D. Note that the equation representing the temperature during turn offs is not valid for time periods shorter than a few minutes, this due to the fact that the equation does not consider the maximum temperature of 140 °C.

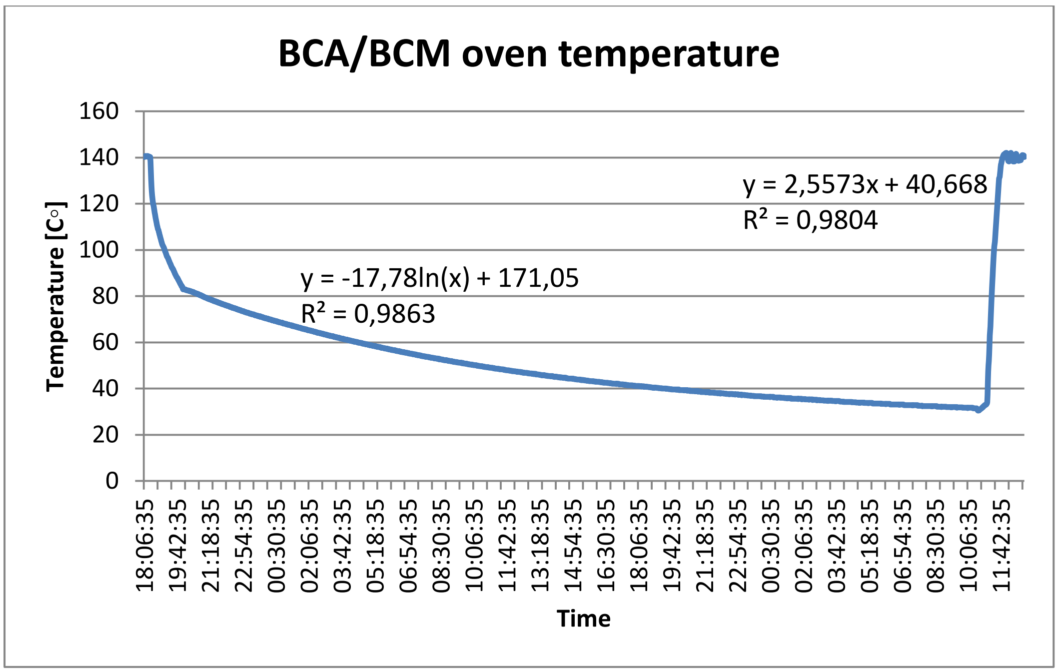


Figure 38: BCA oven temperature during shutdowns and startups

The economic outcome of an active standby mode is presented for shorter time periods, less than an entire shift. Otherwise the implementation of strategy 1 or 2 is more suitable. Since the ovens will maintain its temperature during a shorter activation of the standby mode, the oven's interior such as pipes, walls etc. are assumed to retain a reasonable amount of heat. Using the values for average oil consumption during production and startups, presented in the empirical data chapter 4.7, as well as the equations above, the savings per time unit can be calculated. These are displayed in table 32 below and further explained in appendix D.

Table 32: Cost reductions for strategy three

Time until production [min]	Diff in oil consumption [liters]	Cost diff [SEK]
30	7	88
60	17	216
90	28	361
120	40	521
150	53	683
180	66	853
210	79	1024
240	92	1195
270	105	1367
300	118	1540
330	132	1713
360	146	1892
390	159	2065
420	173	2245
450	186	2419
480	200	2599

This relation shows that there are cost savings regarding oil consumption when implementing strategy three after only 30 minutes without production. However, it is recognized that certain aspects of the production environment is neglected by this reasoning. One of the aspects is the abrasion of the equipment that regulates the oil consumption. How strategy three would affect this aspect, as well as similar ones, is not further analyzed due to the time frame of this thesis and is instead highlighted for future research.

Since the ovens for BCA and BCM operate at the same temperature, strategy three is considered valid for these ovens. The CCM and ACL ovens are tempered differently and will not act identical. However, the reasoning for strategy three is applicable and with oven specific equations, see figure 36, similar strategies could be obtained.

5.3 Production planning model

The strategies presented above will all generate benefits in terms of reducing efficiency losses during production rate reductions. However, it is unclear when the strategies are applicable in the current production facility. Numerous aspects need to be evaluated in order to determine the actual production rate for when each strategy will be feasible.

As recognized by authors on the subject of scientific models, the actual production environment and the reality in general is complex and time consuming to analyze in detail (Swoyer, 1991). This makes it suitable, and even necessary, to evaluate this situation with the assistance of a scientific model. As mentioned in the empirical data chapter 4.9, the production planning is currently supported by an excel model which simplifies the reasoning regarding different production structures. However when investigating the model the accuracy of the resulting production values are questioned. This partly since the model does not include the actual time losses associated with disturbances such as shortage, instead the model uses a compensation factor that is constant for all shifts. This aspect among others is analyzed, the reasoning is presented below.

5.3.1 Disturbances

In order to establish the accuracy of the current model and the compensation factor, the actual production during the time period of 02/24/14 – 04/11/14 was compared to the production target generated by the model for the painting lines and the ACL. These production sections were chosen since they are most relevant to consider when generating strategies, by the reasoning explained earlier in the analysis chapter 5.1.2. The reason for not including the inspection for this analysis is that all cabs that pass by the painting lines will pass by inspection without any buffer in between i.e. the analysis would not add any additional value. This time period was chosen due to the fact that this is the only data available since the latest production rate reduction and since the model was first used for production planning at this production rate. The actual production distribution per line for this period was used as input into the model. The results are presented in table 33 below.

Table 33: Comparison of current model's production targets and actual production outcome

	Difference between models
BCA	
Shift 1	10
Shift 2	7
Shift 3	-14
BCM	
Shift 1	1
Shift 2	1
Shift 3	-3
CCM	
Shift 1	1
Shift 2	0
Shift 3	0
ACL	
Shift 1	18
Shift 2	3
Shift 3	-15

As the production targets above suggests, and as expected, the current model generates higher production targets for the busy shifts i.e. shifts 1 and 2 throughout BCA and ACL, than the actual production can cope with. This results in the model neglecting the need of production during shift 3. The reason for this is that the model does not include time losses associated with production disturbances such as shortage. The model's production targets for BCM and CCM is more accurate regarding the actual production outcome due to the fact that these lines are less busy. This results in that the model generates a higher maximum allowed time for disturbances which compensates for not including the actual time for disturbances such as shortage. Moreover, the model is considered confusing since there is a compensation factor for the time-loss of disturbances, but also a maximum allowed time for disturbances

Further, by not considering the actual time for disturbances, such as shortage for each shift, the model generates the same production target for shifts with equal operating time, disregarding if the shift is carried out in the day or evening. This aspect is also questionable since the actual time for disturbances, presented in the empirical data chapter 4.6, varies depending on the time of day.

With this in mind, the current model would generate inaccurate and higher production targets, for when strategy one would be feasible, compared to reality. If the strategy then was to be applied, based on the production targets generate by the current model, the production targets would not be reached and ultimately, customers would not get deliveries on time. This would in a long term perspective be negative for the company.

Since the current model's production targets fit well with reality for this time period, the model would currently generate a relatively accurate production rate for when strategy two would be feasible. However, if the production distribution would vary and the utilization of BCM or CCM would increase, the model's accuracy would decrease.

5.3.2 Equipment utilization

Another aspect connected to the current model that is not considered optimal is the fact that the model generates production values based on the target JPH instead of the actual production facility capabilities. This results in the model not fully utilizing the production equipment, but leaves the margin of maximum allowed time for disturbances which, as explained above, often is lower than the actual time for disturbances. When considering the fact that the compensation factor currently is supposed to compensate for the time losses related to disturbances, the model once again implies a confusing impression.

The model also includes measuring of OPE, described in the theoretical framework and empirical data chapter 4.3.3, for efficiency of the production section. This measure is based on the maximum allowed time for disturbances which, as explained above, is often far lower than the actual time of disturbances. The measurement of OPE will therefore not consider the disturbances related to the compensation factor. This result is a misleading OPE as it will be higher than reality i.e.it gives an image of a more efficient production process.

5.3.3 Production distribution per shift

As mentioned earlier in chapter 5.3, the current model generates a somewhat misleading distribution of production between shifts since the compensation factor is constant during all shifts for each production section. As explained in the empirical data chapter 4.9, the current model generates production targets per shift and day based on the target JPH i.e. the production targets are completely separated from the current production rate. This aspect further contributes to a misleading production distribution between shifts and is visualized when analyzing the production targets for varying production rates. Two examples of this phenomenon, throughout the BCA line, are listed below.

- For production rates between 0-X, the production targets for BCA during shift 3 become negative, which also means that production targets for the other shifts are higher than necessary.
- For production rates between 1,23X - ∞, the production targets for BCA during shit 3 imply a shorter cycle time than possible for the equipment associated with this painting line.

These examples from the model affect all production sections, BCM, CCM, inspection and ACL, and shifts in a similar manner as the one described above but with different production rates.

5.3.4 Logic and user friendliness

Earlier analysis, chapter 5.3, concludes that the model presents a somewhat confusing impression with regards to certain aspects. These aspects are listed below.

- Both the compensation factor and the maximum allowed time for disturbances relate to the time-loss related to disturbances, but are inaccurate.
- With reduction in production rate, the production targets for different shifts become higher than necessary and the production targets during shift 3 become negative.
- With increased production rate, the production target for different shifts and production sectors imply higher cycle times than the production equipment allows during night shifts.

One final aspect to consider regarding the logic, or user friendliness, of the current model is that the production distribution between the painting lines i.e. the distribution of cabs to each line, is concealed in the programming code. This gives the user the impression that these factors are constant and not to be altered. However, these factors are of vital importance for the model and need to be updated for the model to function properly. The current model would benefit from displaying these values as production parameters.

5.4 New production planning model

It is recognized that a scientific model is well suitable for evaluating strategies. However, as established earlier in the analysis chapter 5.3, the production planning model currently used throughout the paint shop contains certain flaws, resulting in inaccurate production targets during frequent production. By using the current model as a foundation, but reconfiguring mentioned aspects, the aim is to establish a more accurate model to support the implementation of strategies and thereby the reduction of efficiency losses during production rate reductions.

5.4.1 Disturbances

Since the disturbances within the current model are handled in an insufficient way, this aspect is important to consider when developing a new model. The identified issues related to disturbances are listed below.

- The compensation factor that is supposed to compensate for disturbances does not consider the time for actual disturbances such as shortage.
- The compensation factor is constant for all shifts, resulting in an equal time for disturbances for each shift, which according to the actual time for disturbances, presented in the empirical data chapter 4.6, is incorrect.
- By using both a compensation factor and a maximum time for allowed disturbances, both connected to time losses for disturbances, the model gives a somewhat confusing impression.

By adding another input parameter, “Time for disturbances”, based on the actual time for disturbances denoted in the manual disturbance list for each production sector, and by eliminating the compensation factor, the issues above will be addressed. This implies that the “Time for disturbances” will consider all disturbances that occurred within production, including shortage. The new input parameter will also separate the time for disturbances for each shift and finally eliminate the confusion connected to the compensation factor by eliminating it.

The “Time for disturbances” will be based upon the actual disturbances occurred within production for a specified period of time. By constructing a new feature of the model that allows the user to directly add the actual time for disturbances by simply copy and paste the disturbance list for each production sector into the model, see appendix E for instructions, the new input parameter is constructed. However, it is crucial for the model’s accuracy that the disturbance lists are properly filled out. Since the disturbance lists currently are manually denoted, it is of vital importance that the procedures are well managed.

As for the earlier applied compensation factor, it is still important to update all model inputs; now also including the “Time for disturbances”. This will enhance the accuracy of production targets generated by the model and increasingly reflect the current production environment. However, explained earlier in the analysis chapter 5.1.2, the actual time for disturbances is strongly related to the production rate. This makes the model relevant for the current production rate and production rates within a close interval. By updating the “Time for disturbances” on a regular basis the relevant interval will follow the variation in production rate and increase the model’s accuracy over time.

5.4.2 Equipment utilization

In addition to adding the “Time for disturbances”, using the current production rate and the cycle time for each production sector as a basis for the production target instead of the target JPH, the model is allowed to fully utilize the equipment within the production. Since the “Time for disturbances” is based upon the actual disturbance list, there is no need for additional disturbance time, as “Maximum allowed time for disturbances” used earlier. This action is further strengthened by the relation between production rate and disturbances since it is clear that the total amount of time for disturbances will be lower during higher production rates i.e. higher production utilization.

Furthermore, by using the “Time or disturbances” as a base for the OPE measure, instead of the earlier used “Maximum allowed time for disturbances”, a more realistic measurement of OPE is obtained.

5.4.3 Production distribution per shift

The accuracy of the production distribution per shift will gain from using “Time of disturbances” since the actual time for disturbances per shift will be used. By including two simple conditions for the production target for each production sector and shift, the identified issues associated with production distribution per shift can be solved. These conditions are further explained below.

- By adding conditions to the production target for each shift and production sector to not produce more than the remaining amount of cabs, based on the production target, the model will not generate negative production targets and thereby not exceed the production target for other shifts.
- By adding conditions to the production target for each shift and production sector to be based upon the cycle time, instead of “Target JPH” as earlier, the model will not generate production targets that exceeds the equipment capacity i.e. cycle time.

5.4.4 Logic and user friendliness

In addition to the action presented above, by visualizing the production distribution as a production parameter, instead of being constant within the programming code, the user friendliness is enhanced by the ease of altering these figures.

5.5 Model comparison

The accuracy of the current model and the new model were compared to the production outcome during the time period of 02/24/14 – 04/11/14. This validation method is built into the model and allows the user to simply copy and paste the actual production outcome into the model for validation to reality, see appendix E for instructions. The results of this comparison are displayed in table 34.

Table 34: Comparison of the current and new model regarding the actual production outcome

	Difference current model	Difference new model
BCA		
Shift 1	**10**	-1
Shift 2	**7**	-5
Shift 3	**-14**	6
BCM		
Shift 1	**1**	-3
Shift 2	**1**	-4
Shift 3	**-3**	6
CCM		
Shift 1	**1**	2
Shift 2	**0**	-1
Shift 3	**0**	0
ACL		
Shift 1	18	5
Shift 2	3	-6
Shift 3	-15	7

The results of the comparison, displayed in table 34, show that the new model generates more accurate production targets than the current. As explained earlier in the analysis chapter 5.3 the current model works quite well for production sectors with less frequent production, such as BCM and CCM, however it lacks accuracy for production sectors with more frequent production, such as BCA and ACL. The difference between production targets generated by the new model and the actual production outcome differ with 50% or less that for the current model, regarding production sectors with frequent production. Figure 39 shows the summarized difference regarding the average production outcome and production targets per day generated by each model.

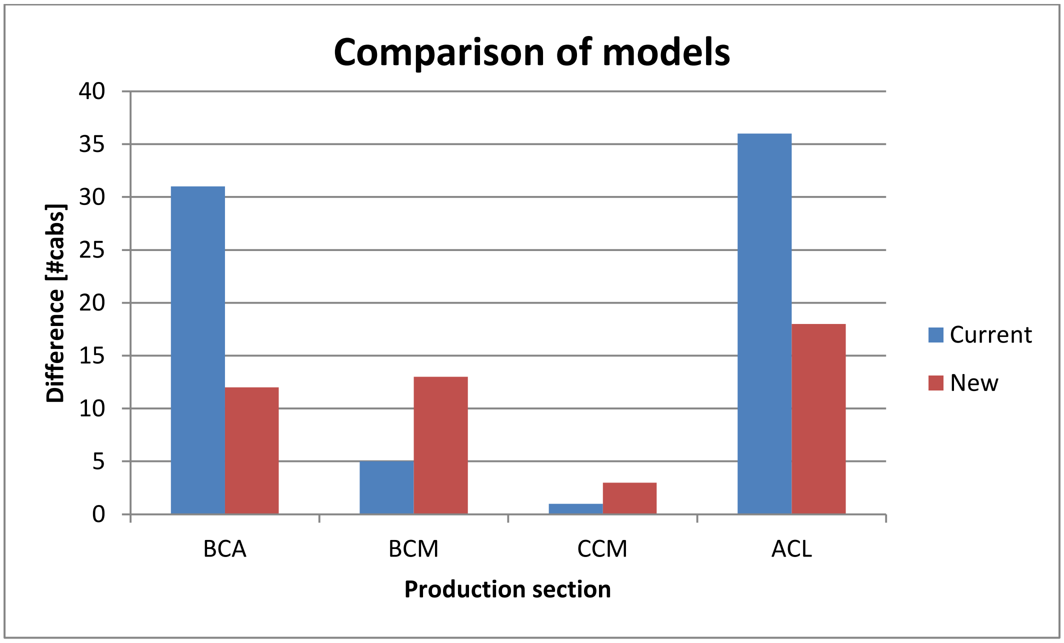


Figure 39: Difference between the actual production outcome and the models' production target per day

The difference in production targets for each model regarding CCM is a total of two cabs per day. This number is low compared to the total amount of cabs produced. The reason can be coincidental and is too small to evaluate is therefore neglected from further analysis.

There is however a slightly larger difference in production targets between the models for BCM. The new model generates a production target that differs more from the actual number of produced cabs than the current model does. Since the new model generates production targets that do not exceed the capacity of the equipment and since the model includes all time losses for the specific time period, it is remarkable that the actual production produces more cabs than the production targets generated by the model during shift 1 and 2. Since BCM is a manual painting line, the difference could be linked to a varying cycle time. This aspect is however connected to the human factor and therefore not further analyzed. It is most likely that the difference also could be linked to manual disturbance lists. This suggestion is further strengthened by the fact that several disturbances are documented incorrectly; obvious examples from the disturbance list affecting BCM are displayed in table 35.

Table 35: Issues in disturbance documentation

Disturbance cause	Area of documentation	Issue
BCM robot 1	BCA	"BCM robot 1" does not affect BCA
BCM robot 2	BCA	"BCM robot 2" does not affect BCA
Lost takt due to dusting	BCM	"Lost takt due to dusting" does not affect BCM
BCM painting gun left	CCM	"BCM painting gun left" does not affect CCM

As shown in table 35, errors occur in the manual documentation of disturbances. Other disturbance issues, that are not as obvious, could potentially be hidden in the list of disturbances as well. As discussed earlier in the analysis chapter 5.1.2, some disturbances are not denoted at all due to reasons such as lack of staff or disagreements regarding the process of reporting disturbances. These aspects reveal the margin of error in the generation of production targets for the new model and strengthen the argument to focus on improving the documentation of disturbances.

Errors occurring during measurement procedures are problems that are also recognized in theory. The errors in measurements of time losses connected to disturbances would be categorized as major errors, described in the methodology, by the reasoning that they are caused by manual mistakes. Theory further describes the measurements connected to humans and the importance of defining what to measure and how to measure with regards to the subject. This theory further strengthens the suggestion that the new model's accuracy is strongly dependent on accurate input data in terms of correct time of disturbances. Moreover, the same theory also highlights the importance of improving the documentation of disturbances.

5.6 Feasibility of strategy implementation

It is essential to discuss for what production rates the different strategies and recommendations stated throughout the thesis are relevant. As mentioned earlier during the strategies, the production rate when the strategies become feasible is highly variable and is affected by numerous parameters. The two parameters that mainly affect the breakpoint for implementing the strategies are the total time of disturbances and the distribution between the painting lines.

5.6.1 Strategy 1

The relations between the disturbances and the production rate for the painting lines, figures 29 and 30, are evaluated in table 36. Further, table 36 shows the actual disturbances per day, in minutes, for BCA during the production rate X, collected from the manual disturbance list, and the disturbances calculated with the relation. As shown, the approximated trend is highly accurate and reflects reality well. The production rate evaluated, X, is a production rate within the interval of the relation. Due to the difficulty of identifying additional production rates to extend the relation interval, it is difficult to evaluate how well the relation reflects reality beyond the interval. As a result of the relation between production rate and disturbances being linear, it is evident that the relation is unsuitable for production rates that significantly differ from the interval. This since the relation indicates that the disturbances would decrease and reach zero for a certain production rate, a strategy that is not realistic. When decreasing the production rate significantly the relation also indicates that the disturbances would increase significantly and at a certain production rate reach unreasonable values.

Table 36: Comparison of actual disturbances and calculated disturbances for BCA

X takt	Monday	Tuesday	Wednesday	Thursday	Friday	Total
Shift 1 (actual)	176,5	168,3	168,3	176,5	119,0	808,6
Shift 1 (relation)	169,1	161,2	161,2	169,1	114,0	774,5
Shift 2 (actual)	171,9	163,1	163,1	171,9	112,4	782,0
Shift 2 (relation)	164,7	156,2	156,2	164,7	107,7	749,0

As a result of the reasoning above, the process of finding the actual production rate where the implementation of strategy one is feasible is complex. When using the new production planning model presented earlier in the analysis chapter 5.4, and inserting disturbances calculated from the relation, strategy one is not feasible during the interval that the relation is built upon. This conclusion is drawn since the production target for the night shift exceeds zero cabs for all production rates within the relation. Therefore, the production rate when strategy one becomes feasible is currently unknown.

5.6.2 Strategy 2

Table 37 shows the actual disturbances collected from the manual disturbance list of BCM and the disturbances calculated with the relation between production rate and disturbances for BCM/CCM, figure 29 and 30, for the production rate of X. As shown, the approximated trend is quite accurate and reflects reality well. The difference in disturbances can be explained due to the fact that the actual disturbances in reality represent a production rate that differs from the production rate used for production planning.

Table 37: Comparison of actual disturbances and calculated disturbances for BCM/CCM

X takt	Monday	Tuesday	Wednesday	Thursday	Friday	Total
Shift 1 (actual)	205,8	197,3	197,3	205,8	147,4	953,6
Shift 1 (relation)	191,8	183,7	183,7	191,8	136,4	887,4
Shift 2 (actual)	208,7	198,5	198,5	208,7	141,2	955,4
Shift 2 (relation)	181,2	172,8	172,8	181,2	127,3	835,2

There are two methods to find the feasible production rate for strategy two, one analytical and one qualitative. The analytical method is a five-step method including the new production planning model presented above:

1. Insert production rate, note the total production target for shift 1 and 2 for BCM or CCM.
2. Reduce the cycle time by 52% for BCM and 35% for CCM.
3. Calculate the theoretical production rate if the total production target, from step 1, was to be produced during one shift.
4. Calculate the disturbances with the relation, disturbance and production rate, for the theoretical production rate from step 3 and insert in the production planning model.
5. Check if the new production target for shift 1 exceeds the production target from step 1.

If the production target from step 5 exceeds the production targets from step 1, strategy two is assumed to be feasible for the production rate inserted in step 1.

The second method to determine when strategy two is feasible is a qualitative method. The reasoning is illustrated with an example, see table 38. By decreasing the cycle time for the line of interest the production target for each shift is updated for the current production rate. In table 38, the disturbances for shift 1 and 2 are still based on the previous cycle time. The qualitative approach implies that the production target for shift 2 should be discussed to be produced during the disturbance time of shift 1. Note that when implementing strategy two, it is assumed that the buffer allocated to the lines has been increased during the night and day shift. Therefore it is assumed that disturbances such as “shortage 640” can be minimized.

Table 38: Example of strategy 2 where the cycle time for BCM has been decreased

		Monday	Tuesday	Wednesday	Thursday	Friday
BCM shift 1	Production time	486	466	466	486	348
	Disturbances	205,8	197,3	197,3	205,8	147,4
	Operating time	280	269	269	280	201
	Production target	0,14X	0,13X	0,13X	0,14X	0,1X
BCM shift 2	Production time	408	388	388	408	276
	Disturbances	208,7	198,5	198,5	208,7	141,2
	Operating time	199	190	190	199	135
	Production target	0,008X	0,008X	0,008X	0,008X	0,004X

This approach has to be done for both BCM and CCM to confirm that both painting lines fulfill the criteria of producing the entire production target during one shift in order to implement strategy two.

5.6.3 Strategy 3

As noted earlier strategy three becomes feasible, based on the assumptions for strategy three presented earlier in the analysis chapter 5.2.3, from an economic perspective when shutting down an oven for only a few minutes. Therefore this strategy is assumed to be feasible for all production rates.

6 Recommendation and conclusions

This chapter will summarize the general conclusions from the analysis, present recommendations to cope with efficiency losses during production rate reductions and state recommendations regarding future work to support the reasoning. Finally authors' personal reflections regarding the thesis and construction are presented.

6.1 General conclusions

It is evident that efficiency losses are recognized, both in theory and in practice. There is however little theoretical research connecting them to production rate reductions. This aspect is consistent in practice, where several losses in efficiency are highlighted but disconnected from production rate. To fulfill the purpose of the thesis, these losses have been left for future research.

Theory often describes efficiency losses, or inefficiencies, as time losses. These are recognized as production disturbances in practice and are commonly discussed and evaluated from a cost perspective. All costs are not equally important to consider. Large and variable costs imply greater potential savings and flexibility during variation in production rate. Relevant costs within an automotive paint shop, exemplified by Scania, are costs associated with personnel and energy, particularly oil and heat.

During production rate reductions within a specified interval, empirical data shows that efficiency losses in terms of the total time for disturbances increases. It is however difficult to conclude any similar relation for specific disturbance categories, which can be explained by manual errors in the disturbance documentation. It is also difficult to conclude how the total time for disturbances behaves outside the specified interval of production rates, since there is no data to support this relation. Since it is not reasonable to believe that disturbances would either be completely eliminated or constitute the entire time of production, speculations indicates that the relation levels out in both directions beyond the interval. Furthermore, efficiency losses in terms of costs are most evident visualized by the relation of cost per manufactured cab, which increases as the production rate decreases. To fully grasp the magnitude of efficiency losses, energy costs should be included in the cost per cab evaluation.

To cope with efficiency losses during production rate reductions, numerous actions can be taken. By focusing on reducing costs associated with personnel and energy while considering time losses within production, beneficial strategies can be developed. Identified strategies, for this particular case, include altering shift forms and implementing energy conserving standby modes. In order to determine the feasibility of such actions, a scientific model can be used. This way a complex environment can be simplified, by certain assumptions. It is important to acknowledge that a model never reflects a real situation with complete accuracy but by maintaining the model's relevance, by updating input data, the accuracy is enhanced.

As strategy three is currently presented, it is feasible disregarding of production rate. Costs related to abrasion are however neglected and need to be further investigated before implementation. The feasibility of strategies one and two cannot currently be determined due to lack of relevant production data. Since the model is based on time for disturbances, which in turn depends highly on production rate, the model will be able to determine the feasibility of each strategy first when the production rate is closer to the feasible one. This indicates that the developed model will work more successfully when production rate reductions are performed gradually. The relation between disturbances and production rate, if documented beyond the interval mentioned above, could support more drastic reductions in production rate.

The summarized conclusion of this reasoning is that efficiency losses are closely related to time losses and costs. Within an automotive paint shop, time losses are mainly associated with time for production disturbances and relevant costs to consider are costs for personnel and energy in terms of oil and heat. It is clear that the losses in efficiency rises with production rate reductions, which is visualized by the increasing time of disturbances and cost per cab. Focusing on these aspects, efficiency losses can be reduced by developing strategies to utilize personnel and energy more efficiently. If the situation requires, a scientific model can simplify a complex environment and by maintaining the model relevance or expanding the production rate documentation interval, the feasibility of strategies can be determined.

The conclusions stated above are considered to answer the research questions stated and thereby fulfill the purpose of the thesis.

6.2 Recommendations

The authors' recommendation to Scania is to implement all identified strategies when feasible. Even though strategy three implies great potential savings and is feasible for all production rates, the costs associated with abrasion need to be further evaluated before the strategy is implemented. Each strategy with its respective economic outcome is presented in table 39.

Table 39: Recommended strategies with respective economic outcomes

Strategy	Description	Economic Outcome
1	Shutting down the night shift throughout production	42 329 SEK/day
2	Performing all daily production for BCM and CCM during one shift and shutting down the opposite line	15 007 SEK/day
3	Implementing a standby mode on ovens for energy conservation	88 – 2599 SEK/shift and oven

It is important to highlight that the economic outcome of each strategy is based on assumptions and are therefore not exact. However, the reasoning behind each number implies the potential savings. It is also important to consider that the implementation of each strategy, and thereby the economic outcome, is not immediate but gradual.

To recognize the feasible production rates for strategies one and two, the authors recommend Scania to use the developed production planning model. Since the model's accuracy is highly affected by the time for disturbances, and thereby production rate, the authors further recommend Scania to constantly update the input data of the model, according to instructions presented in appendix E. This will assure the accuracy for production rates within a close interval of the current. By documenting varying production rates and their respective time for disturbances, the relation between the two can be used to predict accurate time of disturbances for diverse production rates, and thereby support the model accuracy.

The model will serve the purpose of investigating the strategy implementation, but will also generate more accurate production targets than the current production planning model. Therefore, the model can be used in the daily production planning work as well. This means that the model could be used to support strategic planning for strategy implementation, on management level as well as for daily production planning by the production planning staff.

6.3 Future research

The recommendations can be considered immediately. There are however future actions that would support the recommendations. Some of these are even crucial for the functionality of the developed model and are therefore considered as areas of future research.

The model and strategies developed are, as mentioned countless times, strongly dependent on the time of disturbances and the production rate. To be able to evaluate the relation between these aspects it is crucial that the disturbances are documented correctly. Moreover, the evaluation of strategy implementation would benefit from accurate time for disturbances, not just as a group but divided into correct categories as well. Since this is currently not the case, there is great potential in developing a standard procedure for documenting disturbance times.

This field is left as future research for Scania to perform. The authors have generated, from their perspective, two interesting aspects for inspiration with regards to the subject, listed below. It is important to highlight that these aspects are not evaluated with depth but only ideas.

- Less disturbance categories; by investigating the relevance and the value added by each disturbance category, there is a potential in removing those that do not add value. Fewer categories could in turn reduce confusion and enhance accuracy.
- Disturbance ranking system; by implementing a ranking system among disturbances, the choice of disturbance category could be more consistent when choosing among several.

Another area considered of great potential is data collection. Currently, as exemplified by the documents used for the model input data, data is collected from several locations within several systems. This is time consuming and enhances the risk of manual errors along the way. Currently a major part of the required data can be collected within the same system, it would be beneficial for Scania to develop data collecting methods regarding this system.

This area is not crucial for the recommendations stated above, but would simplify the procedure as well as other documentation related procedures. The authors recognize a great time saving potential in perusing this aspect.

6.4 Authors' reflections

Final reflections cover the gap between theory and practice. During the construction of this thesis, it has become clear to the authors that theoretical reasoning is not always applicable to practical situations. A major part of this is constituted by the human element that is unpredictable and strongly affects the issue at hand. Delimiting the thesis has made it easier to proceed with the thesis, mainly managing qualitative aspects, as human involvement, on the surface. By also delimiting the thesis to only include the top coat paint shop, a deeper analysis of the organization could be obtained. The lack of theory regarding production rate reductions further results in difficulties in applying methodology that builds upon theory for the subject of this thesis. Since the issue at hand clearly involves problem solving, the methodology chosen is considered the most suitable by the authors.

The data collection during this master thesis has been challenging from numerous perspectives. Occasionally, the time periods that data has been collected from can seem too brief and it could be questionable if the data is representative for the production process. This is however an active choice due to the fact that numerous changes and improvements have been carried out throughout the production process. Having the purpose of the thesis in mind, relevant time periods to collect data from are previous reductions in production rate. This is however something that is done not all too frequent. The data presented is however considered valid and representative after discussions with the employees within the top coat paint shop.

Moreover, the reasoning and conclusions generated are considered applicable to organizations and businesses in various fields. Efficiency losses during production rate reductions is a phenomenon that most likely occurs in most manufacturing companies and even others. The strategy generation and the use of scientific models could easily be modified and used outside Scania. However, there are detailed aspects, such as production distribution and working procedures, which would indeed demand certain modifications for the specific parts of the reasoning to be applicable. Except for the applied reasoning and recommendations to reduce efficiency losses during production rate reductions, this thesis will contribute Scania with a production planning model for daily procedures and inspiration for future research.

A final conclusion is that the authors consider the time period of this thesis a great experience. By using numerous fields connected to the Master of Science education, the authors consider that the construction of the thesis summarize their educational well. Working with Scania has also allowed the authors to build valuable contacts for their future careers as engineers.

References

Published literature

Al-Darrab, I.A (2000), "Relationships between productivity, efficiency, utilization, and quality", Work Study, Vol. 49 Iss: 3, pp.97 – 104

Aspinwall, E. and Elgharib, M. (2013), "TPM implementation in large and medium size organisations", Journal of Manufacturing Technology Management, Vol. 24 Iss: 5, pp.688 – 710.

Bamber, C.J., Castka, P., Sharp, J.M., Motara, Y. (2003), "Cross-functional team working for overall equipment effectiveness (OEE)", *Journal of Quality in Maintenance Engineering*, Vol. 9 Iss: 3, pp.223 – 238.

Bicheno, J., Holweg, M. (2008). The Lean Toolbox 4: th edition. Buckingham: PICSIE Books.

Björklund, M., Paulsson, U. (2003), Seminarieboken – att skriva, presentera och opponera. Studentlitteratur.

Burgess, T.F. (1990), "A Review of Productivity", *Work Study*, Vol. 39 Iss: 1, pp.6 – 10.

Carlborg, P., Kindström, D., Kowalkowski, C. (2013), ”A lean approach for service productivity improvements: synergy or oxymoron?”, *Managing service quality*, vol.23, No.4, pp.291-304.

Chen, L., Meng, B. (2010), “The Application of Value Stream Mapping Based Lean Production System”, *International Journal of Business and Management*, Vol. 5, No. 6, pp.203-209.

Daugherty, P., Rogers, D., Spencer, M. (1990), "Just-in-Time Concepts: Applicability to Logistics/Transportation", *International Journal of Physical Distribution & Logistics Management*, Vol. 20 No.7, pp.12 – 18.

Ellram, L. (1996), “The Use of Case Study Research in Logistics Research*”*, *Journal of Business Logistics*, Vol.17, No.2, pp.93-138.

Farrell, M.J. (1957) “The measurement of productive efficiency”, *Journal of the Royal Statistical Society. Series A (General)* Vol. 120, No. 3, pp. 253-290.

Frigg, R. and Hartmann, S. (2012), "Models in Science", *The Stanford Encyclopedia of Philosophy,* Edward N. Zalta (ed.).

Garg, A. and Deshmukh, S.G.(2006), "Maintenance management: literature review and directions", *Journal of Quality in Maintenance Engineering*, Vol. 12 Iss: 3, pp.205 – 238.

Hartmann, S. (1996), “The World as a Process. Simulations in the Natural and Social Sciences”, in Hegselmann et al. 1996, pp.77–100.

Höst, M., Regnell, B., Runeson, P. (2006), Att genomföra examensarbete. Studentlitteratur.

Hines, P., Rich, N., Bicheno, J., Brunt, D., Taylor, D. (1998), “Value stream management”, *International Journal of Logistics Management*, Vol. 9 Iss:1, pp. 25–42.

Hitchens, D. (1999). Just In Time second edition. Vermont: Gower Publishing Limited.

Ireland, F. and Dale, B.G. (2001), "A study of total productive maintenance implementation", *Journal of Quality in Maintenance Engineering*, Vol. 7 Iss: 3, pp.183 – 192.

Islam, S. and Shazali, S.T.S (2011), "Determinants of manufacturing productivity: pilot study on labor-intensive industries", *International Journal of Productivity and Performance Management*, Vol. 60 Iss: 6, pp.567 – 582.

Jeong, K-Y. and Phillips, D.T. (2001), "Operational efficiency and effectiveness measurement", *International Journal of Operations & Production Management*, Vol. 21 Iss: 11, pp.1404 – 1416.

Jönsson, B. and Reistad, N. (1987), Experimentell fysik. Studentlitteratur.

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

Kwon, O. and Lee, H. (2004), "Calculation methodology for contributive managerial effect by OEE as a result of TPM activities", *Journal of Quality in Maintenance Engineering*, Vol. 10 Iss: 4, pp.263 – 272.

Lander, E., Liker, J. K. (2007), “The Toyota Production System and art: making highly customized and creative products the Toyota way”, *International Journal of Production Research*, Vol. 45, No. 16, pp. 3681–3698.

Laugen, B.T., Acur, N., Boer, H., Frick, J. (2005), "Best manufacturing practices: What do the best-performing companies do?", *International Journal of Operations & Production Management*, Vol. 25 Iss: 2, pp.131 – 150.

Liker, J. (2004), The Toyota Way. Madison: McGraw-Hill.

Lowe, E.A. and Soo W.F. (1980) "Organisational Effectiveness — A Critique and Proposal", *Managerial Finance*, Vol. 6 Iss:1, pp.63 – 77.

Magnani, L., Nersessian, N. (2002), *Model-Based Reasoning: Science, Technology, Values*. Dordrecht: Kluwer.

Maier, C. (1970), "Between Taylorism and Technocracy: European Ideologies and the Vision of Industrial Productivity in the 1920s", *Journal of Contemporary History*, Vol.5, No.2, pp.27–61.

Mauri, F., Garetti, M., Gandelli, A. (2010), "A structured approach to process improvement in manufacturing systems", *Production Planning & Control: The Management of Operations*, Vol. 21 Iss:7, pp.695-717.

Misterek, S.D.A., Dooley, K.J., Anderson, J.C.(1992), "Productivity as a Performance Measure", *International Journal of Operations & Production Management*, Vol. 12 Iss: 1, pp.29 – 45.

Moore, R. (1997), "Combining TPM and reliability-focused maintenance", *Plant Engineering*, Vol. 51 No. 6, pp. 88-90.

Nakajima, S. (1988). Introduction to TPM : Total Productive Maintenance. University of Minnesota: Productivity Press.

Näslund, D. (2002), "Logistics needs qualitative research – especially action research", *International Journal of Physical Distribution & Logistics Management*, Vol. 32 Iss: 5, pp.321 – 338.

Oakland, J.S. and Wynne, R.M. (1991) "Efficiency of UK Engineering Production Management Systems Part II: A Methodology for Improvement", *International Journal of Operations & Production Management*, Vol. 11 Iss: 2, pp.14 – 26.

Pramod, V.R., Devadasan, S.R., Muthu, S., Jagathyraj, V.P., Dhakshina Moorthy, G. (2006), "Integrating TPM and QFD for improving quality in maintenance engineering", *Journal of Quality in Maintenance Engineering*, Vol. 12 Iss: 2, pp.150 – 171.

Rolstadås, A. (1998), "Enterprise performance measurement", *International Journal of Operations & Production Management*, Vol. 18 Iss: 9/10, pp.989 – 999.

Rosengren, K-E. and Arvidsson, P. (2002), Sociologisk metodikk. Liber.

Sarmiento, R., Byrne, M., Contreras, L.R., Rich, N. (2007), "Delivery reliability, manufacturing capabilities and new models of manufacturing efficiency", *Journal of Manufacturing Technology Management*, Vol. 18 Iss: 4, pp.367 – 386.

Seale, C. (1999), "Quality in Qualitative Research", Qualitative *Inquiry*, Vol.5, No.4, pp. 465-478.

Sohal, A., Olhager, J., O'Neill, P., Prajogo, D. (2010), "Implementation of OEE – issues and challenges", Poliscript, Milano.

Stainer, A. (1997), "Capital input and total productivity management", *Management Decision*, Vol. 35 Iss: 3, pp.224 – 232.

Sugimori, Y., Kusunoki, K., Cho, F., Uchikawa, S. (1977), “Toyota production system and Kanban system - Materialization of just-in-time and respect-for-human system*”, International Journal of Production Research*, Vol.15, No.6, pp.553-564.

Swoyer, C. (1991), “Structural Representation and Surrogative Reasoning”, *Synthese* 87, pp.449–508

Tangen, S. (2004), Evaluation and Revision of performance measurments systems. Woxen Centrum, production engineering. Stockholm: Royal Institute of Technology.

Upadhye, N., Deshmukh, S.G., Garg, S. (2010), “Lean Manufacturing for Sustainable Development”, *Global business and Management Research: An International Journal*, Vol.2, No.1, pp.125-137.

Uzun, A. and Ozdogan, A. (2012), "Maintenance parameters based production policies optimization", *Journal of Quality in Maintenance Engineering*, Vol. 18 Iss: 3, pp.295 – 310.

Wittenberg, G. (1994), "Kaizen—The many ways of getting better", *Assembly Automation*, Vol. 14, No. 4, pp.12-17.

Womack, J., Jones, D., Roos, D. (1990), The Machine That Changed the World. New York: Simon & Schuster.

Electronical

Swedish Petroleum and Bio fuel Institute: Sales price heating oil in Sweden [Online]. Available: http://spbi.se/statistik/priser/eldningsolja/ [2014-04-25]

Eon Sweden: Hear prices 2014, industrial customers [Online]. Available: http://www.eon.se/upload/eon-se-2-0/dokument/foretagskund/produkter_priser/varme/Prislistor_2014/Ftg-Syd-prislista-2014.pdf [2014-04-25]

Toyota: Toyota Production System and what it means for business [Online]. Available: http://www.toyota-forklifts.eu/SiteCollectionDocuments/PDF%20files/Toyota%20Production%20System%20Brochure.pdf [2014-05-05]

Scania: Scania Annual Report 2013 [Online]. Available: http://www.scania.com/Images/Scania_ENG_2013_index_tcm40-416122.pdf [2014-05-05]

Scania: Scania’s strategic platform [Online]. Available: http://www.scania.com/scania-group/strategic-platform/ [2014-05-05]

Scania Internal, Wonderware Information System

Scania internal, Production system Oskarshamn

Scania Internal, Scania Production System Booklet 2007

Interviews/continuous contact

Magnus Rosvall, Industrial Engineer BCA/Paint kitchen, Scania CV AB

Pernilla Zackrisson, Industrial Engineer BCM/CCM, Scania CV AB

Johan Nilsson, Manager Production Engineering, Scania CV AB

Hasan Bahtijaragic, Industrial Engineer ACL, Scania CV AB

Michael Andersson, Industrial Engineer Inspection, Scania CV AB

Ola Daleman, Industrial Engineer Ventilation, Scania CV AB

Mats-Gunnar Nilsson, Dynamate AB

Mats Dremer, Automation Technician, Dynamate AB

Jens Enocksson, PPG

Eva Lyth, Inspection Supervisor, Scania CV AB

Dimitris Karagianis, Controller, Scania CV AB

Joakim Roth, Maintenance Manager, Dynamate AB

Eva Vesterberg, Environmental Coordinator, Scania CV AB

Appendix

Appendix A – Top disturbances throughout the painting lines

Top disturbance BCA 1,06X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2014-01-20	Evening	Shortage 640	04:18
2013-11-22	Night	Facility	04:12
2013-10-31	Day	Shortage 640	03:06
2013-11-15	Day	Full forward	02:28
2014-01-14	Day	Full forward	02:24
2014-01-02	Evening	Facility	02:24
2014-02-05	Night	BCA Robot 2	02:14
2014-01-17	Evening	Cleaning	02:13
2013-11-19	Day	Full forward	02:05
2013-12-16	Evening	Shortage Facility	02:02
Top disturbance BCA X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2014-02-10	Evening	BCM Robot 2	03:25
2014-03-06	Day	Shortage 640	03:12
2014-02-28	Evening	Planned stop	01:57
2014-02-23	Night	BCA Robot 6	01:30
2014-03-12	Day	Planned stop	01:30
2014-02-21	Evening	Planned stop	01:26
2014-03-06	Evening	Shortage 640	01:25
2014-03-11	Day	Facility	01:22
2014-02-24	Day	Planned stop	01:20
2014-02-27	Day	Full forward	01:20

Top disturbance BCM 1,06X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2013-11-18	Evening	Planned stop	07:12
2013-11-27	Evening	Shortage 640	06:57
2014-01-17	Evening	Planned stop	06:12
2013-11-20	Evening	Shortage 640	04:38
2014-01-02	Evening	Shortage 640	04:30
2013-12-03	Day	Shortage 640	04:12
2014-01-21	Day	Shortage 640	04:10
2013-12-23	Day	Shortage 640	04:07
2013-12-11	Evening	Shortage 640	04:00
2014-01-09	Evening	Shortage 640	04:00
Top disturbance BCM X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2014-02-28	Evening	Planned stop	06:12
2014-03-05	Evening	Planned stop	04:48
2014-03-07	Evening	Shortage 640	04:11
2014-02-26	Evening	Shortage 640	03:56
2014-02-18	Day	Full forward	03:52
2014-03-04	Day	Shortage 640	03:52
2014-02-13	Day	Shortage 640	03:30
2014-02-10	Evening	BCM Robot 1	03:20
2014-03-14	Evening	Shortage 640	03:18
2014-02-18	Evening	Shortage 640	03:17

Top disturbance CCM 1,06X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2013-10-21	Evening	Shortage 640	06:18
2014-01-03	Evening	CCM robot 2	06:12
2014-01-29	Day	Other faults-test cab	04:42
2013-12-05	Evening	Color delivery	03:58
2013-11-15	Day	Full forward	03:44
2013-10-23	Evening	Shortage 640	03:32
2013-10-31	Day	Shortage 640	03:25
2013-11-04	Evening	Shortage 640	03:22
2014-01-28	Evening	Shortage 640	03:15
2013-11-05	Day	Shortage 640	03:10
Top disturbance CCM X takt			
Date	**Shift**	**Cause of error**	**Duration [h]**
2014-03-10	Day	Other faults-test cab	04:28
2014-02-20	Day	Planned stop	02:32
2014-02-17	Day	CCM robot 1	02:30
2014-02-27	Evening	Planned stop	02:22
2014-02-27	Day	Shortage 640	02:05
2014-02-11	Day	Shortage 640	01:55
2014-02-17	Day	Facility	01:51
2014-02-13	Day	Shortage 640	01:50
2014-02-24	Day	Planned stop	01:50
2014-03-06	Evening	Shortage 640	01:48

Appendix B – Energy consumption per month

Energy consumption/month during 2013						
	jan	**feb**	**mars**	**april**	**maj**	**jun**
El	1007	1024	1076	1112	1209	1242
Olja	647	511	396	493	441	542
Fjärrvärme	1782	1581	1836	1335	757	354
Tot	3437	3116	3309	2941	2408	2138
Antal hytter 612	3672	3562	3918	4323	4482	4105
	jul	**aug**	**sep**	**okt**	**nov**	**dec**
El	880	1288	1406	1492	1388	1201
Olja	264	521	536	593	588	461
Fjärrvärme	184	326	783	973	1350	1240
Tot	1328	2135	2725	3059	3327	2902
Antal hytter 612	2168	3335	5136	5711	5377	4174

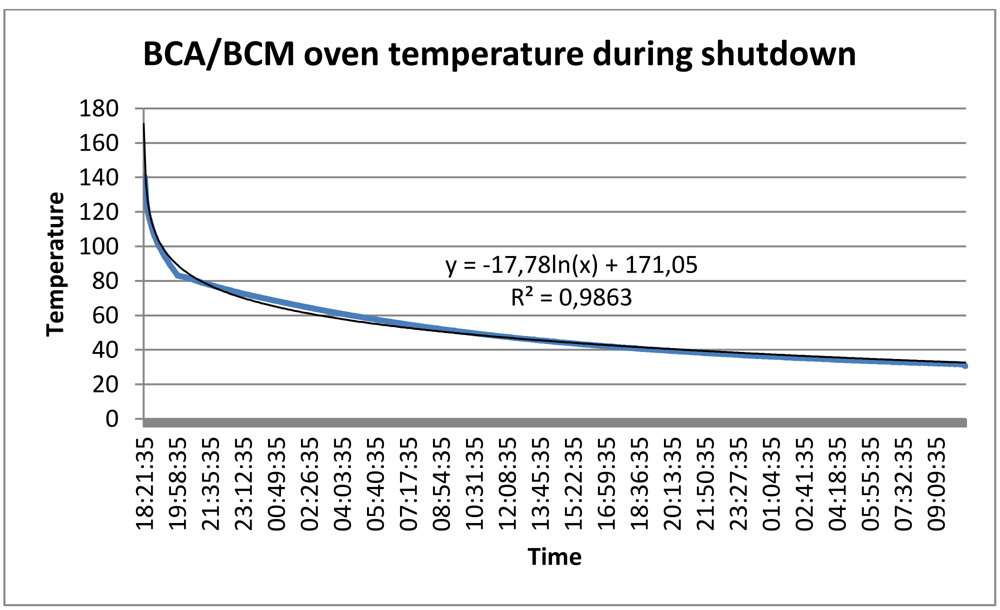
Appendix C – Scheduled maintenance off production

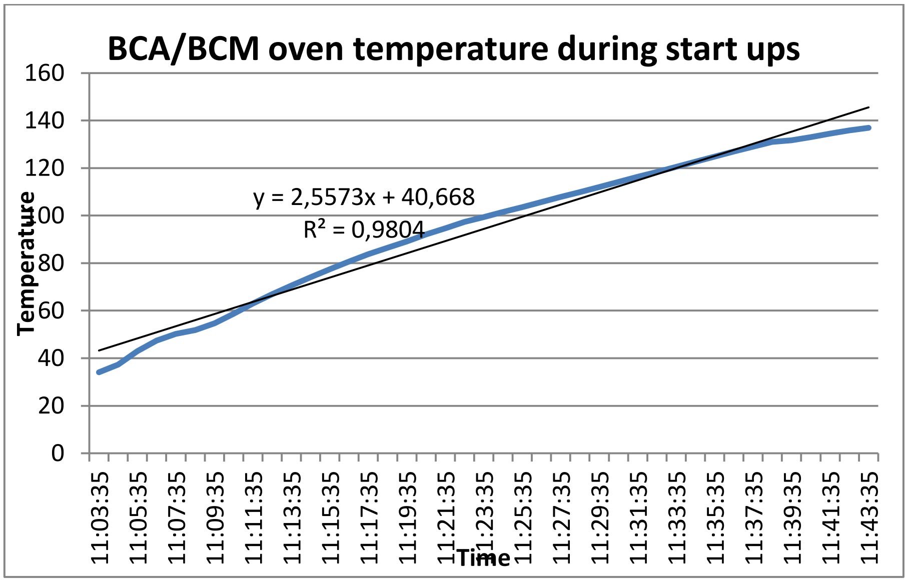
Summa av Tid/åtg	Kolu																
Radetiketter	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425
610 Slutbättrins Boxar	4	5,3		2	6	7,3		4,5	6	5,8		2,5	4	5,3		2	6
610 Slutbättrins Boxar EX ZON		3,3								3,3							
612 ACL Booth														3,6		3,6	
612 ACL Manual Work			1,5				0,6			8,2	1,5				1,4		
612 ACL Oven															4		1,8
612 After Input Storage								1,7		8,2							
612 Allmänventlilation UH FU	5,6				7,2		3		6,8				5,6				5,6
612 Applicering CCM line UH FU				4,4		2,4		9,4		0,8		3,4				3,4	
612 Applicering Manuell Line UH FU EX ZON		4		6	2	4		4		4	2	6		4		4	2
612 Appliceringsutrustning UH FU EX ZON		10,6		1,2		10,6		1,2		10,6		1,2		10,6		1,2	
612 AUTOMATLINE			1,8						6,3		0,4						
612 AUTOMATLINE EX ZON			0,8								0,6						
612 Before BCA/BCM/CCM	3,8									4,9							
612 Before Input Storage									2,3								
612 Before Inspection										1,4			5,2				
612 Before Output Storage											4,8		2,4				1,4
612 Before Spot Repair	1	1										2,4			8,6		
612 Befuktningsanläggning andningsluft																1	
612 Buffert 100	1				1				1				2,6		8,6		1
612 CCM Line				2,3						4,8		0,4					
612 CCM Line EX ZON				0,6				0,4		0,2		3				0,4	
612 Cooling Zone BCA Oven							1,5			1,8			0,8				
612 Cooling Zone BCM Oven				1				1,5			1,8			0,8			1
612 Cooling Zone CCM Oven									1,5			1,9			0,8		
612 Destilator					6												
612 Elskåpskylaggregat															0,5		
612 Empty Skid Stacker ACL 1		6											1	1			6
612 Empty Skid Stacker ACL 2			5,2														
612 Empty Store Hanger	3,5				2	1										3,5	
612 Flash Off	22,4												1,5	1			1,5
612 Färgdistr. Pumprum Plan2	3				3				3				3				3
612 Färgdistr. Pumprum Plan2 EX ZON		1,5		1,8				1		2,9		0,6				1	
612 Före Montering 1														3			
612 Före Montering 2															5,1		
612 Hängskidshantering									10,5								
612 Indunstare																	
612 Inspection			1	0,6			0,6	0,5		0,6	3,2		7,1			0,6	3,1
612 Kilremsbyte på ventilationsaggregat			7		5		7								3,5		6,5
612 Kranlager Grundlack UH FU		4,9		1		1		1,4		2	3,7	1		2,6		1	
612 Kylzoner UH FU*																	
612 Lasermärkmaskin																	
612 Manuell applicering CCM line UH FU				4,2		4,8		0,4		2						0,4	
612 MANUELL Line		2,5								0,3							
612 MANUELL Line EX ZON		1,2								0,3							
612 MANUELL Utlastning				0,7													
612 MCC Booth		0,2				0,6											
612 MCC Booth EX ZON						1,6						0,5		0,8			
612 MCC Line															3		
612 Monteringsskidshantering	9,8			2,5					0,9	1			7,5			6,9	0,4
612 Nya Utlastningsbanorna							2,5										
612 Ovens							5,9										
612 Portar Spot Repair																	
612 Processventilation UH FU	14,4	7	7,9	6	9,8	9,4	6,5	7	9,5	9,8	13,4	7	8	9,4	11,3	10,2	10,2
612 Pulvertestmaskin UH FU																	
612 Returbana Buffert-50											0,3				3		
612 Robot 1-2 BCM line UH FU		2															
612 Robot 1-2 BCM line UH FU EX ZON		2			3								3				
612 Robot 1-6 för automatline UH FU EX ZON		4,6				14		10,2		11				7,6		3	
612 Robot1-2 CCM line UH FU		7						2		7				4			
612 Rostskydd UH FU				0,5		0,2				3,2						0,2	
612 Skid Return from buffert 100																	
612 Skid Return to B640									7,9								
612 Smörjpunkter ventilationssystem, kylzon UH FU	1	1,5	2,4														
612 Spot Repair Sanding														2,4			
612 Säkerhetsstopp	8,1					4,6	2,4	5		4,9	4,8	1,8	8,1				
612 V.O.C Reningsanläggning UH FU	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,9	0,5	0,7	0,5	0,7	0,5	0,7
612 Vattenbehandling UH FU		0,3	0,7	0,6		0,3	0,8			0,3	0,2	0,6		0,3	0,8		
613 Kranlager Täcklack UH FU	0,7		2,3	0,4	0,7	0,2	0,7	4,2	0,7	0,4	4,2		0,7		0,7	0,6	0,7
(tom)																	
Totalt	**79**	**65,4**	**31,3**	**36,3**	**46,4**	**62,5**	**32,2**	**54,9**	**57,1**	**100**	**41,8**	**32,8**	**61,2**	**56,9**	**52**	**43,5**	**50,9**

1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	(tom)	Totalt
7,3		4	6	5,3		2	4	5,3		4	6	8,3		4	6	5,3	2	2	4	5,3		2	6	7,3		4		161
3,3								3,3								3,3								3,3				19,8
		1									3,6													3,6		3,6		19
	6,6				0,6		8,2		1,5				0,6				1,5				0,6	8,2	0,8		1,5			43,3
			1,9									4													1,8			13,5
							8,2									1,7						8,2			2			30
			5,6				5,6				7,2		3		6,8				9,7				5,6					77,3
6		3,4		0,8		3,4				9,4		1		9,8		4,8		3,4		6		3,4				3,4		78,6
4		6		4	4	4		4		6	2	4		4		4	2	6		4		4	2	4		6		116
10,6		1,2		10,6		1,2		10,6		1,2		10,6		1,2		10,6		1,2		10,6		1,2		10,6		1,2		130
4	0,4								0,4								6,7								0,4	4		24,4
																	1,8											3,2
							5,1															4,9						18,7
						2,3															2,3							6,9
										5,2															5,2			17
								4,8													2,4		4,8					20,6
0,6												8,6														0,6		22,8
																								1				2
			1				1				1		8,6		1				1		1,6		1			0,2		31,6
		0,4								0,4								5,8								0,4		14,5
						0,4								0,4				0,2				0,4						6
							1,8				1,5	1									0,8	1,8						11
								1,8				1			1,5							0,8	1,8		1			14
									1,9										1,5	1			0,8	1,9				11,3
													6															12
															11	7,5												19
				0,5				2,9						6														23,4
5,2									1,2						5,2													16,8
0,7				3									3,5											1		0,7		18,9
1			1,5	1					16																			45,9
			3				3				3				3				3				3					33
				2,9		1,6				1,5		1,8		1		2,9		0,6				1						22,1
	1				1,6						3															3		11,6
		0,4				2,8						5,1																13,4
1,8						10,5															10,5							33,3
							1																					1
	1			2,1	0,6				1	7,7						0,6	1			0,5		0,6			11,2			43,6
3																												32
1		1,9		1		1		5,1		4,5		2		1,4		1		1		1,4		1,5	3,7	1		1,4		47,5
	4,8																								6,8			11,6
1																												1
				2		0,4						4,2		5,2		2						0,4						26
0,3						5,8		0,3	0,2							0,3								0,3				10
0,3						0,4		0,3								3,3								0,3				6,1
	0,7									0,5						0,7												2,6
								5,8																				6,6
				0,8								0,8								1,3								5,8
			8,4																									11,4
			2,2				8,1						6,9		0,4								0,4					47
	5,1				4,8																5,3							17,7
				5,9															5,9									17,7
	4																											4
8,8	9,5	8,2	12,9	7	11	9	9,8	9,4	6,5	6	8	8,8	8,9	7	9,5	8	9,8	9,4	11	9,4	9,5	9,6	12,6	8,8	9,5	6,4		401
								0,5																				0,5
			6,6																									9,9
										2																		4
			3								3								3									17
3		3,2	16	21		7		10,2				6		6,2		7				15,6		7		7		3,2		163
3		2						16				2		2		3				4				7		2		61
				0,2	3					0,2		0,3				0,2		3				0,2						11,2
	6,4																											6,4
1,4		0,6															7,9									1,4		19,2
									1	1,5	2,4																	9,8
		9,5																										11,9
4,6	2,4	5		5,9	4,8	1,8	8,1					4,6	2,4	5		4,9	4,8	1,8	8,1					4,6	3,4	5,8		118
0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,7	0,5	0,9	0,5	0,7	0,5	0,7	0,5	0,7	0,5		26,8
0,3	0,2	0,6		0,3	0,8			2,3	0,2	0,6	0,5	4,3	0,8			0,3	0,2	0,6		0,3	0,8			0,3	0,2	0,6		19,1
1,6	0,7		0,7	0,4	4,9	0,9	0,7	0,2	0,7	0,4	0,7		0,7		2,3	0,4	0,7	0,2	4,2	4,2	0,7	0,4	0,7		0,7			44,3
73,3	43,5	47,9	69,5	75,2	36,8	55	65,3	83,3	31,3	51,6	42,6	78,9	42,1	53,7	47,4	72,3	39,1	35,7	52,3	64,1	35,2	56,1	43,9	62,5	44,4	48,4		2356

Appendix D – Start up and shutdown of ovens

Time until production	Time for shutdown	Temperature after shutdown	Time for start up	Oil consumption during start up	Oil consumption during normal production	Diff in oil consumption	Cost diff
30	21	117	9	7	14	7	88
60	46	103	14	12	28	17	216
90	72	95	18	14	42	28	361
120	100	89	20	16	56	40	521
150	128	85	22	17	70	53	683
180	157	81	23	18	84	66	853
210	186	78	24	19	98	79	1024
240	215	76	25	20	112	92	1195
270	244	73	26	21	126	105	1367
300	273	71	27	21	140	118	1540
330	302	70	28	22	154	132	1713
360	332	68	28	23	168	146	1892
390	361	66	29	23	182	159	2065
420	391	65	29	23	196	173	2245
450	420	64	30	24	210	186	2419
480	450	62	30	24	224	200	2599





BCA/BCM oven temperature during start ups
160
140
120
100
80
60
40
20
0
Temperature
y = 2,5573x + 40,668
R² = 0,9804
11:03:35
11:05:35
11:07:35
11:09:35
11:11:35
11:13:35
11:15:35
11:17:35
11:19:35
11:21:35
11:23:35
11:25:35
11:27:35
11:29:35
11:31:35
11:33:35
11:35:35
11:37:35
11:39:35
11:41:35
11:43:35
Time

Appendix E – Instructions for new model

Painting lines – input data for disturbance

Step	Manual activity	File calculations/comments
1)	Choose an optional time period from the disturbance list regarding BCA, BCM and CCM.	
2)	Copy all fields and paste into the model, see figure G1. Choose "Paste Special" values when pasting.	This is done to avoid copying the underlying equations from the disturbance list which can result in wrong numbers. The date, week and total time of the disturbance are now presented as numbers.
3)	Press the button "Uppdatera pivottabell", see figure G2.	The file will gather and summarize all disturbances by painting line and cause of error and present it in the pivot table. The data presented in the pivot table is in number of days, e.g. 0,02 days = 0,02*24 = 0,48 hours. The total disturbance time for the different shifts during the time period are highlighted by the red elipse in figure G2.
4)	Enter the number of working days for each painting line and shift from what period the data is collected from, cells are highlighted in figure G3.	Simultaneously the disturbances for each shift and painting lines will be presented in figure x. Note that the total time is calculated in the pivot table and for the calculation of disturbance/shift it is required that the number of working days for the time period of the data is entered manually.

Indata för målningsliner för beräkning av stopptider												
Datum	**Vecka**	**Skift**	**Line**	**Kod**	**Störningsorsak**	**DM**	**Hytt id/ Skid nr**	**Störningsbeskrivning**	**Antal**	**Från**	**Till**	**Total tid**
41712,00	1411,00	kväll	bcm	4,00	Hyttbrist 640			Helgstädning		0,64	0,78	0,14
41712,00	1411,00	kväll	bca	24,00	BCA Robot 8			För hög ledlast		0,64	0,64	0,00
41712,00	1411,00	kväll	bca	24,00	BCA Robot 8			För hög ledlast		0,64	0,64	0,00
41712,00	1411,00	kväll	bca	4,00	Hyttbrist 640					0,65	0,66	0,01
41712,00	1411,00	kväll	ccm	9,00	Rengöring			Helgstädning		0,70	0,73	0,03
41712,00	1411,00	kväll	bca	9,00	Rengöring			Helgstädning		0,73	0,76	0,03
41715,00	1412,00	dag	bca	2,00	Dammlucka			Dammlucka	4,00		0,40	0,01
41715,00	1412,00	dag	bca	2,00	Dammlucka			Dammlucka	2,00		0,52	0,01
41715,00	1412,00	dag	bca	2,00	Dammlucka			Dammlucka	3,00		0,63	0,01
41715,00	1412,00	dag	ccm	8,00	Planerat stopp			Tage sätter dit filter på pistolerna /		0,27	0,31	0,05
41715,00	1412,00	dag	bca	4,00	Hyttbrist 640			optimering / reset pendant robot 3	10,00	0,32	0,38	0,05
41715,00	1412,00	dag	bcm	4,00	Hyttbrist 640					0,34	0,38	0,04
41715,00	1412,00	dag	ccm	6,00	Anläggning		75-1427	Port till flash-off larmar, UH återställer.		0,33	0,33	0,01
41715,00	1412,00	dag	bca	32,00	Kvalitet 640		75-1433	krater hö dörr		0,35	0,36	0,01
41715,00	1412,00	dag	bca	8,00	Planerat stopp			Planerat stopp pga strul i 640		0,38	0,42	0,04
41715,00	1412,00	dag	bcm	8,00	Planerat stopp			Planerat stopp pga strul i 640		0,38	0,42	0,04
41715,00	1412,00	dag	bca	19,00	BCA Robot 4			A1 servo1/accu ingen signal		0,44	0,45	0,00
41715,00	1412,00	dag	bcm	4,00	Hyttbrist 640			och Janne kör testbil		0,42	0,52	0,10
41715,00	1412,00	dag	bca	4,00	Hyttbrist 640			komplett rengöring	27,00	0,47	0,52	0,05

Figure G2: In data for painting lines copied from the manual disturbance list

Uppdatera pivottabell

Kommentar pivottabell

Summa av Total tid	Kolumnetiketter				
Radetiketter	dag	kväll	(tom)	natt	Totalt
bca	**1,411111111**	**1,27986111**		**0,02083333**	**2,71180556**
Anläggning	0,115972222	0,02430556		0,02083333	0,16111111
Fullt framåt	0,117361111	0,21388889			0,33125
Hyttbrist 640	0,451388889	0,2375			0,68888889
Planerat stopp	0,110416667	0,14027778			0,25069444
Rengöring	0,110416667	0,24791667			0,35833333
Övriga fel & Test Hytt		0,01388889			0,01388889
Dammlucka	0,4375	0,36388889			0,80138889
BCA Robot 1		0,00069444			0,00069444
BCA Robot 4	0,011111111	0,00625			0,01736111
BCA Robot 5	0,009722222				0,00972222
BCA Robot 8	0,009027778	0,00833333			0,01736111
BCA Robot 7	0,003472222	0,0125			0,01597222
BCA Robot 6	0,01875				0,01875
Kvalitet 640	0,015972222	0,00902778			0,025
BCA Robot 3		0,00138889			0,00138889
(tom)					
(tom)					
ccm	**0,49375**	**0,56875**			**1,0625**
Anläggning	0,045138889				0,04513889
Fullt framåt	0,041666667	0,16527778			0,20694444
Färgleverans	0,047916667	0,05486111			0,10277778
Planerat stopp	0,079166667	0,24722222			0,32638889
Rengöring		0,05277778			0,05277778
Övriga fel & Test Hytt	0,051388889				0,05138889
CCM handpistoler Vänster	0,001388889	0,00138889			0,00277778
CCM robot 1	0,220138889	0,04375			0,26388889
CCM robot 2	0,004166667				0,00416667
CCM handpistoler Höger	0,002777778	0,00347222			0,00625
bcm	**1,738194444**	**1,49583333**			**3,23402778**
Anläggning	0,007638889				0,00763889
BCM Robot 2	0,000694444				0,00069444
Fullt framåt		0,06597222			0,06597222
Färgleverans	0,018055556	0,01458333			0,03263889
Hyttbrist 640	0,665277778	0,89097222			1,55625
Planerat stopp	0,979861111	0,51736111			1,49722222
Rengöring	0,001388889	0,00347222			0,00486111
Övriga fel & Test Hytt	0,026388889				0,02638889
BCM Robot 1	0,038888889	0,00347222			0,04236111
Totalt	**3,643055556**	**3,34444444**		**0,02083333**	**7,00833333**

Figure G2: Pivot table for updating disturbances

Beräkning stopptid/skift BCA			
	Dag	Kväll	Natt
Total stopptid för tidsperiod [h]	33,8667	30,7167	0,5
Antal arbetsdagar för tidsperiod [st]			
Stopptid/skift [h]	#######	#######	#######
Beräkning stopptid/skift BCM			
	Dag	Kväll	Natt
Total stopptid för tidsperiod [h]	41,7167	35,9	0
Antal arbetsdagar för tidsperiod [st]			
Stopptid/skift [h]	#######	#######	#######
Beräkning stopptid/skift CCM			
	Dag	Kväll	Natt
Total stopptid för tidsperiod [h]	11,85	13,65	0
Antal arbetsdagar för tidsperiod [st]			
Stopptid/skift [h]	#######	#######	#######

Figure G3: Illustration of disturbances per line and shift

Inspection – input data for disturbance

Step	Manual activity	File calculations/comments
1)	Choose an optional time period from the disturbance list regarding the inspection decks (entire weeks if possible).	Public/paint/engineering/arbetsmappar/Mikael/inspektion/produktionsuppföljning - Omräkning CT_OPE_JPH_2014
2)	Copy the columns associated with disturbances (HastLoss, SaknadTid, StoppFram, StoppBak and PlaneratStopp) for each inspection section into the model, see figure G4.	Modellen – inspection data input
3)	Enter the number of weeks, regarding inspection decks and shifts, from which the data is collected. The cells are highlighted in figure G5.	Simultaneously the disturbances for each shift and inspection deck will be presented in figure G5.
4)	The time for disturbances will automatically be updated in the model.	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Datum	Omrade	ArbetsTid	IdealTid	DriftTid	HastLoss	SaknadTid	StoppFram	StoppBak	PlaneratStopp	LevAntalHytter	TeknT	Defekta	CykelTid	OPE_Tal	JPH	Drift	Idealtid %
62	2014-03-02																	
63	2014-03-03	Insp2	527	170	271	101	0	1	254	0	33	100	0	8,22	63	7,3	51	32
64	2014-03-04	Insp2	527	180	191	11	0	2	335	0	35	100	0	5,45	94	11,0	36	34
65	2014-03-05	Insp2	527	150	239	89	0	0	289	0	29	100	0	8,22	63	7,3	45	28
66	2014-03-06	Insp2	527	205	296	91	2	0	229	0	40	100	0	7,39	69	8,1	56	39
67	2014-03-07	Insp2	360	116	116	0	0	2	242	0	27	100	0	4,30	100	14,0	32	32
68	2014-03-08																	
69	2014-03-09																	
70	2014-03-10	Insp2	527	90	176	86	0	0	351	0	17	100	0	10,34	51	5,8	33	17
71	2014-03-11	Insp2	527	110	405	295	0	1	121	0	21	100	0	19,28	27	3,1	77	21
72	2014-03-12	Insp2	527	110	247	137	0	1	280	0	21	100	0	11,74	45	5,1	47	21
73	2014-03-13	Insp2	527	85	252	167	0	1	274	0	16	100	0	15,77	34	3,8	48	16
74	2014-03-14	Insp2	360	100	148	48	0	0	211	0	19	100	0	7,81	67	7,7	41	28
75	2014-03-15																	
76	2014-03-16																	
77	2014-03-17	Insp2	527	125	173	48	0	0	354	0	24	100	0	7,19	72	8,3	33	24
78	2014-03-18	Insp2	527	115	372	257	0	0	155	0	22	100	0	16,90	31	3,5	71	22
79	2014-03-19	Insp2	527	100	205	105	0	0	322	0	19	100	0	10,80	49	5,6	39	19
80	2014-03-20	Insp2	527	135	296	161	8	3	221	0	26	99	0	11,40	44	5,3	58	26
81	2014-03-21	Insp2	360	95	167	72	0	0	193	0	18	100	0	9,27	57	6,5	46	26
82	2014-03-22																	
83	2014-03-23																	
84	2014-03-24	Insp2	527	115	243	128	0	1	284	0	22	100	0	11,04	47	5,4	46	22
85	2014-03-25	Insp2	527	115	225	110	1	0	301	0	22	100	0	10,21	51	5,9	43	22
86	2014-03-26	Insp2	527	125	246	121	15	6	260	0	24	97	0	10,25	48	5,9	50	24
87	2014-03-27	Insp2	527	135	381	246	0	0	146	0	26	100	0	14,64	35	4,1	72	26
88	2014-03-28	Insp2	360	105	200	95	0	6	154	0	20	100	0	10,02	52	6,0	56	29
89	2014-03-29																	
90	2014-03-30																	
91	2014-03-31	Insp2	527	160	252	92	0	1	274	0	31	100	0	8,11	64	7,4	48	30
92	2014-04-01	Insp2	527	135	278	143	0	0	249	0	26	100	0	10,68	49	5,6	53	26
93	2014-04-02	Insp2	527	90	254	164	0	0	273	0	17	100	0	14,94	35	4,0	48	17
94	2014-04-03	Insp2	527	135	279	144	0	3	245	0	26	100	0	10,73	48	5,6	53	26
95	2014-04-04	Insp2	360	115	166	51	0	0	195	0	22	100	0	7,52	69	8,0	46	32
96	2014-04-05																	
97	2014-04-06																	
98	2014-04-07	Insp2	527	95	234	139	0	0	293	0	18	100	0	12,98	41	4,6	44	18
99	2014-04-08	Insp2	527	100	239	139	6	0	282	0	19	99	0	12,59	41	4,8	46	19
100	2014-04-09	Insp2	527	95	298	203	0	0	228	0	18	100	0	16,57	32	3,6	57	18
101	2014-04-10	Insp2	527	100	218	118	0	0	309	0	19	100	0	11,48	46	5,2	41	19
102	2014-04-11	Insp2	360	85	236	151	0	0	124	0	16	100	0	14,77	36	4,1	66	24
103	2014-04-12																	
104	2014-04-13																	
105	2014-04-14	Insp2	527	170	283	113	1	0	243	0	33	100	0	8,57	60	7,0	54	32
106	2014-04-15	Insp2	527	140	234	94	5	0	287	0	27	99	0	8,68	58	6,9	45	27
107	2014-04-16	Insp2	527	195	298	103	0	6	224	0	38	100	0	7,83	66	7,7	56	37
108	2014-04-17	Insp2	527	190	290	100	0	2	234	0	37	100	0	7,85	65	7,6	55	36

Cykeltid_OPE_1401 | Rakline 2014 Skift1 | Rakline 2014 Skift2 | **Inspektion 2 2014 Skift1** | Inspektion 2 2014 Skift2 | Inspektion 3 2014 Skift1 | Inspektion 3 2014 Skift2 | Fö

Figure G4: In data for the inspection copied from the manual disturbance list

Antal data-veckor	5

Stopptider per vecka (inklusive raster och möten)						
	Rakline skift 1	Rakline skift 2	INSP 2 skift 1	INSP 2 skift 2	INSP 3 skift 1	INSP 3 skift 2
HastLoss	717	653	479	514	284	294
SaknadTid	1	11	10	8	24	9
StoppFram	147	149	5	10	3	2
StoppBak	195	168	1312	1178	2003	1845
planerat stopp	0	0	0	0	0	0
Totalt	1060	981	1806	1710	2314	2150

Figure G5: Entering of number of days and calculation of disturbance per line and shift

ACL – input data for disturbance

Step	Manual activity	File calculations/comments
1)	Choose an optional time period from the manually generated disturbance list regarding the ACL (entire weeks if possible).	Public/paint/topcoat/MBCTA/RTM – RTM uppföljning
2)	Copy all columns into the model, see figure G6.	The distribution between disturbance times will be updated into the model.
3)	Use the same time period as chosen in step 1, for the automatically generated disturbance lists regarding the ACL (entire weeks).	Public/paint/engineering/arbetsmappar/Hasan/JPH
4)	Copy the columns for the first week of the time period chosen in step 1, presented in figure G7, and paste into the model. Choose "Paste Special" values when pasting.	The time for each disturbance category will be updated into the model.
5)	Repeat step 4 with the next week of the time period until all weeks have been pasted. Continue pasting in the cell to the right of last week, see figure G8.	The time for each disturbance category will be updated into the model.
4)	Enter the number of weeks from which the data is collected, step 1. The cells are highlighted in figure G9.	Simultaneously the disturbances for each shift and inspection deck will be presented in figure x.
	The time for disturbances will automatically be updated in the model.	

V.			Datum	IN Skift1	IN Skift2	UT Skift1	UT Skift2	Teknik Skift1	Teknik Skift2	Skrot 1 Skift1	2 Skift2	Mattline Skift1	Mattline Skift2	Bamse Skift1	Bamse Skift2	Mabema Skift1	Mabema Skift2	Robot Skift1	Robot Skift2
	ON	3,2	2014-01-01	170															
	TO	3,2	2014-01-02	24															
	FR	3,2	2014-01-03																
	LÖ	3,2	2014-01-04																
	SÖ	3,2	2014-01-05																
2	MÅ	3,2	2014-01-06																
	TI	3,2	2014-01-07																
	ON	3,2	2014-01-08		27										2				5
	TO	3,2	2014-01-09	75	29													9	5
	FR	3,2	2014-01-10	20	35														5
	LÖ	3,2	2014-01-11																
	SÖ	3,2	2014-01-12																
3	MÅ	3,2	2014-01-13	137											5				
	TI	3,2	2014-01-14	105											5				
	ON	3,2	2014-01-15	75	11										8				
	TO	3,2	2014-01-16																
	FR	3,2	2014-01-17																8
	LÖ	3,2	2014-01-18																
	SÖ	3,2	2014-01-19																
4	MÅ	3,2	2014-01-20	54															
	TI	3,2	2014-01-21																
	ON	3,2	2014-01-22		10														
	TO	3,2	2014-01-23	35	27														11
	FR	3,2	2014-01-24	99															
	LÖ	3,2	2014-01-25																
	SÖ	3,2	2014-01-26																
5	MÅ	3,2	2014-01-27	25	17														
	TI	3,2	2014-01-28	17															
	ON	3,2	2014-01-29												10				
	TO	3,2	2014-01-30		35													14	10
	FR	3,2	2014-01-31																6
	LÖ	3,2	2014-02-01																
	SÖ	3,2	2014-02-02																
6	MÅ	3,2	2014-02-03																
	TI	3,2	2014-02-04																
	ON	3,2	2014-02-05																
	TO	3,2	2014-02-06									6							
	FR	3,2	2014-02-07																
	LÖ	3,2	2014-02-08																
	SÖ	3,2	2014-02-09																
7	MÅ	3,2	2014-02-10	45	128										5				
	TI	3,2	2014-02-11	36															
	ON	3,2	2014-02-12		18													3	
	TO	3,2	2014-02-13		11										2				

Datum	Acl Skift1	Acl Skift2	Buy-off Skift1	Buy-off Skift2	Ugn Skift1	Ugn Skift2	Wipe-off Skift1	Wipe-off Skift2	Jokan Skift1	Jokan Skift2	CK 16 Skift1	CK 16 Skift2	HA 22 Skift1	HA 22 Skift2	B 310 Skift1	B 310 Skift2	HA 33 Skift1	HA 33 Skift2	IT Skift1	IT Skift2	Övrigt Skift1	Övrigt Skift2
2014-01-01																						
2014-01-02																						
2014-01-03																						
2014-01-04																						
2014-01-05																						
2014-01-06																						
2014-01-07																						
2014-01-08												14										
2014-01-09																					12	15
2014-01-10		15	17							3												
2014-01-11																						
2014-01-12																						
2014-01-13				5								5									6	
2014-01-14																						20
2014-01-15			4																			
2014-01-16		5																				32
2014-01-17																						
2014-01-18																						
2014-01-19																						
2014-01-20		18												12								
2014-01-21														2								2
2014-01-22																						
2014-01-23																						
2014-01-24																						
2014-01-25																						
2014-01-26																						
2014-01-27			8								6											
2014-01-28																						
2014-01-29		55	24																		13	5
2014-01-30		14												16				20				
2014-01-31			10											5								3
2014-02-01																						
2014-02-02																						
2014-02-03						35				5												
2014-02-04																						
2014-02-05																						
2014-02-06			7														17					
2014-02-07																						
2014-02-08																						
2014-02-09																						
2014-02-10			6																			15
2014-02-11		4	14																			
2014-02-12			7																		7	
2014-02-13						7																85

Figure G6: In data for the ACL copied for the manually generated disturbance list

Stopporsak	Tid (min)
JPH	3342,2
Instopp	51
HA22	46
CK16	43
Lasergravyr	31
ACL Robot	25
T093RP02	15
BO1	30
ACL	146
Wipeoff	208
BO2	103
Ospecifierad tid	-14,1

Figure G7: Automatically generated disturbance list

Stopporsak	Tid (min)	Stopporsak	Tid (min)	Stopporsak	Tid (min)	Stopporsak	Tid (min)	Stopporsak	Tid (min)	Stopporsal	Tid (min)
JPH	3326,4	JPH	3373,65	JPH	3153,15	JPH	3326,4	JPH	3364,2	JPH	3342,15
Instopp (Plan 3)	239	Instopp	26	Instopp (Plan 3)	218	Instopp	123	INSTOPP	176	Instopp	51
Omklädnad	156	HA33	80	Egenstopp fre	144	HA22	66	CK16	40	HA22	46
TV17	75	HA22	33	HA22	32	CK16	31	HA22	23	CK16	43
Lasergravyr Bamse	59	TV17	19	Buyoff	25	Eisenmanstativ ha33	15	Lasergravyr	18	Lasergravy	31
Buyoff 2	55	B310	10	HA33	20	CK04 utlastning	15	TV04 VRIDBORD	8	ACL Robot	25
HA22	52	Ugnen	2	ACL lans täppt	25	Lasergravyr	13			T093RP02	15
T096RB26	48			Jokanbanan	18	TV17	6				
RP17 Ljusbom	31			mattline	18						
CK16	7			Lasergravyr	10						
Ugnen	7			ACL Robot restart	15						
		BO1	16	ACL BOX	61			Buy off 1	61	BO1	30
		ACL	185	Wipeoff	95	ACL Boxen	84	ACL BOXEN	57	ACL	146
		Wipeoff	219			Wipeoff	190	WIPEOFF	158	Wipeoff	208
		BO2	86			BO2	128	Buy off 2	109	BO2	103
						BO1	98				
Ospecifierad tid	20,6	Ospecifierad tid	6,35	Ospecifierad tid	55,85	Ospecifierad tid	-9,4	Ospecifierad tid	7,8	Ospecifiera	-14,15

Figure G8: Pasting of all weeks from the time chosen in step 1

Antal data-veckor	6

Totala stopptider		
	Skift 1	Skift 2
Totala stopptider	353,349	358,326

Manuella stopptider		
	Skift 1	Skift 2
Instopp	1133	593
Utstopp	155	255
Teknik	0	0
Mattline	6	30
Bamse	22	69
Mabema	0	0
Robot	56	70
ACL	10	141
Buy-off	309	24
Ugn	36	42
Wipe-off	0	0
Jokan	9	17
CK16	31	71
HA22	5	98
B310	10	7
HA33	17	135
IT	0	0
Övrigt	189	464
Totalt	1988	2016
Andel av stopp	0,4965	0,5035

Figure G9: Entering of number of weeks and calculation of disturbances

Instructions for validating the model versus actual production outcome

Step	Manual activity	File calculations/comments
1)	Chosen a number of weeks from which the top coat paint shop has been operating according to the production rate entered into the model.	
2)	Calculate the average production outcome per day and shift for the weeks chosen from step 1 and insert into “verkligt utfall”, highlighted in figure G10.	It is important to use an average production outcome per day as the production outcome for specific days can vary significantly depending on variations in disturbances.
3)	The model provides the user with the difference between the production targets and the actual outcome, “Difference” in figure G10.	

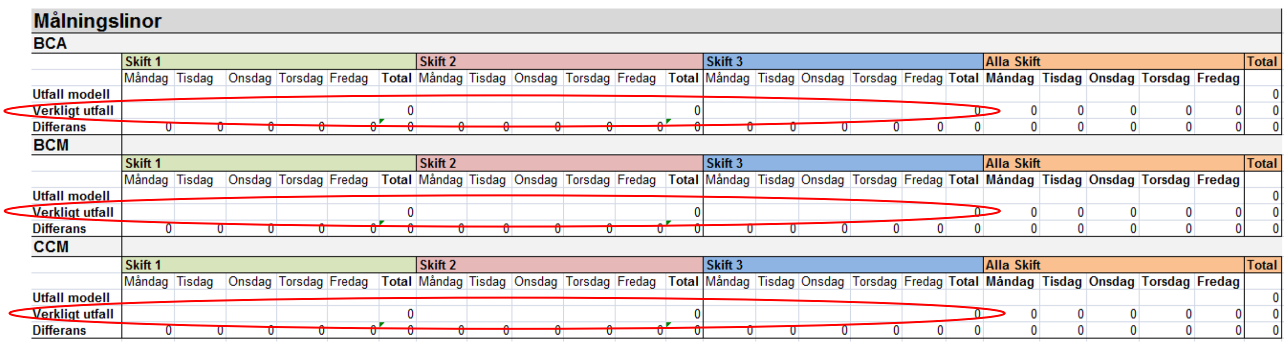


Figure G10: Inserting the average production outcome per line, shift and day