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Next generation rear axle assembly
A case study of Scania CV AB

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Preface

This Master Thesis concludes a five-year master's degree in Industrial Engineering and Mechanical Engineering at Lund University, at the Faculty of Engineering (LTH). The study was conducted during the spring of 2021 in collaboration with the Swedish heavy truck and bus manufacturer Scania CV AB.

Initially we would like to thank our supervisor at Lund University, Bertil Nilsson, for the continuous feedback, tips, guidance and support. Bertil went above and beyond his commitments to be made available at a moment's notice throughout the study. Thank you for your engagement Bertil, it has been a pleasure to make your acquaintance and work with you.

Furthermore, we would like to express our gratitude to all employees at Scania who contributed to this study in one way or another. A common thread while communicating with and requesting information from Scania employees was receiving enthusiastic responses filled with useful insights. We would also like to take the opportunity to acknowledge our supervisor and contact person at Scania, Zebastian Hallsten, for continuously contributing with smart tips and guiding us in the right direction. Thank you for your commitment and assistance Zebastian, we have enjoyed working with you.

Stockholm, June 2021
Richard Andrae & William Bergmark

Abstract

Title:	Next generation rear axle assembly line: A case study at Scania
Authors:	Richard Andrae & William Bergmark
Background:	Following the development of industry 4.0, new production technologies enabling more efficient assembly processes constantly evolve. Scania is a leading manufacturer of trucks in Sweden, offering a wide product portfolio and the possibility for their customers to customize their orders. A large portion of the production of rear axles for Scania is today made at four different assembly lines (also called “Zones”) at Södertälje. The assembly line at Zone 1 is approaching the end of its economic lifespan. Simultaneously, its current design complicates the introduction of new products, which may complicate the transition to producing trucks with electrical power trains.
Purpose:	The study aims to evaluate how Scania can design a new assembly line for rear axles at Zone 1 which improves its production flexibility, the production efficiency and ergonomics. The study consists of three research questions:
Research Question 1 (RQ1):	How can Scania meet the present and future challenges at Zone 1 of the rear axle assembly line?
Research Question 2 (RQ2):	How can a new assembly line be designed to increase the production flexibility, production efficiency and ergonomics of the rear axle production at Scania - and at what cost?
Research Question 3 (RQ3):	How can the method for evaluating this challenge be applied to other assembly line projects?
Methodology:	The study is based upon a case-study built upon mainly qualitative data from interviews and observations and quantitative production data. In the beginning of the study an exploratory research design was applied, which was later succeeded by a problem-solving research design. The overall method can be divided into three steps; The theoretical background/literature study, Empirical Research at Scania and Concept generation and evaluation.
Conclusions:	The results of this study concludes that the current assembly line has multiple imperfect solutions. Through automating tasks that are currently performed manually Scania can improve the ergonomic grading of the assembly line, reduce the labour costs and free up both space and time to introduce new products. Furthermore, a method that is applicable for designing new or renovating old assembly lines is developed and presented.
Keywords:	Assembly line, Rear Axle, Automation, Industry 4.0, Ergonomics, Takt time

Sammanfattning

Titel:	Nästa generations bakaxelmontering: En fallstudie hos Scania
Författare:	Richard Andrae & William Bergmark
Bakgrund:	Efter utvecklingen av industri 4.0 utvecklas ständigt nya produktionsteknologier som möjliggör effektivare monteringsprocesser. Scania är en ledande tillverkare av lastbilar i Sverige och erbjuder en bred produktportfölj med möjligheten för sina kunder att skräddarsy sina beställningar. En stor del Scanias bakaxelmontering sker idag vid fyra olika monteringslinjer (även kallade ”Zoner”) i Södertälje. Monteringslinan vid Zon 1 närmar sig slutet av sin ekonomiska livslängd. Samtidigt komplicerar dess nuvarande design införandet av nya produkter vilket kan komplicera övergången till tillverkning av lastbilar med elektriska drivlinor.
Syfte:	Studien syftar till att utvärdera hur Scania kan utforma en ny monteringslinje för bakaxlar vid Zon 1 som förbättrar produktionsflexibiliteten, produktionseffektiviteten och ergonomin. Studien består av tre forskningsfrågor:
Forskningsfråga 1 (RQ1):	Hur kan Scania möta de nuvarande och framtida utmaningarna för Zon 1 på bakaxelmonteringslinjen?
Forskningsfråga 2 (RQ2):	Hur kan en ny monteringslinje utformas för att öka produktionsflexibiliteten, produktionseffektiviteten och ergonomin för bakaxelproduktionen i Scania - och till vilken kostnad?
Forskningsfråga 3 (RQ3):	Hur kan metoden för att utvärdera denna utmaning tillämpas på andra projekt för design eller renovering av monteringslinor?
Metod:	Studien bygger på en fallstudie som huvudsakligen baseras på kvalitativa data från intervjuer och observationer samt kvantitativa data från Scania. I början av studien tillämpades en undersökande forskningsdesign, som senare ersattes med en problemlösande forskningsdesign. Den övergripande metoden kan delas in i tre steg; Teoretisk bakgrund / litteraturstudie, Empirisk forskning vid Scania och konceptgenerering och utvärdering.
Slutsatser:	Resultaten av denna studie visar att den nuvarande monteringslinjen har flera suboptimala lösningar. Genom automatisering av arbetsuppgifter som för närvarande utförs manuellt kan Scania förbättra den ergonomiska graderingen av monteringslinan, minska arbetskraftskostnaderna och frigöra både utrymme och tid för att introducera nya produkter. Dessutom utvecklas och presenteras en metod som är användbar för att utforma nya och renovera gamla monteringslinjer.
Nyckelord:	Monteringslinje, Bakaxel, Automation, Industri 4.0, AGV, Ergonomi, Takttid

List of abbreviations

- AGV = Automated Guided Vehicles
- DfA = Design for Assembly
- HRC = Human Robot Collaboration
- IIoT = Industrial Internet of Things
- MES = Manufacturing Execution System
- MTO = Make-to-order
- RFI = Request for Information
- RQ = Research Question
- SES = Scania Ergonomic Standards
- SPS = Scania Production Systems

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1. Introduction

In the first chapter the background and context of the problems that Scania faces at Zone 1 assembly line is outlined. This is followed by the purpose, as well as the research questions, delimitations and objectives of the project.

1.1 Background & Context

1.1.1 Context

In a world where the pace of technology development is constantly accelerating it becomes increasingly difficult for manufacturing to stay competitive and up to date with current production technologies. Companies in the automotive industries face multiple challenges such as keeping up with the emerging technologies of Industry 4.0, as well as developing high quality electric vehicles that meet their customers' rapidly increasing demands and expectations.

Industry 4.0 covers a wide variety of concepts with focus on interconnectivity, network communication, automation, digitalization, mechanization and miniaturization (Lasi et al. 2014). When implemented successfully, the emerging technologies of Industry 4.0 have the potential to capture and create value in areas such as production efficiency, productivity, ergonomics and flexibility.

Scania CV AB has for long been a market leader in the truck manufacturing industry, and wants to keep their strong market station as the trend shifts towards a new industrial revolution.

The rear axles are essential parts of any truck or bus, since the axles are responsible for delivering power to the driving wheels. Heavy trucks and buses have several rear axles, both of a driven and supporting type. It is therefore in Scania's interest to examine how their rear axles assembly line can benefit from emerging technologies.

1.1.2 Truck manufacturing in a historical context

In order to generate a complex concept such as a new rear axle assembly line for a truck manufacturer, it is necessary to look into several different fields of technology. When designing an assembly line to meet the future demands of designing & manufacturing of trucks, a large emphasis will be placed on the current state of the art manufacturing technologies and what the trucks can look like in the future. But examining the developments in the past can also help generate valuable insights into the future (Akamatsu et al., 2013)

In the 1950's Scania often incorrectly dimensioned components in their trucks. Over-dimensioning would lead to unnecessarily high production costs, while under-dimensioning could lead to not only dissatisfied customers but also serious truck failures causing accidents. Up until then, Scania had dimensioned components based on the calculations of each component's strength under static loads. This meant that no reference was made to the truck's actual use and the dynamic loads they would carry over time.

For example, the prevailing view up until the 1950's was to have one axle gear for each different engine size, regardless of application. When reassessing dynamic loads instead of static loads, Scania's technical director Sverker Sjöström and his team realized that it was the vehicle weight and the topography of the transport routes, rather than the engine size, that were the dimensioning factor.

These insights paired together with increasingly complex customer demands resulted in a fully modularized truck range. With a limited number of main components, but allowing the customer to choose components based on the specific application of the truck, it was possible to create an almost unlimited number of truck variants. Allowing individual customization of every individual truck that Scania sells marks a paradigm shift in how the company went from producing trucks for customers before the order was placed, to instead begin production after the order has been placed. This shift has changed not only how trucks are sold, but also how inventory is managed, monitored and what levels of flexibility that assembly lines within Scania need to be able to handle. The modularization is an example of a shift in manufacturing that first was deemed impossible to succeed with according to competitors.

1.1.3 Scania in brief

Scania CV AB (Scania), founded in 1891, is a world leading provider of transport solutions in more than 100 countries. The company annually produces around 100 000 heavy trucks and buses and it employs more than 50 000 employees. Fully owned by the German company Traton Group, Scania produces in Europe as well as in Latin America and Asia. Research and development is mainly concentrated in Sweden, which also hosts the largest production facility in Södertälje, Sweden (Scania, 2021a).

1.1.4 The production philosophy of Scania

Scania applies a make-to-order (MTO) principle, which essentially means that the company does not start manufacturing a truck before it has been ordered by the customer. This is a part of Scania's strategy of offering a very high degree of customer specific configurations for each truck in their product offering. After the truck has been ordered, it will be produced in accordance with an internal production strategy called the *Scania Production System* (SPS).

The SPS can in short be summarized as an overarching strategy, built on four principles developed in the 1990's, with the aim to allow for high customer product customization while achieving increased profitability, growth and competitiveness. The four principles that the SPS are built on are standardising work methods, individual accountability, need-driven production and continuous improvements. (Scania, 2021b).

1.1.5 Modularisation & Design for Assembly

The mechanical assembly and subassembly of decomposable parts is a cornerstone process in manufacturing. Through dividing products into smaller components using modularity, and designing these with ease of assembly in mind, the assembly time can be lowered. Simultaneously, increasing product variety affects multiple domains such as production and assembly efficiency and quality variation. The higher the number of product variants is, the more it may impact the performance of a manufacturing system's assembly line (Elmaraghy, 2009).

Scania uses a modular approach to assembly and production in order to lower the production time as well as providing the opportunity to produce and sell highly customized trucks to their customers. Due to this business decision the assembly process of a Scania truck is divided into numerous decomposable sub processes. For instance, the assembly of gearboxes, rear axles, engines and chassis are all located at different premises, and are in their own turn decomposed into smaller Zones and work stations.

In order to optimize the assembly process Scania applies a *Design for Assembly* (DfA) in their product design. The DfA product design considers ease of assembly and the variety of ingoing parts in components in order to reduce assembly time and costs (Boothroyd, 1987).
However, even though Scania pursues a DfA mindset and a modular assembly line, the high variety of their products in combination with their MTO-system poses a big challenge for the flexibility and productivity of their assembly lines.

1.1.6 Rear axles in trucks

The rear axle is the final component of most internal combustion engine (ICE) driven powertrains, onto which the rear wheels are attached. For most trucks, the rear axle is also the driving axle which means it converts torque from the universal joint and the engine towards the wheels. Traditionally the optimal configuration for an ICE powertrain places the engine at the front and uses a cardan shaft to transfer power and torque from the engine to a central gear which is mounted on a driven rear axle. The central gear then converts the power and torque to kinetic energy which spins the wheels. However, rear axles come in many forms and shapes and trucks that carry heavy loads sometimes include additional non-driven rear axles as well.

1.2 Problem statement

The current assembly line for Zone 1 of the rear axles division was introduced in 2008. Over time the assembly line has grown old. Scania projects that service and repairs of the assembly line will be costlier than investing in a new one within a few years.

Moreover, due to the continuous introduction of new products, components and rear axle variants in the assembly line, over time the flexibility has decreased. Currently, Zone 1 of the rear axle assembly line is heavily customized for the present product offering, making the introduction of new rear axle products a challenge. Using the words of a Scania production engineer, they have "*moved themselves into a corner*" in terms of production flexibility.

Meanwhile, following the trend of electrification in the automobile sector, Scania plans to roll out multiple new powertrains in the coming years to satisfy growing market demand. Since Zone 1 of the rear axle assembly line is tailored for the present powertrain solutions, this poses a challenge for the introduction of new products in the assembly line.

Furthermore, representatives at Scania communicated that it is common for employees who have worked in the same business units for a long time to have very strong belief in current Scania practices, working methods and routines. This may prevent some problems being approached from new angles, and certain problems to be observed from new perspectives. Even though Scania is a very successful company with many years of experience in the field there is often room for improvement, however large or small.

1.3 Purpose of the project

The purpose of this project is to develop, describe and evaluate possible solutions for the future of the rear axle assembly line in *Zone 1* at Scania. Since the current assembly line was introduced over a decade ago Scania have discovered an opportunity to realize the benefits of modern technologies for improvements in the line. The proposed solutions should focus on improvements in the three following areas:

1. **Production flexibility:** measuring the capacity to produce a wide variety of rear axle variations as well as adjusting the production volume.
2. **Production efficiency:** measuring the number of required workstations, workers, workspace and the cost per produced unit and the cost and pay-back time for the introduction of new tools, robots and/or workstations.
3. **Ergonomics:** measuring the safety as well as psychological and physical stress of labourers.

Furthermore, it is of interest of Scania to evaluate and develop their working method for renovating current assembly lines as well as designing new ones.

1.4 Key research questions

The project has three main questions:

- **Research Question 1 (RQ1)**: How can Scania meet the present and future challenges at Zone 1 of the rear axle assembly line?
- **Research Question 2 (RQ2)**: How can a new assembly line be designed to increase the production flexibility, production efficiency and ergonomics of the rear axle production at Scania - and at what cost?
- **Research Question 3 (RQ3)**: How can the method for evaluating this challenge be applied to other assembly line projects?

1.5 Delimitations

The project has several delimitations due to factors such as a calendar constraint, uncertainty and a lack of access to information required for objective decision making. The following limitations are those that were agreed upon:

- Due to lack of time and resources, only automated solutions were considered. No solutions that required new manual tools and/or new ways of working were considered.
- Due to the absence of a monetary valuation of ergonomic and flexibility improvements at Scania today, no mutual valuation of the three variables (flexibility, efficiency & ergonomy) was made.
- Only solutions for Zone 1 of the rear axle assembly line will be investigated. Other Zones of the line are outside of the scope.
- In order to not disrupt the current or future flow of the assembly process, the takt time is not allowed to be higher than 78 seconds.
- The project will mainly focus on assembly solutions for rear axle models that are currently in production in Zone 1.
- No solutions that require product modifications will be considered.
- The project will not go in depth regarding how adjacent areas such as logistics and Zone 2 - 4 will function with implemented solutions.
- The assembly line needs to be compatible with the space constraints for Zone 1 given by Scania.
- The intended timeline for the introduction of a new assembly line is in a couple of years.

1.6 Project objective

The main objective of this project is to present a feasible solution for an improved future rear axle assembly line at Zone 1. The solution shall describe which tasks that should be completed at each station, and how these tasks could be solved technically. The solution shall provide an overview of the assembly line, what improvements that could be made and an estimate of the cost of building the line.

1.7 How to read this report

Chapter 1	• The first chapter introduces the reader to the project. A brief background, a problem statement, the key resarch questions, important delimitations and the purpose of the project are presented.
Chapter 2	• The second chapter presents a brief introduction to research strategy and design in general, as well as the specific research method used in the project.
Chapter 3	• The third chapter contains the literature study of the project. Twelve subject areas, identified as relevant to the project, related to manufacturing, assembly and Industry 4.0 are selected and presented on a very high-level.
Chapter 4	• The fourth chapter contains the empirical knowledge gained and employed in this project. It is one of the largest chapters covering different areas relevant to the assembly line design.
Chapter 5	•The fifth chapter presents the results of this project. The layout and dimensions for the assembly line is presented followed by subchapters covering the efficiency, ergonomy and flexibility of the new line together with the estimated investments needed and cost savings.
Chapter 6	• The sixth chapter covers the analysis of the results. The results are commented and discussed, a risk assessment for the proposed assembly line is presented and the methodology used in this project is evaluated.
Chapter 7	• The seventh chapter of the report contains the conclusions, in the form of condensed answers to each of the three key research questions introduced in chapter 1. Future considerations important for the rear axle assembly line at Scania are also presented.
Chapter 8	• In the eighth chapter the contribution of the study, a method for designing assembly lines, is presented. An overview of the method is outlined followed by detailed explanations of each ingoing step.
Appendix	• In the appendix, three areas of the repor are extended. These areas are an in-depth analysis of the assembly stations used today, of the proposed new assembly stations and finally, an interview guide used with Scania employees.

2. Methodology

In the second chapter the methodology of the project is presented. First, the research strategy and the research design is presented at a general level. This is followed by the research methodology specific for this research project.

2.1 Research strategy and design

2.1.1 Research strategy - qualitative & quantitative analysis

Research strategies and methodologies are generally divided into two scientific groups, the scientific quantitative research and the constructive qualitative research.

Quantitative research is centred around numerical data and has a deductive relation between theory and research. In quantitative research methods data is gathered, quantified and analysed in order to test a hypothesis. The epistemological orientation of quantitative research is that of natural sciences and positivism, and the ontological orientation is that of objectivism (Bell & Bryman, 2011).
One advantage of quantitative research is the possibility to isolate certain variables and study cause through for instance correlation. Another advantage is that quantified data can easily be presented and interpreted by others through tables and diagrams. However, there are many critics of the quantitative research method who argue that a natural science method is insufficient to study and explain the social world (Bell & Bryman, 2011).

Qualitative research on the other hand is centred around words rather than numbers. It is a research strategy with an inductive view on the relation between theory and science, where theory is generated through research (Bell & Bryman, 2011).

The epistemological orientation of qualitative research is interpretivist and argues that the social world is understood through the interpretation of its participants. Furthermore, the ontological orientation is constructionist, implying that social properties are derived from the interactions of individuals and that knowledge is created through interaction (Bell & Bryman, 2011).

The advantage of a qualitative method is that it can gain more in depth understanding of different views, opinions and perspectives through unstructured interviews and/or observations. However, there are also disadvantages with qualitative methods. For instance, it is based upon the experience of the researcher which may cause problems such as bias. Furthermore, the data is oftentimes harder to present than quantified data, and the results can be hard to replicate.

This being said, even though there are differences between the two research models they should not be exaggerated. Many researchers employ both a qualitative and a quantitative research method, and sometimes the line between what constitutes which is not clear (Bell & Bryman, 2011).

The development of a new rear axle assembly line at Scania requires observations and interpretations of the current situation through site visits as well as unstructured and semi-structured interviews. This will cause our subjective understanding and theory to be induced from empirical data. Furthermore, qualitative data will be obtained when possible, and quantitative assessments of qualitative data will be made in order to rank and evaluate different solutions.

2.1.2 Research design

The research design refers to the general strategy being used in order to conduct a research study. In other words, a research design is not a detailed action plan but rather an overall framework that guides the researcher from objectives to insights and conclusions (Höst, Regnell & Runesson 2006).

Depending on the character and goals of the research study, the choice of research design often differs. For engineering's master's thesis studies there are often four generic types of research designs (Robson 2002):

1. *A descriptive research design* has the purpose of describing a phenomenon. It focuses on the how and what rather than the why.
2. *An exploratory research design* aims to study a phenomenon in depth in order to explain how it works. In contrast to a descriptive research design an exploratory design goes beyond describing the key functions and characteristics in order to gain deep insight into the research problem.
3. *Explanatory research designs* investigate causation and correlation in order to explain the cause for a phenomenon.
4. *Problem solving research design* focuses on finding a solution to an already identified problem.

A research project is not strictly prohibited to use a single research design, and it is common that multiple designs are used for the same project. For instance, an initial descriptive or exploratory study may identify a problem which a problem-solving research study later focuses on and solves (Höst, Regnell & Runesson 2006).

After choosing one or numerous research designs it is time to decide upon a research method in order to implement the strategy of the research design. One can utilize different tools or methods for gathering data and insights. Some frequently occurring data gathering tools are interviews, questionnaires, observations, and document analysis (Höst, Regnell & Runesson 2006).
Just like the case for research designs the choice of research method differs depending on the scope and nature of the research study. Some of the most common research methods are Surveys, Case studies, Action research and Experiments.

For this project an initial exploratory research design with a case study method will be implemented in order to gain deeper insight of Zone 1 of the rear axle assembly line at Scania. After the initial phase a problem-solving research design will take place in order to produce a new assembly line solution.

2.2 Research method

For this research project the research method is centred around utilizing the existing knowledge and expertise within Scania. The data collection is therefore mainly centred around site visits, expert interviews, observations, internal online training and knowledge databases acquired at Scania premises or from Scania employees.

There are several reasons why internal Scania sources have been chosen ahead of external sources. The main reason is the feasibility of each technology considered. There are very strict quality standards and security requirements on technology implemented in Scania's operations. The rear axle assembly is a part of one of the most business critical production lines within all of Scania - the main production line of trucks in Södertälje. Given the time constraints, where Scania wants to have a suggestion on a new assembly line that can be implemented in 3-5 years' time, some technologies will not be considered mature enough within Scania to be considered for this assembly line. Some technologies or stages of them, for example some levels of Human Robot Collaboration will not have been tested or examined thoroughly enough by Scania to be deemed relevant for the rear axle assembly line within this timeline.

Usually, Scania Smart Factory Lab or the R&D-department test new technologies before they are implemented in assembly lines. This is done to ensure the assembly line technology is compatible with the flexibility of the Scania Production System (SPS). Therefore, the research method includes the restrictions that mainly solutions which include already implemented technologies will be considered.

2.2.1 Theoretical platform & literature study

The first step of this research project involved getting acquainted with smart manufacturing and industry 4.0 concepts and production technologies. This was conducted through a literature study, where secondary data from existing research was gathered. The main purpose of the literature review was to get a general introduction to which assembly line technologies exist in production and planning today, as well as their benefits and drawbacks.

In order to find subject areas of interest to the study multiple Scania employees, both working in production and in R&D and/or Scania Smart Factory Lab, were asked to suggest technologies of interest. Furthermore, a mapping of which industry 4.0 technologies were mature and in-production at Scania today was made.

When searching for relevant literature mainly the LUBsearch database was used. The keywords that were used were mainly the technology in question + "assembly line" or "manufacturing". For instance, when searching for relevant literature within HRC, one search that was used was "HRC assembly line".

A considerable portion of the sources used in this paper were not the original paper that was found through the LUBsearch engine, but rather one of the sources the article cited.

2.2.2 Empirical research at Scania

In order to supplement the elemental information and insights gathered from the literature study a more in-depth analysis of various production technologies was conducted at Scania premises and using Scania resources.

2.2.2.1 Job shadowing on the assembly line

With the purpose of achieving in-depth understanding of the current assembly line solution, as well as which tasks are required for the current rear axle models a job shadowing was conducted at the current assembly line. During the job shadowing an operator was followed and observed while completing tasks for different rear axle variants at every workstation in Zone 1.

2.2.2.2 Utilizing internal Scania resources

Various internal documents and online courses were reviewed in order to learn from the current insights and competence present at Scania. The internal documents that were most frequently used were:

- E-learning / online courses for various subject areas such as AGV:s, HRC and assembly technology.
- Documents which were the basis for previous assembly line decision-making processes.
- Product sheets for different assembly line tools and robots.
- Production and safety data for implemented assembly line technologies.
- Quotes and operating costs for machines and tools.
- Scania PUS: a tool where all stops on the assembly line are gathered.

2.2.2.3 Conducting interviews

Interviews are a common method used for data collection and for receiving feedback and opinions on proposed solutions. Depending on the purpose of the interview the selection process for interviews may differ. Furthermore, interviews can be both open, semi-structured or structured. In order to record what has been said the interview is usually transcribed either via text or recording.
When conducting an interview there are generally four phases:

1. Context: the purpose and expectations of the interview is explained. The interviewee is told why he/she has been chosen and is asked for consent regarding how data from the interview is handled and presented.
2. Introduction: initial relevant neutral questions are asked regarding for instance experience in the subject area, education, line of work
3. Main questions: the more specific interview questions are asked in a logical order. By the end more open questions can be asked in order to create a good atmosphere and enable future collaboration
4. Summary: the interview is summarised, and the interviewee is allowed to make clarifications and comments. The conditions for how the interview may be referenced is also agreed upon.

(Höst, Regnell & Runesson 2006)

In order to obtain in-depth knowledge and expert opinions regarding various technologies and assembly line solutions, multiple Scania experts were interviewed. Interviewees were mainly found through the Scania intranet. If an employee was attributed expertise in a topic area of interest him/her was contacted. Furthermore, a snowball sampling method was used while conducting interviews.

The interviews were conducted through a standardised interview guide (*Appendix C: Interview guide - employees at Scania*), with certain customisation for the technology area. The interviews were based upon a non-randomised assessment selection and conducted through a semi-structured structure. All interviews were transcribed via text through notes.
The following roles were at some point interviewed or consulted regarding an area where they possessed topical expertise, the names are anonymized due to secrecy policy at Scania:

- **Sebastian** - *Industrial Engineer DTTAE* - Thesis supervisor, first point of contact.
- **Adam** - *Manager DTTAE* - regular check-ups and guidance.
- **Hannah** - Industrial Engineer *DTTAE* - Teams meeting regarding lifting tools.
- **Alexander** - *TEIS* - Teams meeting regarding MES-systems.
- **Jonatan** - *Prepare Technician DTTAM* - Teams meeting regarding MES-systems.
- **Niklas** - *Industrial Engineer DTTAE* - round tour of painting department.
- **Niclas** - *Logistics Developer DTLTD* - meetings and round tour at logistics.
- **Klara** - *Industrial Engineer DTTGE* - round tour at gearbox assembly.
- **Lars** - *Project Engineer - TEED* - Scania Smart Factory Lab site visits.
- **Petter** - *Global inhouse logistics development* - Teams meeting about AGV:s.
- **Lennart** - *Senior Engineering Advisor TEED* - Teams meeting about AGV:s.
- **Olof** - *Senior Engineer TEEC* - Teams meetings about carrier/conveyor systems.
- **Eric** - *Project Leader DTTGP* - Teams meeting about HRC at Scania.
- **Anna** - *Sourcing Manager* - First point of contact at the purchasing department.
- **Fredric** - *Industrial Engineering Expert - Automation* - Teams meetings about automation, HRC and evaluation feasibility of proposed solutions.
- **Johannes** - *Senior Project Engineer - Assembly systems* - Teams meetings about automation, conveyor system and evaluating feasibility of proposed solutions.

2.2.3 Concept generation and evaluation

With the aim of creating and evaluating new assembly line solutions a linear process was used for generating and evaluating different assembly line technologies. Below is a summary of the process.

2.2.3.1 Strategy for identification of improvement areas

The strategy pursued to identify and evaluate different improvement areas, and at the end propose a new solution, was conducted through looking at the current assembly line through three different perspectives:

I. **Ergonomics**: is there any way the already identified red or yellow ergonomics classifications could be solved through automating or changing the way of working here?
II. **Automation compatibility**: is the complexity for the task at hand low enough to enable automation and reduce the number of required operators?
III. **Utilization of takt time**: Are there a lot of no-jobs at the station, or is only a small portion of the takt time required to perform the task at the station? If the answer is yes to those questions - can this task be combined with another workstation to reduce the number of operators?

2.2.3.2 Generate possible solutions

After identifying which stations had room for improvement, possible solutions were generated and considered. The main solution generator that was used was the possibility of automating the task at hand. When considering automated workstation two types of solutions were considered:

a) **Replace the current workstation with an automated station**: this means the old manual workstation is replaced by a new automated station located at the same location as the old manual station.
b) **Move and combine the tasks of the current station into another station**: this means the old manual station is removed and replaced by a new station which is located at either an existing automated workstation (station 6) or at another suggested automated station.

2.2.3.3 Present generated solution to industry experts

In order to get an estimation of which automated workstations are feasible to implement, industry experts at Scania were consulted. The consultation was made over Microsoft Teams, where the experts were presented with the current solution as well as an oral and visual explanation of its proposed replacement. The following industry experts were consulted:

- Fredric - Industrial Engineering Expert - Automation TEEC
- Johannes - Senior Project Engineer M.Sc. Assembly systems

2.2.3.4 Construct a new balanced assembly line

After settling on which proposed solutions are feasible a new assembly line needs to be designed. In the new assembly line, the new tasks will need to be combined with the old tasks that have not been replaced. Furthermore, it is required to specify where each station will be placed, what space it needs, what will be performed there and how much time each task requires.

In an assembly line, the takt time is decided by the weakest link. Therefore, in order to minimize the takt time it is desirable to create a line where each station requires roughly the same amount of time to complete, and also where each station utilizes a large portion of the available takt time. Due to the fact that Scania produces a wide range of rear axle variants with low standardization line balancing is a complex task. A single workstation at Scania can sometimes have more than a hundred different types of instructions depending on which variant is presented.

Zone 1 at Scania currently produces two parent-variants of rear axles, axles with drum brakes and axles with disc brakes. Even though there are variations within rear axles with drum and disc brakes they are very similar. Therefore, each station needs to be balanced for both disc- and drum brake variants. At each station, it is always the most time-consuming variant within each parent group that dictates the takt. At the same time, different variants within the same parent group will require the most time at the different stations.

The construction and balancing of the line were divided into four parts:

1. **Compile a list of the required time to finish each task**
   In order to balance an assembly line, it is detrimental to know how much time each task requires to finish. Therefore, it is required to estimate what time is required for current manual tasks, new manual tasks to be added and the time requirement for new robot cells.

2. **Create a sequencing chart and map the possible chronological order of tasks**
   In an assembly line the order in which certain tasks are carried out is important. Therefore, it is important to map the chronology of which each task can be performed, in relation to other tasks. For instance, tasks concerning processing of the central gear unit cannot be performed until the central gear unit has been fitted in the rear axle bridge.

3. **Determine the spatial constraints and measurements for each station**
   At Scania, space within the factory is scarce. Expansion of a production unit requires either expansion of the factory, or takes place at the expense of other production lines. Therefore, it is desirable to design the assembly line to be as small as possible.

   When creating the layout for the assembly line there are various considerations to be made. This includes the form of the line, the flow of material, which stations to include and their size, placement of material storage and space for workers to move between stations.

   Moreover, it is important to consider external business units that collaborate with Zone 1 when designing the assembly line. For Zone 1 at Scania, compatibility with the logistics department can significantly reduce their costs. Therefore, solutions which can facilitate their delivery of material are highly desirable.

4. **Distribute tasks between the different workstations**
   The final task is to distribute the new and old work tasks at the various workstations in a way that provides the lowest possible takt time, while at the same time being spatially and sequentially feasible.

2.2.3.5 Price and feasibility estimation from suppliers through sending out Requests for Price Information-documents (RFI)

In order to further estimate the feasibility of the proposed automated robot cells request for price information was sent out to multiple suppliers. Before the RFIs were sent out, the Scania purchasing department was consulted.
When sending out the RFIs the suppliers were all given the requirements of the engineering project:

- A description of the current solution and a textual as well as visual explanation of the new proposed solution
- Information regarding the spatial constraints of the new station
- A layout of the entire planned assembly line
- Other relevant information

2.2.3.6 Internal sales: summarize the designed solution and present it to Scania representatives

The final part of the method is internal sales. In order to transfer as much knowledge and insights as possible to Scania the final solution is presented in two ways:

1. Through a report covering all details.
2. Through an online presentation cover the most important sections.

The point of the presentations is to maximize the knowledge transfer and to have the opportunity to answer potential questions regarding the proposed solution.

3. Literature review

The third chapter contains the literature review of twelve focus areas within industry and assembly technology identified as especially relevant to the project.

3.1 Industry 4.0

The fourth industrial revolution, or Industry 4.0, is a term coined to describe the ongoing automation of traditional manufacturing and industrial processes. To put in a historical perspective, the first industrial revolution is widely considered to have taken place between 1760 to 1840, characterized by the transition from hand production to machine production fuelled by steam power. The second industrial revolution is considered to have taken place between 1870 and 1914 and is characterized by the development of railroad and telegraph networks. The third industrial revolution is considered to have taken place between 1950 to 2000 and is characterized by a shift from mechanical and analogue technology to electrical and digital technology.

The fourth industrial revolution and Industry 4.0 was first publicly introduced in 2011 at the Hannover Fair in Germany as part of a German strategic government project. The phrase was spread to a wider audience in 2015 when Klaus Schwab of the World Economic Forum published his article "The Fourth Industrial Revolution - What It Means and How to Respond" in the magazine Foreign Affairs. While there is debate whether a fourth industrial revolution really is taking place in the automotive industry right now or not, there seems to be more consensus on which technologies are included in the industry 4.0 (Pardi, 2019). While the specifics of the technologies included in Industry 4.0 are rapidly changing and expanded, there are a few themes that are relevant to the automotive industry which will be listed in this chapter.

3.2 Industrial robots

Industrial robots are defined as "*automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications*" (ISO 2012). In manufacturing, industrial robots are most often used to complete standardized tasks such as painting, assembly, tightening screws, heavy lifting, picking and rotating. Today there are approximately more than 2,7 million operational industrial robots worldwide, and the demand is continuously increasing (IFR 2020).

There are many advantages with industrial robots in contrast to manual labour. For physically demanding tasks a robot can relieve labourers of physical stress and risk of injuries, while simultaneously often lowering employment costs. Fully autonomous robots also have the possibility to work around the clock which can compensate for cases where it is less efficient than a manual labourer.

Industrial robots are not a new technology emerging from industry 4.0 technologies, however there are varying degrees of autonomy within manufacturing robots. The least advanced autonomous industrial robots are hard programmed to repetitively execute standardized tasks with high accuracy. The actions and movement of the robot are often pre-determined from a set of code. For instance, Scania uses this method for some robots in their paint department. This solution is efficient when the product mix is standardized, however the flexibility is lower and when faced with new or uncertain situations, malfunctions or accidents can occur.

More advanced industrial robots have sensor-systems in order to increase their flexibility and determine their movements. These are often called vision systems, which identify objects in the near surroundings of the robot in order to guide and instruct the robot which tasks to perform. Guidance systems are helpful when the industrial robot needs to be able to complete a wider set of tasks. For instance, Scania uses autonomous robots with vision systems based on image recognition in multiple areas of their assembly lines, since they have a wide product mix and with multiple variations. The challenge with these robots is that whenever the robot fails to recognize a product it causes a halt in production.

The most advanced autonomous industrial robots are programmed to identify and analyse unknown objects instead of recognizing known ones. For instance, they may render 3D models of nearby surroundings in order to calculate the most efficient way of gripping the surface.

3.3 Industrial Internet of Things

Industrial Internet of Things (IIoT) is a concept that can be used to explain interconnected machinery, tools, robots, devices and computers. All of these can be connected to the internet without the need of a designated personal computer. Connecting industrial systems, using sensors and enabling both transmission and reception of information between them directly, can make automation smarter. Smarter automation can for example provide value to a manufacturer by enabling more efficient operations (Zhong et al., 2017).

The opportunities for improvements using IIoT are many and the entry costs are lowered with the cost of sensors continuously reducing. But the pitfalls are many and IIoT is still a challenging platform to implement with few “off-the shelf solutions” available. One of the greatest difficulties lies in implementing a virtual and physical system in parallel (Cronin et al., 2019).

3.4 Human Robot Collaboration

A relatively new concept that has risen in popularity in recent years is Human Robot Collaboration (HRC). In contrast to fully automated or manual labour, HRC is a hybrid solution where both humans and robots work simultaneously in a collaborative environment.

Traditional manual labour in assembly lines is oftentimes repetitive, and in some cases include poor ergonomic design. When labourers perform ergonomically demanding tasks such as heavy lifting, their long-term work productivity decreases due to physical stress. This in turn leads to costs such as productivity losses and sick leave (Krüger, Lien & Verl, 2009). This can make some important assembly tasks unfit to be carried out by humans. If the lifting is complex to do because of how the object is shaped, it can be too difficult to replace the human with a robot. This leaves the only option left to keep human operators performing poorly ergonomic lifting.

Automated robot solutions generally lack flexibility in operations while they still require substantial investment costs with long payback time. The most advanced robots, which can carry out the more complex tasks with higher degrees of flexibility, are more susceptible to failures, which causes downtime in the assembly line (Bley et al., 2004).

The trade-offs of both a fully manual and a fully automated assembly solution has led to the development of HRC. The aim of HRC is to have the flexibility, skilfulness and cognitive ability of a human combined with the strength, endurance and precision of a robot. With the right design, this can create a more efficient assembly process with decreased cost and better ergonomic conditions (Tsarouchi, Makris & Chryssolouris 2016).

HRC technology is still not fully mature due to yet unsolved challenges. The most pressing challenge is the safety aspect for the workers. Currently many industrial robots are prohibited to work without a physical fence isolating them from people. In order to remove physical fences, reliable virtual fences built with sensors and safety systems need to be developed.

3.5 Digital Twin

A digital twin, also known as device shadow, digital shadow or mirrored system can be described as *"... a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling, and improved decision making."* (Rasheed, San & Kvamsdal 2019). In other words, a digital twin is a simulated replica of a physical entity such as an assembly line.

An optimally configured digital twin accurately represents a physical object in digital form, and hence can be used for simulation, stress- and performance testing, efficiency improvements as well as for predicting the consequences for planned changes of the physical entity it represents. Digital twins are often used for supply chain optimisation and visualization, line balancing, predictive maintenance and for energy optimization within the manufacturing sector.

The challenge with digital twins is to collect the necessary data and apply realistic physical and mathematical models to represent the physical identity. When implemented incorrectly, the Digital Twin may act as a tool for decision making without actually providing valuable insights.

3.6 AGV - Automated guided vehicles

Robots have transported goods for a long time in a wide array of different settings. There are many different names used to refer to this in an industrial setting depending on the functionality, such as Autonomous Mobile Robots (AMR), Automatic Guided Carts (AGC), Autonomous Intelligent Vehicle (AIV), Industrial Mobile Robot (IMR) & Self-Driving Vehicles (SDV).

While it is important to differentiate between the names and the corresponding technologies and functions, Automated Guided Vehicles (AGV) can be used as an umbrella name to gather all of these technologies under one name. AGV:s are smart vehicles, and while they vary in shape and size, they are all unmanned using different control methods for navigation.

AGV:s can introduce benefits such as cost savings, freeing up manual labour, and increased levels of safety if implemented efficiently. They can for example replace forklifts, where each replaced forklift also requires one less operator in head count. AGV:s can also be significantly more space efficient than forklifts, not having to be designed to accommodate an operator or rely on his/her line of sight when driving. By removing the need for human involvement when transporting heavy goods, accidents caused by human error can be removed and the consequences of accidents can at the same time be reduced efficiently. [Scania internal resource]

While the vehicles are smart and often efficient, enabling the AGV flow in an industry is often computationally expensive. Integrating an AGV in a dynamic environment where people operate can present a lot of difficulties. One way of differentiating between AGV:s is based on the type of guidance technology required; fixed or free. (Mehami, J. et al., 2018).

With a fixed guidance, the AGV follows a laid-out path that the AGV will sense and follow. This path can i.e., be laid out with magnetic strips or optically with tape or colouring. Often resulting in a low installation and material cost, the fixed path offers little flexibility in route changes. While the free guidance offers flexibility, it requires higher installation cost and more complex AGV systems using one or several techniques to navigate within the factory. Examples of navigation systems can be GPS, LiDAR, Computer vision or optical sensors.

3.7 Vision system

Automatic assembly lines are becoming more and more common; however, autonomous systems are not always suitable for assembly lines which feature high mix low volume manufacturing (HMLV). As the customers of manufacturing companies require more and more customization of their desired products, manufacturing companies need to accept that certain automation strategies no longer apply (Canali et. al, 2014).

Similar to a voice recognition system, a vision system recognizes and evaluates images. The system typically consists of a front-end camera which captures images of the nearby environment and sends the pictures for processing at a backend computer processing system. Depending on the design and purpose of the vision system the computer then processes and/or stores the images in order to interpret the surrounding.

Vision systems can be applied to a wide range of activities within manufacturing companies, with the most common being quality control, guiding robots to pick the correct parts, registering the presence of objects and recognizing certain models. For companies with a wide product mix, one major challenge with industrial robots appears when they are presented with objects of unknown, or random stationing (Mouri et. al, 2007).

For a company like Scania who boasts a wide range of products and components at their assembly lines, vision systems could be used in combination with industrial robots to combine a flexible assembly line with the perks of automation. Far from perfected, the technology is still relatively mature and robotic vision systems are already implemented in some of the full-scale production lines within Scania today.

3.8 Virtual Reality

Virtual Reality (VR) is a technology that enables the creation of 3D-rendered environments which can be explored and interacted with by humans. VR is a mature technology within the manufacturing sector and is widely used today in training, testing and for visualizing products and assembly lines before building them in real life. The visualization aspect of VR enables companies to spot weaknesses and make adjustments before completing real life construction, which can both save time and money and improve safety. For instance, Ford Motor Company accredits the usage of VR to certify vehicle assembly processes before start of production to play a crucial role in their progress of reducing injury rates by 70 percent in their assembly lines (Ford, 2015).

Through completing 3D prototype assembly line environments, VR tools can assist in getting early feedback from production and design technicians as well as cleaning staff, assembly line workers and team leaders.

3.9 Augmented Reality

While Virtual Reality is oftentimes restricted to training, visualization and testing, Augmented Reality (AR) can create virtual environments that complement a worker's ordinary view.
Since assembly line activities are often not supported by extensive instructions, AR can generally complement workers with identification of parts, guidance and inspection. Compared to paper-based instructions AR-solutions tend to reduce the number of errors made but increase the assembly time of the same activities (Botto et al, 2020).

Currently, AR is not a mature technology and faces many technological challenges such as a short range of visibility. Furthermore, accounts of headaches have been reported from workers who've worn AR-equipment designed for assisting workers to pick the right products for more than 40 minutes at a time [Scania internal resource]. If implemented in an ergonomic and non-intrusive way, AR can increase the workers' flexibility to assemble more different types of products by providing the right number of instructions at the right time.

3.10 Simulation used for line assembly

Creating a virtual representation of a physical assembly line can be done to enable simulations of the assembly process. These simulations can be performed to predict maintenance needs and improvements during the operational phase, such as in the case of a Digital Twin. But simulations can also be used in the design process of developing an assembly line.

Scania currently uses several software such as Catia, LayCAD and Avix to model assembly processes in a cost effective and easily modifiable way. With a defined set of tasks needed in the assembly process and a mapping of their interdependencies, software can be used to perform line balancing. This is a way of optimizing the sequence of tasks in the line to find the best performing line layout. Performance can be simulated and measured in several different ways, for example in takt time, workload smoothness, number of stations, power consumption, number of operators needed and reliability.

3.11 Wearable technology

New technology and increased connectivity have driven the development of wearable technology, such as devices and sensors embedded in clothing and handhelds or protective gear. This section on wearable technologies and use cases is purposely wide in scope because they are all essentially targeting the same goal - enhancing operations carried out by humans. While many technologies in industry 4.0 are targeting fully automated production processes in the end, wearable technology is aimed at enhancing manual operations or human - robot collaboration (HRC).

As mentioned on the topic of HRC, it can offer the combination of speed and precision of a robot with the flexibility and ability to react to abnormalities of a human. One of the most pressing challenges when introducing Cobots in an assembly line is safety for the operator working with the robot. One way to increase safety during operation is by letting the operator use a wearable armband linked directly to the robot that can sense muscle signals and detect what the person is doing at all times. In a performance test comparing a human-robot collaboration with a fully automated robot process, the armband that was used enabled safe operations for the operator with the results that the human-robot collaborative process was both faster and more effective than the fully automated robot process (Coban, Gelen, 2018).

Wearable tech can also help the operators in assembly line stations where no robots are involved. One example is by easing quality control measures, such as signing or stamping physical product orders, by embedding a digital operator signature directly in a glove for example. Wearable electronics have been limited in their usage, largely due to a lack of robustness of the devices during operation and washing. Radio Frequency Identification (RFID) tags can offer a solution to this, since they offer a chip less technology that can offer robustness at costs low enough to allow for implementation in gloves, for example (Corchia et al., 2019).

More than assisting workers in the assembly operations, wearable technology can also enhance safety and health of the workers in an industrial environment. One use case of RFID technology is to create Body Area Networks (BAN) using RFID tags embedded in the clothing, gloves and protective shoes. The BAN network can be used as a part in both monitoring the worker’s health, through sudden changes in body temperature for example, or the workers station relative to other moving objects such as AGV:s and forklifts to prevent collisions (Sole et al., 2013).

In Scania’s Smart Factory Lab, a team has been looking into how wearable RFID tags can help monitor the ergonomics of a worker during the workday. Placing several RFIDs in a shirt allows for monitoring of their relative stations, which can be translated into the corresponding posture of the worker. Monitoring this over time can help identify if a worker is at a risk of suffering from repetitive strain injuries or is overworked in any other way. While wearable technology can offer increased safety and easier operations, it introduces a new type of considerations and challenges. According to the team, increased surveillance and its implications on personal integrity is one of the key challenges.

3.12 5G communication

The fifth generation of cellular networks, 5G, is set to offer peak speeds up to 100 times faster than 4G. Other than a theoretical higher speed, 5G will also offer lower latency and increased reliability according to the telecommunications and network company Ericsson. (Ericsson, 2021). In an industrial landscape, one of the key capabilities 5G looks set to offer the industries are private networks. These are on-premises networks deployed solely for the customer's (in this case, the industry) use. In its core, 5G offers an alternative to the cables used for today's reliable, secure and high-speed networks connected to machinery and robots in an industry. The case for going wireless includes higher flexibility and mobility for robots, smart tools and AGV:s not having to rely on fixed cables for connectivity.

In a joint report written by Ericsson, Hexagon and consulting firm Arthur D. Little, a case study is performed looking at five use cases enabled by 5G technology in an automotive supplier's factory where mainly stamping and assembly operations are conducted. The five use cases are AGV:s, collaborative robots (Cobots), augmented reality (AR), predictive maintenance and digital twins. The results of combining these use cases is that they provide a combined return of investment (ROI) of 116% by year five after a full deployment of the use cases. (Ericsson & Hexagon, 2020). While it is of less interest to look at the specific ROI-levels in a cherry-picked marketing example such as in this case study, it is more interesting to look into how a private network provides the enabling infrastructure. It is clear that a private 5G network when implemented right can provide tangible benefits by reducing the need of manual labour, by speeding up operations through adding cobots and AGV:s in the assembly lines and by increasing overall uptime through digital twins and predictive maintenance.

4. Empirical knowledge

The fourth chapter of the report contains the empirical knowledge gathered through both internal and external resources outside of Scania.

The literature study provides a very brief and general understanding of smart manufacturing methods and technologies that can be used in an assembly line. But to be able to suggest several viable assembly technologies that are relevant for Zone 1 of the rear axle assembly line at Scania in Södertälje, in-depth knowledge about the opportunities and limitations of these technologies is needed.

When gathering information and insights on which assembly technologies that can be relevant for Scania, internal Scania resources have been used primarily. Examples of internal resources used are interviews with internal domain experts and production engineers. Smart Factory Lab is another internal resource devoted to research and development of new technologies. Reports on previous, current and planned projects at Scania have been used to identify solutions that can be applied to the rear axle assembly as well. There are also internal e-learning portals at Scania on a wide range of technologies.

4.1 Rear axle assembly at Scania in Södertälje

At the transmission assembly of Scania in Södertälje, gearboxes and axles of several types for Scania's different trucks and busses are produced and assembled. The transmission assembly employs more than 1000 people in the Södertälje factory alone. The rear axles assembled in Södertälje are then transported to the chassis assembly lines located both in Södertälje as well as Angers (France) and Zwolle (Netherlands). Since Scania is owned by the Traton Group, which also controls German truck manufacturer MAN, some rear axles intended for MAN trucks are also assembled in the Södertälje factory.

As a result of Scania's MTO-principle and high degree of customization, components such as the rear axles of Scania trucks can be quite different from each other in terms of dimensions and properties. These differences also apply within the same model programs. Scania also builds each individual truck in an order based on when it was ordered. With several different sales functions around the world, this can cause significant differences in truck configurations and their corresponding rear axles that are going to be produced after each other. It should be noted that production planning is used to optimize the actual assembly flow. Some axle variants are for example not allowed to be assembled multiple times in direct sequence since this would lead to a halt in production. In total, the transmission assembly needs to be able to assemble 212 unique types of rear axles at any given time.

It is worth noting that some of the more rarely sold rear axles, currently 32 axle variants, are grouped into something called "Special axles" (SAX) which are all assembled on a manual, smaller line in the factory. Of the remaining 180 axles, the rear axle assembly teams need to be able to assemble each one of these during the takt time for every station. The Scania logistics team in Södertälje supplies the assembly area with the right material and parts needed, at the right time.

The assembly line for the rear axles needs to assemble all of the axle variants within the same takt time (takt). Because of the differences between axles, some will require less individual assembly moments and time than others to be fully assembled. There are even cases where an axle will pass through a station during a takt in which no work is performed on the axle at that station. This is often referred to as a “No job” and it will essentially give the operator at that station a break during that takt to assist colleagues or organize the work area. The takt time has to be followed throughout the assembly line and during the day to keep the overall production flow in the factory, and to avoid shortcomings or overstocking inventory in the assembly area.

The need of always following the takt time and the varying degree of work needed to assemble a rear axle means that the rear axle type that requires the most time to assemble will dictate the takt time for all of the rear axles. The takt times are always based on the worst-case scenario, which corresponds to the axle variant that requires the most time in a station to be finished.

This can be illustrated in Zone 1 with an arbitrary example. In Zone 1, if there are 10 stations and a takt time of 100 seconds, it will take 1000 seconds to complete one rear axle in this zone. If there are 100 versions of rear axles, each requiring a slightly different work done at each station, the actual work time needed to complete each axle variant will vary. The most complex axle variant might require almost all of the takt time at all stations, resulting in 950 seconds of required actual work time in a 1000 second assembly takt. A simpler axle variant might include three “no job” stations and less time on the other stations, resulting in i.e., only 400 seconds of actual work time in the same assembly takt of 1000 seconds.

4.2 Ergonomics at Scania

4.2.1 Scania Ergonomic Standards

Ergonomics is one of the three main areas in which the next generation rear axle assembly line will be evaluated by. The importance of a good ergonomic workplace is not to be underestimated at Scania. According to several employees in the assembly division, one of the overarching goals is that the ergonomics of each workstation should physically allow for an employee to work within the same Zone in Scania every workday from turning 18 until they retire at age 65 without strain injuries.

Evaluating and comparing the ergonomics of different workstations in a uniform way can be a demanding task. This is because defining and selecting suitable key figures to measure ergonomics seldom is as obvious as key figures in productivity, such as cost or takt time. One way to systematically quantify the ergonomics of a workstation, regardless of where in Scania it is located, is through the Scania Economic Standards.

Scania Ergonomic Standards, SES, is an observational framework and methodology used to assess the ergonomics of the workstations at Scania. The SES framework consists of 20 assessment criteria posed as questions, which are all assessed using a four-grade answer scale. When evaluating a workstation, for example station 1:1 in Zone 1 of the rear axle assembly, the 20 criteria are evaluated and a SES-report for this specific station is generated.

4.2.2 Evaluation criteria and grading of a SES report.

The four levels of the SES grading scale are a green-, yellow-, red- and double red value (DRV) assessment. The levels are ranked by risk and priority as presented below:

Table 1 - Scania SES grading matrix

	Assessment levels			
	Green	Yellow	Red	Double Red Value
Risk	Low risk for strain injuries. Acceptable.	Potential risk for strain injuries. Potentially acceptable.	Medium to high risk for strain injuries. Potentially unacceptable.	High risk for strain injuries. Unacceptable over time.
Priority	Low priority.	Plan improvement measures and implement over time.	Improve within a reasonable time.	Improve immediately.

The four levels are used to answer the 20 assessment criteria. One important criterion regarding the number of repetitions of a body movement per hour. Even if the actual movement is ergonomically acceptable, repetition itself can lead to strain injuries. Other criteria include the force required to perform a work step, the required body station and movements during work. In the evaluation of a workstation, a few open-ended questions other than the 20 criteria are included as well. These questions are aimed at discovering any general discomforts experienced by operators at the work stations.

4.2.3 Automation as an ergonomics improvement measure

Ergonomics at Scania is systematically measured through the internal SES reporting system. The SES reports clearly highlight the areas which need improvement. The four-coloured grading scale helps to visualize the priority order for when and where resources should be focused to improve the ergonomics.

The SES report does, however, never mention how an improvement can be achieved. It only mentions what problem that needs to be addressed. The continuous improvement work, and answering the “how”, is done both by designated ergonomics experts and engineers within the different divisions of Scania.

When interviewing and talking to employees at Scania, it is clear that many see automation as a way to improve ergonomics. The dangers of heavy lifts, forcing the body into an unnatural pose, can be resolved by introducing an automated lifting tool for example. This view on automation is very rational and not surprising to the authors.

What was more surprising to the authors was the difference in how the value of improved ergonomics is perceived by employees at Scania.

On one hand, some employees seem to believe that justifying automating a station requires a clear economic case and a calculable payback time. For example, automating a station should result in a salary saving by reducing staffing and productivity should increase. The fact that ergonomics is improved, or rather, that a poorly ergonomic task is removed, is considered a bonus.

On the other hand, some employees seem to believe that automation can be justified as long as it improves poor ergonomics well enough. For example, this could be an automated lifting tool that removes a heavy lift but still requires the operator at the workstation to perform a manual subtask. In this case, the lifting tool does not pay back the investment annually in a measurable way. Though it should be mentioned that one could argue that the improved ergonomics has positive effects on productivity and staff turnover, which can be converted into a payback time.

These differences in how the value of improved ergonomics is perceived leads to a new question. What is the best way to translate improved ergonomics into a business case for automating an entire workstation? This is not a question that this report aims to answer. Instead of comparing and weighing the saved costs on staff reductions with ergonomics improvements, both of these possible effects of automation will be accounted for and presented separately.

4.3 Order management systems

4.3.1 Order management system and its role today at Scania

Order management & assembly instructions within Zone 1 are two areas where there is potential for significant improvement. As of today, a new assembly order is physically printed out at the beginning of Station 1 for each rear axle that will be assembled. This order informs the operator which variant of the rear axles that will be assembled and how this should be done. This information is both presented as printed text for the operators to read and as printed barcodes, which are then scanned, to prepare the tools and robots involved in the assembly. The order paper does not only provide important information to the operators involved; the order is also signed by the operators at different stations after they have completed an assembly step.

4.3.2 Identified areas of improvement

Through observations directly at Zone 1 and through interviews with employees, a number of areas with room for improvement have been identified regarding the order management system. The main area is time efficiency, where there is potential to free uptime for the operators at each station through a smoother order handling process. Grabbing the orders, flipping pages, scanning the barcodes, stamping the orders and putting the orders back in place at each station requires a significant share of the takt time at the different stations.

Another area of improvement is the readability of the orders. These are bundles of paper filled with a lot of specifications to provide enough information on all of the assembly steps. Using paper as a medium excludes the use of instructional videos or animations to ease the assembly process. With an expected increase in the number of truck models at Scania, and subsequently more rear axle variants and assembly steps, the operators will need to have more different assembly procedures in the back of their heads during work. Using a digital medium instead of paper is one way to convey the right assembly instructions at the right time for an operator. This can both reduce the amount of info an operator needs to have memorized and it can also help filter out unnecessary information by focusing on what is important at that specific moment and assembly station.

Lastly, today's system does not allow for the easy traceability and quality improvements analysis that e.g., a digital system could do. Currently after completing an assembly step, the order is stamped with the operator's individual signature. However, if any error that resulted in a time-consuming fix at the station was made during the assembly, this is not marked in the order. A digital signature could allow for a digital note on the order if anything went wrong and had to be fixed during the assembly. Gathering data on the operator's steps through the assembly process could for example highlight more accurately and faster in which areas where upskilling and training is needed.

4.3.3 EBBA - Part of Scania's new order management system

When identifying alternative ways to improve the current order management process at Zone 1, several Scania employees were interviewed, and a literature review was conducted. There are several different ways to improve the order management, including investing in different IT systems. However, a decision has been made to focus on one specific system instead of evaluating several different systems and combinations of digital tools.

The chosen system is called EBBA and it is a part of a larger system developed by and used at Scania. The EBBA system can, in a rough simplification, be described as part of an IT system that allows a sales order to firstly be translated directly into a manufacturing order and secondly into a detailed set of assembly instructions for each station and corresponding operator involved in the manufacturing process of a Scania truck.

The rationale behind choosing this system as the only alternative in this project is because it is part of a transformation project taking place at Scania. According to Alexander, working within IT and Automation at Scania, implementing EBBA in several divisions of Scania is part of a large strategic roadmap over the coming years. The rear axle assembly is one of the areas where EBBA will be implemented. Therefore, EBBA will be assumed as the underlying IT-structure in this report when identifying and evaluating ways to improve Zone 1 of the rear axle assembly line.

4.3.4 The effects of implementing EBBA & considerations to make

While the underlying IT structure for order management of the next generation rear axle assembly has already been decided, there are still a lot of considerations and decisions to make. The EBBA system offers several advantages, as well as restrictions on how the order management process can be improved.

Implementation of the EBBA system is carried out by a central IT function at Scania, and the cost of this is not directly attributed to the assembly line and the group function that is responsible for the line. However, deciding how information from EBBA will be presented to the operators is up to each group responsible for an assembly line. Information can be presented on screens mounted directly on the carriers, on screens mounted at the workstation, on handheld devices or screens on arms or through AR-glasses for example. This decision, and the resulting costs, are attributed to the assembly line directly.

One of the most important messages, according to the authors, that was conveyed by Scania employees working in EBBA-related projects is on the importance of involving IT technicians early in a transformation process and educating the operators thoroughly on how to use new systems.

According to the employees, implementation of the EBBA system in an assembly line might risk missing out on the intended improvements if operators do not get enough training in the EBBA system. Operators need to be informed about the configuration possibilities of the system to be able to identify how the system can help them in their assembly work. The message is that operators can know best on what information that should be conveyed and where and how it should be presented during the takt time.

4.4 HRC

Human Robot Collaboration (HRC) is an area that is well researched at Scania today and there are several projects including HRC in planning. It is important to note that there are no collaborative robots, only collaborative robot applications. It is not the robot but the whole application that creates the collaboration. HRC at Scania today is focused on applications, where a traditional industrial robot for example can work in the same space as an operator but with different tasks. There is less focus at Scania today on modern robots that will work on the same tasks as a human operator and in closer collaboration in a direct physical sense.

4.4.1 Safety requirements and categorization of HRC

Scania have categorized HRC into four distinct categories: Coexistence, Synchronization, Cooperation and Collaboration. These are ordered in the level of interaction between operator and robot and if & how their workspaces are allowed to intersect. This is illustrated in figure 1 om the next page. According to Eric, who is one of the HRC representatives at Scania, the overall strategy at Scania is to start with Coexistence and Synchronization levels of HRC in the coming years. Cooperation and Collaboration are more advanced and lie further ahead in time. In the Cooperation type, the operator and the robot are allowed to work simultaneously in the same workspace but with different tasks. In the Collaboration type, they are also allowed to work together on the same task in the same workplace.

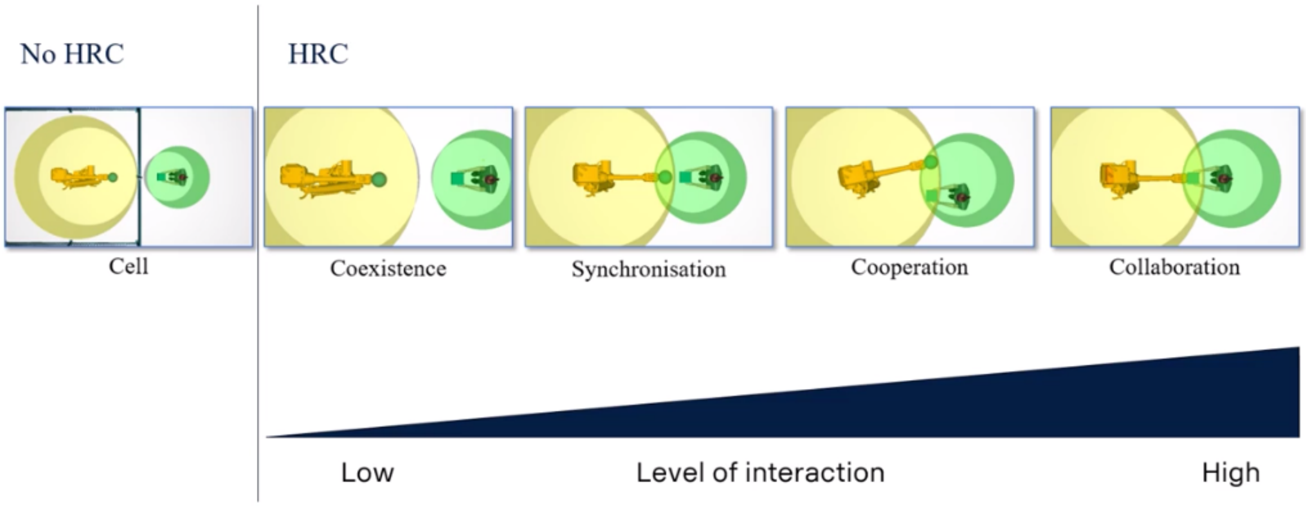

Figure 1 - HRC interaction types

One of the most pressing challenges with HRC is safety for the operator. The safety requirements shift between HRC categories, in the Coexistence type there needs to be a safety distance between the operator and the robot. This distance can vary depending on which part of the body the distance is measured from. For example, there needs to be a 500 mm distance between an operator's head and the robot at all times, while there only needs to be a 300 mm distance between the lower parts of the body and the robot. This is to reduce the consequences of an accident.

In the Synchronization type, the workspace is shared but the operator or the robot are not allowed to move and work simultaneously. This can be solved at Scania through a Safety Rated monitored stop. By equipping e.g., the robot with sensors it is forced to stop when an operator is detected entering the workspace. The robot is prohibited to move as long as the operator remains in the workspace. This is illustrated in figure 2.

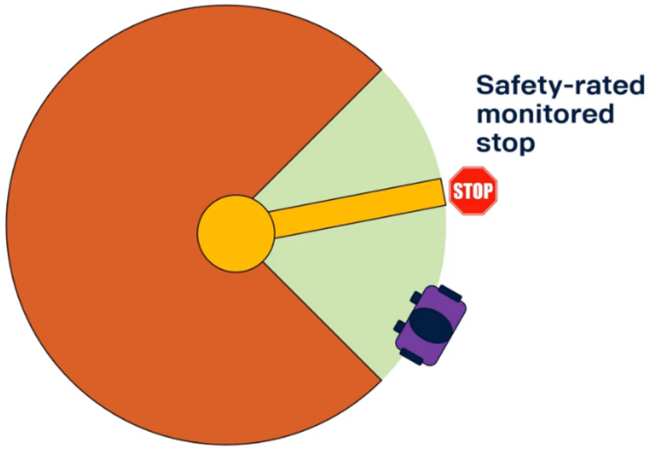

Figure 2 - Safety-rated monitored stop

Another solution is to use Hand guiding. Similar to the monitored stop, the robot stops when an operator enters the workspace. The difference is that the robot is allowed to move, but the robot movements are guided by the operator's hand movements, illustrated in figure 3.

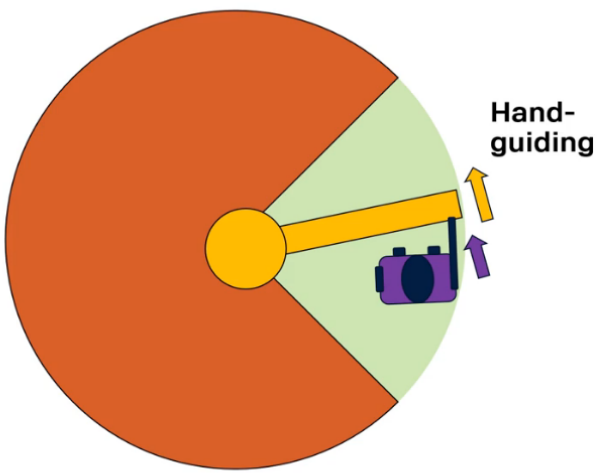

Figure 3 - Hand guiding robot

4.4.2 Why HRC? Identified use cases and their effects on the assembly line.

Fulfilling the safety requirements when implementing HRC can be costly and complex, but the benefits of HRC in assembly can be well worth the initial investment when done properly. As mentioned, HRC offers a way to combine the agility of an operator with the efficiency and precision of a robot. In the rear axle assembly at Scania, a few specific applications where HRC can be an attractive option have been identified.

4.4.2.1 Silicone applications

The application of silicone grease on the rear axle bridge, which currently takes place at station 7 within Zone 1, is one example of where HRC can be used. Applying the silicone grease is a time consuming and relatively simple task. The operator follows a hand drawn line with the silicon gun during application. This is an area where a dedicated silicon-applying robot could work closely with the operator and free uptime for the operator to perform other activities.

4.4.2.2 Lifting applications

Lifting of the central gear and placing it into the bridge is today done through a simple lifting tool that lifts the central gear vertically but has to be moved horizontally to get into position. The central gear weighs 130 kg and it requires a push from the operator to move it horizontally. In the upcoming fully electrified trucks, a component weighing 500 kg will replace the central gear of today. This means that a new lifting tool with capacity to lift both the central gear and the new component will have to be put in place.

One option is to replace the simple lifting tool with a lifting robot. The robot can still be hand guided by an operator, but it can still result in a much quicker lifting process requiring much less physical effort from the operator. This has been identified as an area where collaboration between a lifting robot and a human can increase both efficiency and improve ergonomics at the workstation.

4.4.2.3 Presenting material

According to Eric, HRC improves the assembly process by having a robot present material to the operator. For example, a screw-picking robot can pick the right screw type for each assembly variant and present this to the operator precisely when it is needed. This can reduce time for picking and errors, since a robot can have higher precision, reliability and move faster than an operator.

Using a robot to pick the material can also change how material is packed during transport from logistics to Zone 1 in the assembly line. Today, screws need to be packed in boxes which the operator can carry from the logistics delivery point to the specific work station where they are needed. The box needs to be dimensioned so that a human hand can reach everywhere in the box and pick up screws.

In short, ergonomics imposes constraints on how screws can be packed and transported. If a robot can pick the screws instead directly from the screw boxes, the boxes can be larger, and this can reduce time and cost within the logistics team.

Looking further into how HRC can be used to improve material picking is relevant to the rear axle assembly, where there is currently a lot of manual picking and rearranging of assembly material such as screws and bolts.

4.4.2.4 Why not HRC?

There are both plenty of reasons to apply HRC solutions in general as well as identified HRC applications suitable for Zone 1 within the rear axle assembly at Scania. This also poses the question of when HRC should not be used.

According to Fredric, doctorate within HRC and Automation expert at Scania, the first rule of thumb when considering HRC is to ask why the human is needed for the intended collaboration. This is important because safety is a complex area which drives significant cost in HRC applications. If a station is fully manual, safety requirements are easy and cheaper to fulfil since no robot is present. In a fully automated robot cell, safety requirements are also easy and cheap to fulfil since the robot will be caged within a security fence. Therefore, when considering HRC, it is often worth reconsidering if automating the seemingly difficult task assigned to the human can be done.

Another consideration in HRC applications is how you leverage the work time that has been freed up for the human by assigning tasks to a robot. Given the short takt time of Zone 1, around 80 seconds, this is even more important than with long takt time of several minutes. An example to illustrate this could be a HRC application at a Synchronization level. The robot and the human share workspaces, but are not allowed to work at the same time. We can assume an arbitrary task where the robot is working for 20 seconds, and the human works for 60 seconds during a takt time of 80 seconds. What do the human operator do during the 20 seconds freed up by the robot?

If this is idle time, Scania will be paying 25% of all labour costs at that station for non-value adding time. It can often be more cost efficient to have the human operator do all of the work at the station instead, have 100% of value adding time and reduce the costs of having the robot in the first place. Another option is as mentioned above to fully automate the station instead. This can often be the best solution in the long term. According to Fredric, this might require a higher investment but will reduce the labour cost and make certain no labour cost is spent on non-value adding time.

4.5 AGV

Automated Guided Vehicles (AGV) already exist in several different applications at Scania today. AGV:s are up and running and part of normal operations inside Scania factories today, and there are many projects planned for the near future. Most of the current and planned AGV applications are targeting logistics and the transportation of material. While there are AGV applications directly within production and implemented in the assembly lines, they are relatively few compared to logistics. Implementing an AGV system either in a logistics use case or in an assembly line will result in very different considerations and problems to solve. Below are some of the considerations identified.

4.5.1 Tolerance considerations and implications

It should be noted directly that AGV:s can use very different methods for locating their exact station. Some AGV:s will use magnetic, inductive or optical measures to follow a line in the floor and rely on a predetermined route. Others can move freely, guided by a virtual route and distance sensors to continuously update their station. But regardless of technology used, AGV:s doesn’t have station tolerances fine enough for the demands of an assembly line at Scania today.

This is currently not a problem in the field of logistics, where mostly pallets are transported, and the tolerances often can allow for several millimetres of offset. The case is different, however, when assembling for example a Scania truck engine or rear axle. The tolerances when entering a screw or placing the central gear in the rear axle bridge can be smaller than a millimetre.

Solving for tolerances can be done in several ways. If the AGV transports an assembly component and an operator is performing the assembly work, the operator can often allow for a large tolerance and still perform his or her work without any disturbances. In the case of an automated robot cell, tolerances are generally much smaller to enable the robot to do its work.

In an automated cell, one option is to make sure the AGV and the fixture on the AGV holding the assembly part is perfectly stationed. This can be done by forcing the AGV to dock into a box fixed on the floor. There can also be sensors in the floor, which the AGV needs to align perfectly with before the robot can start its work. One practical drawback of this solution is that it takes time. The AGV needs to slow down even further and sometimes readjust its station when docking to avoid collisions. In a high-volume assembly line with takt times of 80 seconds, this can be a very time-consuming activity that would need to happen at each automated station throughout the line.

Another option is to allow for some offset in the stationing of the AGV, but having the robot recalibrate its workspace depending on where the AGV ended up. This can be done by sensors and/or computer vision. With the fine levels of tolerance needed for assembly, usually a combination of docking the AGV in the right place and calibrating the robot tool can be used.

According to Johannes, senior engineer at Scania, tolerance is the greatest challenge to solve for AGV:s in an assembly line with automated cells. It is a problem with clear solutions in theory, but not in practice. Johannes says that the challenge is the extremely fine tolerances and that the technology is not well developed enough today to work at a satisfactory level.

4.5.2 Operational reliability and safety

AGV:s are generally able to detect if and when they need to stop by measuring the distance to an object ahead of them. The technique used to decide on an emergency stop is considered safe, and the decision is made internally within the AGV. If multiple AGV:s are moving in a line formation and the first AGV in line encounters an emergency stop the others will all stop based on when they detected the one in front of them stopping. This is a chain event of stops and not a centralized stop decision for the whole fleet.

In an assembly line such as the rear axle assembly, it is desirable to have a centralized emergency stop function for all AGV:s moving in the line. This is not only for safety but also practical considerations to have the AGV:s at their respective station in the line instead of having all AGV:s stacked up at one station.

One challenge is how to implement the centralized stop function. Wi-Fi is of course one possible solution in general, but it is not an option at Scania at this point in time. Scania's Group IT does not allow emergency stop signals like that of an AGV to be distributed over Wi-Fi. The reliability of a wireless network is considered too low to allow for a safety critical function like an emergency stop.

Another consideration is what to do when an AGV loses connection to the rest of the fleet and the fleet management system. In an assembly line, each stop costs money. And oftentimes a stopped minute in an assembly line will cost a lot more than a minute stopped when transporting goods.

The centralized emergency stop function is one example of a consideration when moving from wired transport systems to wireless AGV:s. One of the general challenges when moving from wires to wireless is ensuring the network reliability of sending critical input to and receiving data from the AGV:s at the right time.

4.5.3 Data security considerations

Having AGV:s rely on wireless communication does not only result in considerations on operational reliability and safety for the operators. Connecting automated vehicles also requires a look into data security. Connected AGV:s from a third-party supplier exposes Scania to risks associated with industrial espionage for example. Another consideration is the increased level of consequences in the event of a sabotage or network intrusion.

AGV:s are heavy and can reach high speeds, making them a potential danger if the control of them ends up in the wrong hands. Group IT at Scania often solves this by setting up partial networks for applications such as AGV:s, rather than implementing them in the ordinary Scania networks. Discussing the different solutions and drawbacks is a complex topic that will not be covered further in this text. Data security is an area that's important in several other areas than just AGV:s, but it is an important consideration to make when planning on bringing in automated vehicles into an assembly line.

4.5.4 The flexibility of an AGV system in Scania

While the considerations are many and the implementation of AGV:s is a complex and costly process, there are significant benefits to it. In logistic applications, AGV:s often replace the need of a fork truck and subsequently the need of a fork operator. The payback time of an AGV is then often calculated by looking at the initial investment and the realized cost savings on the operator salary. The advantages of an AGV system as a transportation system of parts in an assembly line is slightly different.

One of the main benefits is the flexibility to move and readjust an AGV line. It is considerably cheaper and faster to reroute an AGV fleet than moving a transport system such as a TMS Carrier system or a monorail which are mounted firmly in the roof or on the floor, respectively.

This is a speculative benefit, and more difficult to relate to a payback time. Because when placing an AGV line, it is seldom planned in advance that it will be moved after a while. However, the opportunity to move it easily is there from the beginning which allows for higher degrees of uncertainty when installing the AGV line. According to Johannes, the value of flexibility should not be underestimated at Scania.

4.6 Deciding upon carrier system

The carrier/conveyor system is the complete system which transports the rear axle bridges throughout the complete assembly line. Carrier solutions can vary in design. The carrier system that are most popular at Scania are currently:

- A fixed pallet conveyor system, which is currently found in the rear axle assembly.
- A system of AGV:s carrying the bridges through the assembly line.
- A roof-based monorail system.

Choosing a carrier system is a crucial decision when building an assembly line. The carrier system lays the foundation on which the working stations can be built on. According to senior engineer and industrial expert Johannes at Scania, the cost of purchasing a high-quality carrier system at the rear axle line can be higher than the cost of all the stations at the line combined.

When designing a new carrier system for an assembly line there are four factors that need to be considered before settling on a specific type or model:

1. Should the load carriers move continuously or stop at each station?
2. Which path should the load carriers follow?
3. Should the carrier system be floor-level, elevated or roof-based?
4. Should fine-tuned stationing be made by the carrier system or by the specific stations?

4.6.1 Continuous flow or Stop'n'Go?

One of the first decisions to make is if the assembly line should transport the axle bridges through the line continuously or stop at each station during a takt time. The continuous line moves at a steady and slow pace throughout the line, while the Stop'n'Go moves fast into the next working station where it then stops completely during the remainder of the takt time. This is illustrated below.

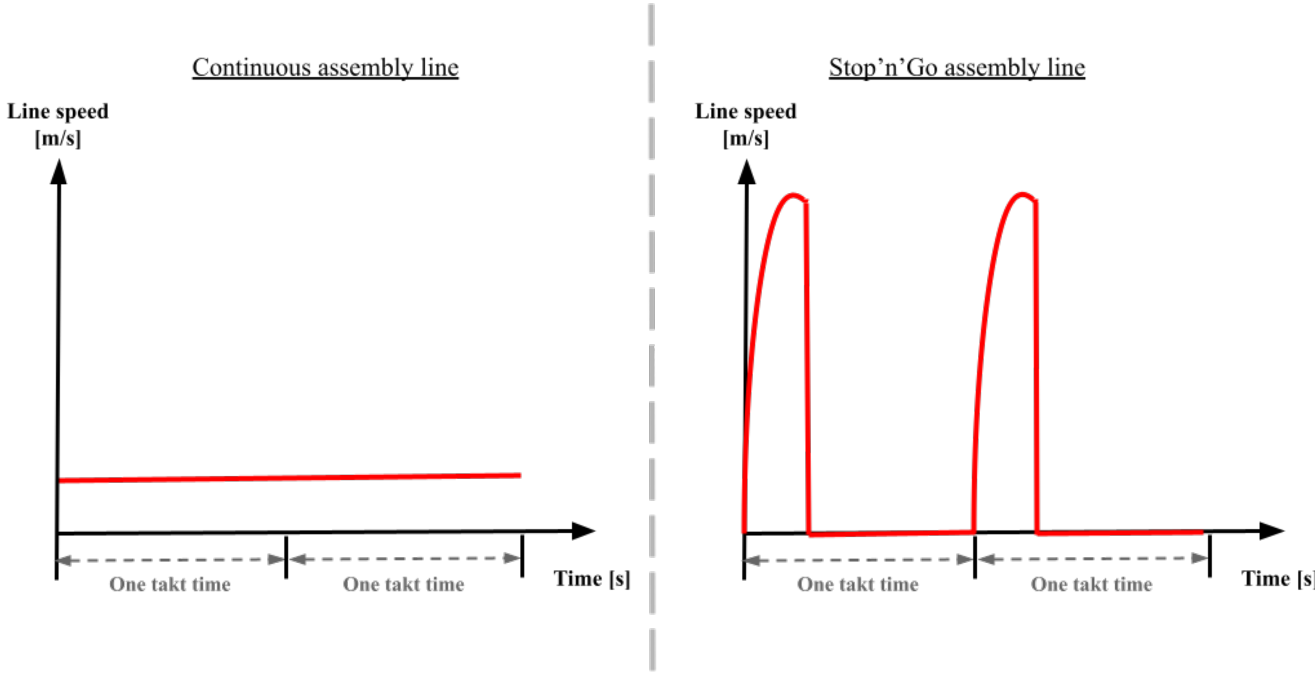

Figure 4 - Line speed as a function of time for Continuous and Stop'n'Go type assembly lines

One of the major decision points when choosing between continuous flow and Stop'n'Go is the potential for automation. A continuously moving line is more difficult to automate than a Stop'n'Go line. This is because it is much more demanding to move a large industrial robot along the assembly than it is for a worker to walk. A moving line also presents a challenge when it comes to stationing tolerances. An automated robot cell will need a very fine station tolerance of only tenths of a mm to safely perform its assembly tasks on the rear axle bridges. These tolerances are easier to achieve in a Stop'n'Go system which can be fixed in its place during the assembly work.

One of the largest drawbacks with the Stop'n'Go system, however, is the time lost to transport between stations and dock the axle bridges into station in an automated cell. This process can take up to 15 seconds out of the available 80 seconds of takt. Still, this waiting time can be used for operators and robots to prepare tools and material and make changes needed for handling several different variants of rear axle bridges. There will also be some time lost for workers walking back into station in a continuous system.

4.6.2 Shape of assembly line - Straight line, U-turn or other form?

When discussing the assembly line shape, we are referring to the placement of the working stations in relation to the carrier system. This can e.g. be in the form of a U, I or S (as illustrated below in figure 5).

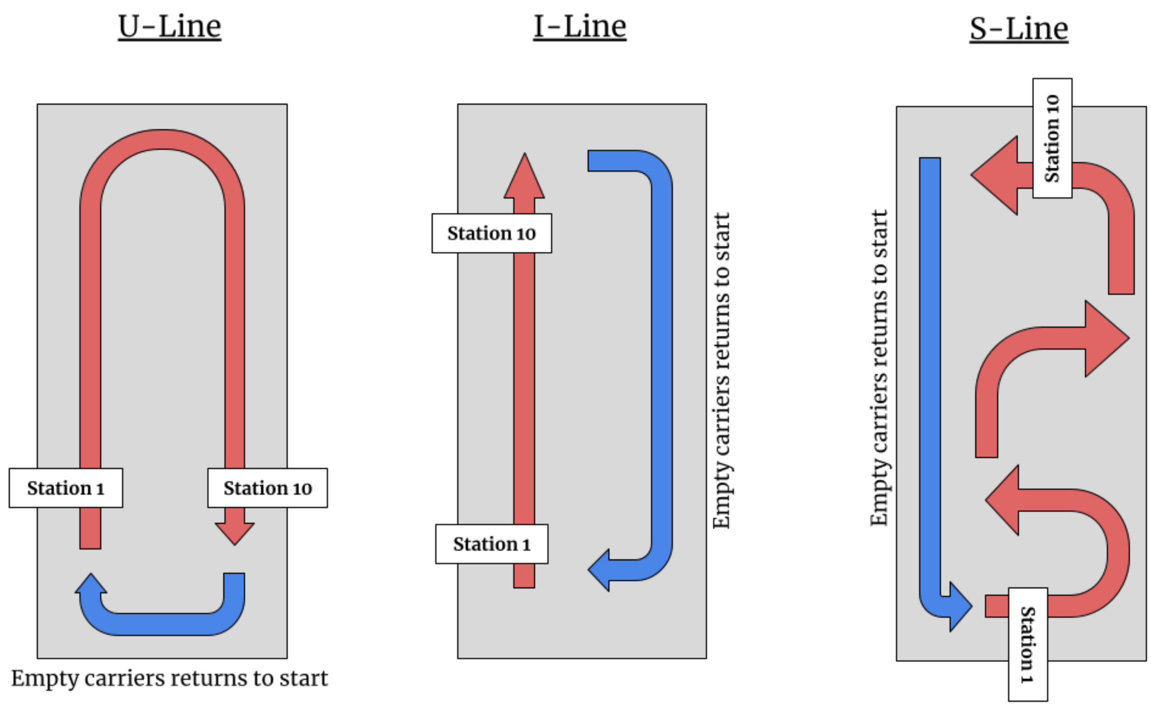

Figure 5 - Different shapes of assembly lines

The carrier system will always be in a "closed loop" since the individual carriers in the system are always transported back from the delivery point (where finished axles are delivered) to the starting point (where empty carriers are loaded with new rear axle bridges).

4.6.2.1 I-shaped assembly line

The option of a straight I-line has several benefits. Firstly, it is simple for team leaders to get an overview of the entire assembly line. Furthermore, it is also possible for installers to work with the load carrier from two sides simultaneously. Finally, an I-shaped production line provides the most space for material storage, enabling storing of material on both sides of the line, which reduces costs for the logistics department.

One major challenge with an I-shaped line however is how to close the loop and return the load carriers from the end of the line to the start of the line. At Scania, the different Zones at the rear axle assembly line do not share the same carrier systems. This means that there needs to be a return loop between station 10 and station 1. The empty carriers can be returned above the line, under the line (under the floor) or next to the line. Returning the load carrier beneath or above the assembly line requires substantial construction investment and having them return next to the line requires a lot of space which is also not preferred.

The I-shaped line will have the most "waste" in terms of carrier length which is not used for value-adding work. The return path, where empty carriers are returned, is equally long as the main path where work is conducted. This results in a material waste, but it does not always have to be a monetary waste. This is because the production and installation cost of an I-shaped line could be lower than for an S-line. The S-line will have several turning areas which are more complex both to build and install, which can drive costs.

Another challenge with an I-shaped assembly line specifically at Scania's rear axle assembly in Södertälje is that the currently used line is U-shaped. This means that the available space for a new assembly line is not ideal for constructing a long assembly line.

4.6.2.2 U-shaped assembly line

The present assembly line has a U-shaped design. Having a U-shaped assembly line removes the issue of returning the load carriers. Since the loop is almost closed by its natural shape, no substantial investment in construction or space is required to close the loop. Furthermore, a U-shaped design enables the possibility of utilizing the turning points for assembly, rather than making closing the loop and returning the load carriers the only task. For instance, the current station 6 (where the load carriers change direction) line is both a turning point as well as an automated station. Moreover, station 11 both performs a handover to Zone 2 as well as return the load carrier to the beginning of the line within Zone 1.

Another benefit with U-shaped lines is that all stations are tightly packed together. In comparison to the I-shaped line this creates a shorter walking distance in between stations. This is essential during increased takt times, for example during the night shifts at Scania. During the night shift, takt time is doubled and staffing is halved. Having shorter walking distances between stations means that the operators can perform work at two adjacent stations during one takt.

Reduced distance between co-workers can increase the sense of togetherness and improve teamwork between the operators working at the line. More than bringing operators closer to each other, the reduced distances between stations has been shown to increase labour productivity, often by more than 10%, at U-lines compared to I-lines (Aase et al., 2004)

The main drawback with a U-shaped assembly line in comparison to an I-shaped one is that it does not provide as much room for material storage as an I-shaped line. Normally the space within the U is assigned to workstations and space for walking in between them. This results in most U-shaped assembly lines having roughly 50 % of the space for a material facade that an I-shaped line with the same amount of workstations would have.

4.6.2.3 S-shaped assembly line

The S-line is practically a repeating U-line, which can be suitable for very long lines. It is a space efficient solution if there are many stations on the line. The S-line will be shorter compared to the I- and U-line, but it will require more width in the factory.

The rear axle assembly line Zone 1 is not long enough to justify an S-line, where the added turns compared to a U-line would have complicated the flow and caused a waste of space at the turning points.

4.6.3 Ground level or raised assembly line floor?

When implementing a new assembly line, one has to decide if the assembly line should be floor-level, elevated or if the load carriers should be above the floor by hanging from something.

There are various benefits with having a carrier system that is either ceiling-hung or level to the factory floor. The main advantage is that a level floor facilitates the job for logistics regarding material delivery. For instance, the current Scania assembly line floor and carrier system is raised above the factory's ground level. This complicates the task of introducing AGV carriers for the logistics department (illustrated below).

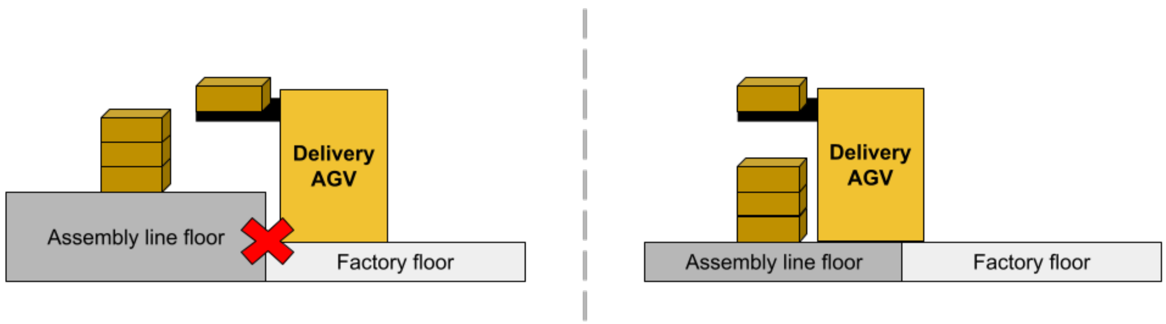

Figure 6 - Differences in floor level of assembly line and factory

Secondly, an assembly line that is not elevated is also preferred from an ergonomic perspective since it removes the need to climb up and down the assembly line floor. When the carrier system is ceiling hung, it is also easy for workers to access the carried material, since their feet can fit beneath the load carrier.

Furthermore, ceiling-based carrier systems often provide good accessibility since the carried material can be handled both from above, from below and sideways.

The main drawback of having a floor-levelled assembly line is that it often requires additional investments. First of all, not all factories have sufficient infrastructure to support a ceiling-based carrier system. Therefore, it often requires considerable investments to be able to support a roof-based conveyor system. Secondly, the cost of levelling the assembly floor with ground level is significant. According to Johannes, the additional cost for immersing a palette system to the floor could be in the range of 1 - 5 MSEK.

Furthermore, the cost of maintenance for an immersed carrier system might be even more important to consider than the additional cost of digging the hole. This is because an immersed carrier system needs to have space available for maintenance teams to access the carrier system. If there's not enough space, maintenance can turn out to be far more expensive than anticipated. This can be accounted for by involving the maintenance teams early in the planning process of the new carrier system. It is an important area to consider early on, and it has been overlooked in the past at Scania, according to Johannes.

4.6.4 Positioning tolerances - starting at the carrier system or workstations?

Fully automated stations require very high precision to operate. This precision can be measured as a stationing tolerance, in which the carrier and the rear axle bridge's station is allowed to vary. For an automated station equipped with an industrial robot tasked with entering screws, the tolerance needs to be very fine. Required tolerances are in the levels of tenths of millimetres for a rear axle bridge with a central gear weighing over 300kg. Historically, these fine tolerances have not been needed thanks to the agility and precision of human workers. With automated stations, precision needs to be increased, and this can principally be achieved in two ways.

One option is to have the complete carrier system constructed with the required precision. This can be achieved by a very rigid construction and by docking the individual carriers/pallets into a fixed space on the floor at each station.

The second option is to have a cheaper and less precise carrier system, such as an AGV system for example, and have each station recalibrate for each takt. This can be achieved by using optical sensors and computer vision systems for example.

Installing a carrier system which does not station itself according to the required tolerance is a lot cheaper than a carrier system that does. However, there are also drawbacks with assigning the tasks of stationing to each automated station.

Firstly, the option of using computer vision systems and optical sensors usually leads to more problems than anticipated. They can take several months to reach desired uptime, even if they use machine learning techniques to continuously improve.

Secondly, these systems are not rigid. If they are moved during scheduled maintenance or by accident, they will require time consuming recalibrations. Since we are working with large and heavy rear axles, considerable forces are in play at all times and screwdrivers will require high amounts of torque. This might cause the axles to move or vibrate unexpectedly during assembly operations, which could cause problems.

Thirdly, if the assembly line will have various automated stations, the aggregated costs of the stationing systems for each automated station may exceed the costs for managing stationing by the carrier system.

Finally, if the automated station interacts with the rear axle in a way which moves the load carrier by a few millimetres, the calibration made will then be worthless and the other task will also have to stop.

4.7 Lifting tools

For the handling and lifting of heavy objects manufacturing companies like Scania utilize lifting tools in order to facilitate the task. There are many challenges and factors to consider when installing a lifting tool onto an assembly line. Below is a summarization of factors that drive complexity and price when installing a lifting tool.

4.7.1 Ergonomics

Repetitive heavy lifting is an activity that may cause physical stress and ultimately results in work-related injuries and sick leave. According to Scania, the main driver for installing lifting tools at the assembly lines is to improve the internal ergonomic classification of a workstation.
A combination of the wide range of variants produced at the assembly line and the fact that the installers who work at Zone one is of different heights and preferences entails that lifting tools need to be modified based on working station.

4.7.2 Productivity and manageability

The required manageability for a lifting tool is also a driver for complexity and price. The shorter timespan the installer has in order to carry out the work and the more variants the lifting tool is required to handle, the higher the complexity and price becomes.

4.7.3 Safety concerns and certifications

In order to avoid injuries and quality deviations in the assembly line safety is a major concern for lifting tools. If it is a complex challenge to counteract the risk of an item being dropped, or for the lifting tool to collide with workers and/or other tools the price for the material and instalment will increase. At Scania it is desired that all lifting tools are CE-marked for the application and weight it carries out.

4.7.4 Space constraints

Depending on the planned or currently available space at the assembly line the price can often differ. Lifting tools that can be installed with stingy space restrictions are oftentimes more expensive.

During the expert interviews at Scania, an ongoing project with the objective to replace the lifting tool at station 5 was encountered. The main driver for the replacement was the fact that the current tool is only used for the heaviest variants because it made the lifting too time consuming. This resulted in the station receiving a red ergonomic classification because of the manual lifting.

The project had boiled it down to four different quotas from different suppliers, all within a similar price range. In order to avoid duplicating already completed work and reach the same conclusions it was decided that their solution would be implemented in the proposal for a new assembly line in the research project.

4.8 Overview of the current rear axle assembly at Zone 1

It is important to understand in detail what steps the currently used assembly process for the rear axle consists of. To design an assembly process that not only offers more flexibility, but also performs better than the current process in terms of cost, efficiency & safety, the current process needs to be analysed in order to use it as a benchmark.

The rear axle assembly line, internally referred to as BAX, consists of four different assembly areas. These are called zones and are numbered from 1 - 4 in chronological order of assembly. Given the limitations in the scope, this section will focus on Zone 1 in the BAX. In Zone 1, there are mainly three things happening:

- The central gear is mounted to the bridge of the rear axle.
- Oil traps and vent pipes are mounted on the rear axle.
- For some of the Scania trucks, a spring system will also be installed.

At the end of Zone 1, each rear axle will be lifted onto a conveyor system called TMS, from where the axle is then carried to Zone 2. This conveyor system is used to ease the rest of the assembly process in Zones 2 - 4.

The assembly process in Zone 1 is split into 10 separate stations, also referred to as positions. All of the rear axle bridges first arrive at station 1 and ultimately leave Zone 1 after they have passed through the 10th station. A station or position can either be completely manual, semi-automated or fully automated. This is summarized in table 2 below. Below in this section follows an in-depth description of the 10 stations in Zone 1.

The work instructions for every rear axle are defined on a piece of paper. Currently, the paper order is printed at station 1, and gets stamped or scanned throughout the stations in the zone for quality assurance, and finally leaves the zone signed after station 10.

Table 2- Summary of tasks and tools at each station in the assembly line

Station #	Description	Type - Tools
1	Bridges arrive from logistics and are placed and secured on the carrier system. Oil traps are mounted on some axle types.	Manual station. Heavy lift arm used to lift the bridge.
2	Screw for central gear assembly is entered into the bridge. Oil traps are mounted on some axle types. Some axles will be marked with a pen to ease the seal process in step 1.7.	Manual station. Screws are manually placed in the bridge. Markings are done using a pen and an overlay template.
3	In case of a spring system to be added, this will be done in stations 3 and 4. Screws are entered in stations 3.	Manual station.
4	Entered screws in station 3 are tightened.	Manual station.
5	Vent pipes are mounted on the bridge. A temporary lifting device is mounted to enable the carrier system to transport the rear axle from station 10 in Zone 1 to the first station in Zone 2.	Manual station.
6	Screws entered in station 2 are tightened by an industrial robot equipped with computer vision. If the robot fails to recognize or screw a bridge, the team leader is notified, who then can complete the job manually at a designated area.	Fully automatic station. Industrial robot caged within a fence.
7	A packing, to seal the gap between the central gear and the bridge, is applied. Some axles require a custom-made silicone packing, which was marked in station 2, and is applied here.	Manual station.
8	Central gear, arriving directly to station 8 from the CVX assembly, is lifted into the bridge. Screws and nuts to mount the central gear are entered.	Manual station. Heavy lift arm used to lift the central gear.
9	Nuts are tightened using a torque wrench.	Manual station.
10	Screws are tightened using a robotic screwdriver.	Semi-automatic station. Screwdriver is manually led into station by the operator.

Figure 7 below is used to illustrate the stations and zones in the BAX rear axle assembly area. The arrows represent the flow of the assembly line and the delivery of large components from logistics. Each axle in-progress is moved to the next station after the end of each takt. In the manual and semi-automatic stations, there is one operator per station yielding ten operators during normal operation. There are also normally two team leaders, supervising the Zone who are ready to assist in any station.

The operators have been trained to work at all positions. They perform six takts at each position before rotating, counter-clockwise to the assembly flow, to the previous position. The rotation does not only create a more varied and stimulating work environment, it also means that all operators in Zone 1 can cover up for each other at all positions if abnormalities occur. The rotation is always counter-clockwise to the assembly flow to guarantee that no operator performs two positions on one individual rear axle. This allows for better quality control since more people can check each other's work.

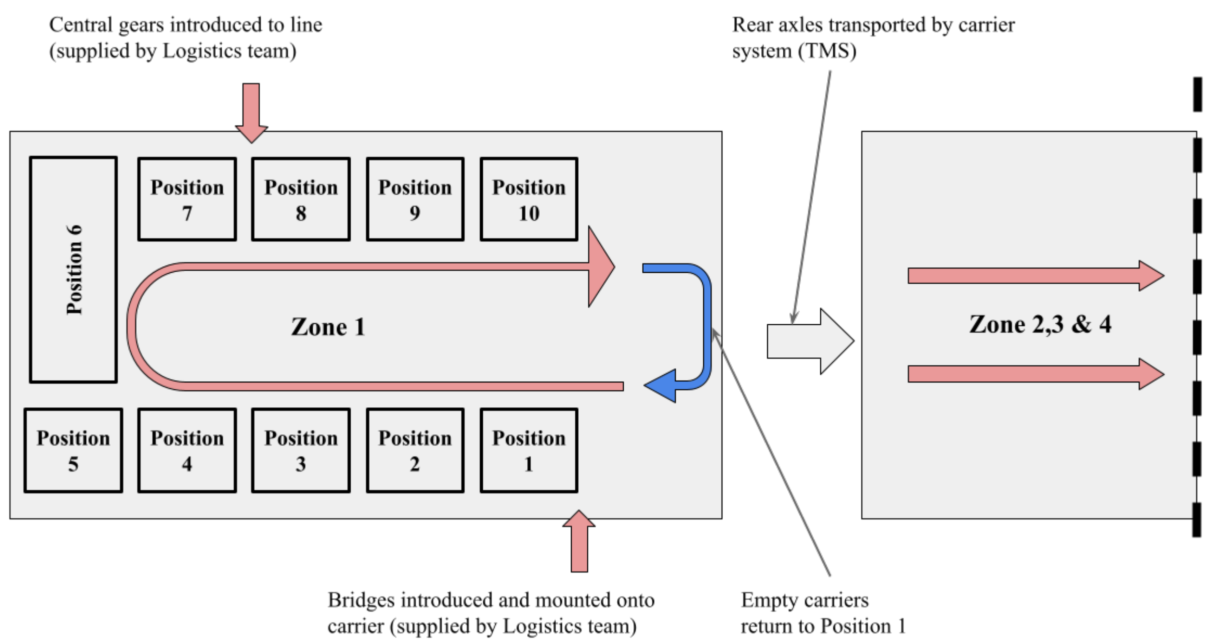

Figure 7 - Schematic overview of Zone 1 and its stations throughout the assembly line

4.9 Analysis of the current assembly line solution at Zone 1

Before developing the next generation's rear assembly line, we looked at the existing line to identify areas of improvement and which parts of the line that performs well. Below is a status summary of our analysis of the stations in the line today. An additional 10 in-depth sections covering more details of each of the stations is presented in *Appendix A: In-depth analysis of each assembly station in Zone 1.*

Table 3 - Summary of takt time utilization, type of station and ergonomic SES-rating of each station

	Takt time	**Manual / automatic**	**# Red erg. markers**	**# Yellow erg. markers**
Station 1	71,1 - 79,9	Manual	6	9
Station 2	41,6 - 80,9	Manual	0	2
Station 3	0 - 79,7	Manual	4 + 2 double reds	4
Station 4	0 - 79,6	Manual	6	2
Station 5	71,2 - 80,5	Manual	9	9
Station 6	78	Automatic	-	-
Station 7	26,8 - 79,4	Manual	7	3
Station 8	76,6 - 78	Manual	4	2
Station 9	67,1 - 79,6	Manual	10	15
Station 10	79,6 - 80	Manual	10	6

4.10 The future design of electrical powertrains at Scania

As mentioned in section 1.1.5, the traditional design of an ICE-powered truck places the engine at the front, and utilizes a cardan shaft to transfer power and torque from the engine on to a central gear and finally to the wheels mounted to the rear axle. According to employees at Scania, there are two main reasons for this. First off, due to the construction of modern ICE-engines and the cargo space container at the back of the truck it is very challenging to fit the motor at the back of the vehicle. Therefore, the motor is almost always placed at the front of the truck in order to maximise the cargo load capacity.

Secondly, rear-wheel drive is the best suited powertrain design for trucks. Because of the cargo container, the majority of the weight is often placed onto the rear axle of the truck. More weight results in more traction, and therefore a front-wheel driven truck would not have enough traction on the driven wheel pair, especially when going uphill. Furthermore, if the front wheels would be connected to a powertrain this would inhibit the ability to steer the truck and reduce the steering radius.

When interviewing Scania employees on the topic of future electric trucks and the resulting changes to the rear axles, it was communicated that several and quite different concepts are being developed in parallel. There is a lot of uncertainty regarding the design of the next generation's rear axles. However, one clear recommendation from the Scania employees was to expect and account for increased weight of new rear axle modules.

4.11 The economy of a rear axle line

This section is dedicated to the costs and cost reductions associated with an assembly line at Scania, either directly or indirectly.

4.11.1 Labour costs at the assembly line

Developing and running an assembly line at Scania will carry several types of direct and indirect labour costs. Some are fixed costs attributable to the initial investment and installation of the line. These include assigning engineers to develop the line, who could have been tasked with other projects elsewhere.
The most significant share of these costs are variable costs attributable to the assembly line operator's running salary costs. Therefore, a simplification is made here to focus only on these running salary costs.

The total cost of an assembly line operator at Scania in Södertälje is estimated to be 500 000 SEK per year. This accounts for salary, employer contribution and social costs.

When automating stations at the rear axle line, the needed number of operators is reduced. Manual labour is replaced by automated workstations. This does, however, not lead to direct layoffs and employee turnover with their respective resulting costs. Scania employees, whose work responsibilities are replaced by automated stations, will be offered new and similar roles within the factory. The salary costs will therefore continue to exist within Scania, but in a new P&L carrying division. Therefore, automating and replacing one operator will still be considered as a cost reduction of 500 000 SEK per year for the rear axle line assembly.

4.11.2 Labour costs as a result of production rate

Scania produces rear axles at a variable production rate that can be changed between a day and night shift the same day, if needed. The baseline, which is considered a 100% production rate, is when the rear axles are assembled at the normal takt of 80 seconds. An assumption, made by Scania, is that the 100% production rate is kept during all day shifts during a year. This is not the case for the night shifts, which can vary between 50% to 100% production rate during the year, depending on what capacity is needed.

At Zone 1 of the rear axle assembly line today, 8 operators are working simultaneously at the assembly stations during a normal, 100%, production rate. There are also two Team Leaders (TL) working at a normal rate. During a night shift, with a 50% production rate, the takt time is 160 seconds instead of the normal 80. Therefore, the number of operators can be reduced since each operator can perform twice the work during a longer takt. Currently, 4 operators plus 1 TL are needed during the 50% production rate.

It is important to note that the number of needed employees is not directly proportional to the production rate. This is easiest illustrated in an example where 9 operators are needed during a 100% rate. When slowing down to a 50% rate, only 4.5 operators would be needed in theory. This, of course, means that in reality 5 operators are needed to perform the work on time and in this case the production rate decrease leads to a direct form of labour waste and underutilization of the workforce. When designing a new assembly line, it is therefore needed to consider the different production rate scenarios and their corresponding labour utilization and costs.

4.11.3 Payback periods and internal rate of returns

Building a new assembly line requires significant investments made in an early stage. The existing line needs to be removed, all the industrial machinery and tools need to be purchased and all the parts of the line needs to be installed - all of this which requires direct investments. There is also a full production stop (even if the industrial summer break can be used to partly reduce the production stop) and a period of testing and trial runs at lower speed required, which causes indirect costs. However, the duration of a needed production stop can be reduced if the assembly line is first constructed at the supplier's own site, where the first stages of testing can be conducted. While building the line at the supplier first will reduce the duration of a full production stop, it will likely increase the cost of the new assembly line.

Part of the objective when designing a new line is to find cost reductions and make the line run in a more cost-efficient way than before. But simply designing a production line that will run cheaper than the previous line is not enough to justify the investments needed. The new rear axle assembly line project is only one small part of the Scania and Traton Group, where a large number of projects compete for limited resources.

Therefore, both the expected payback period and the internal rate of return are important factors to consider. Scania usually requires an investment where production equipment is exchanged to yield an annual net positive effect that pays off the initial investment in 2 to 3 years' time after installation. This time period is referred to as the payback period and is measured in years.

However, the specified payback time cannot be used for investments which are non-optional, for instance renovating an old and malfunctioning assembly line.

4.11.4 Stoppage time in production

Stoppage time at the assembly line is the time that is required to stop the assembly line flow entirely to resolve any problem or anomaly that has occurred. There are several types of causes that can lead to a full stop. Examples are if an operator makes an error needing to be adjusted outside the takt time, if the inbound material to the assembly line would stop or if any machine or part of the line malfunctions. Shorter stops, shorter than a minute, occur every day at the assembly lines. Longer stops also occur, albeit less frequently.

When automating workstations at an assembly line, the stop behaviour is changed. Fewer operators working at the line will likely result in a fewer number of stops caused by human error - assuming the operators perform similarly as before. At Scania, automated stations cause a higher number of machinery and tool malfunctions.

This change in behaviour of the line, seen as one unit, is important to anticipate estimates. One hypothesis, based on previous automation projects at Scania, is that stops in automated cells generally take longer time to resolve than manual errors. Therefore, the automated cells need to have fewer stops per day than the current manual stations have to result in the same total stoppage time of the line.

This leads to yet another consideration. When procuring complete solutions for automated stations, an important part of the requirement specification is the operational reliability. The operational reliability is the expected performance of the automated station, which is the number of production-stops directly caused by the automated station itself (this excludes stops such as inbound logistics shortages) during operation. Of course, requiring a higher operational reliability from the supplier of an automated cell will drive increased costs for procurement. The higher quality comes at a cost.

The consideration to make is therefore at which level of operational reliability that should be demanded from the supplier. The cost of increased reliability needs to be compared to the cost of production stops per unit of time. This is often referred to as stoppage cost and is calculated as a cost per minute based on the production volumes and order values. Stoppage cost varies within different assembly lines at Scania and will not be publicly disclosed.

4.11.4.1 The cost of stoppage time at Scania

In order to be able to calculate the potential cost of increasing the stop time when exchanging a manual station with an automated robot the stop time needs to be calculated. At Scania, the investment & business controller unit estimated the costs in SEK, per minute, is the following for these different assembly lines:

Table 4 - Breakdown of total cost per minute of production stop

Total cost per minute - driven rear axles	**X+Y+Z SEK per minute**
Rear Axles Line	X SEK per minute
Central Gear Line	Y SEK per minute
Axles Paint Shop Line	Z SEK per minute

The stop time cost is relevant for all three assembly lines, since the Central Gear Line is prior to the Rear Axles Line, and the Axles Paint Shop Line is the subsequent line after the Rear Axles Line. This means that if the Rear Axle Line stops for a longer period of time, both previous and subsequent lines will stop as well.

In order to calculate the percentage of stop time at a workstation at Scania, data from the Scania PUS-system was used. At Scania PUS all assembly line stops are registered and saved for future consideration.

The following process was used when extracting data from the system:

- Two periods were chosen: 1st October - 30th November 2020 & 20th January - 20th March 2021. These time periods were chosen since they occurred recently with the automated station 6 in place, they do not include any big holidays such as Christmas, new-years, Easter etc.
- Stop time data from these periods were extracted and all stops that were not due to error of the worker or the tools being used at the station were removed.

The total working time for the time period was calculated using the logic presented in table 5 below:

Table 5 - Total working time during selected periods of observation of assembly line stop times

Shift	**Time in hours (Mon - Thu)**	**Time in hours (Fri)**
Day shift	7:14:00	7:20:00
Night shift	7:15:00	3:37:00
Total	14:29:00	10:57:00
Time period	**# Days (Mondays - Thursdays)**	**# Fridays**
Oct & Nov 2020	34	9
20 Jan - 20 mar 2021	34	9
Both periods	68	18
Total working time	984:52:00 [hours]	197:06:00 [hours]
Combined working time	1181:58:00 [hours]	

Afterwards, the aggregated stop time for a workstation during the time period was divided by the combined working time above in order to calculate the percentage of stop time. The result is displayed in table 6 below:

Table 6 - Stop time percentage of stations during selected observation period

Station	**Stop time (%)**
1:2	0,02 %
1:4	0,08 %
1:6	0,72 %
1:8	0,04 %

Looking at the stop time of the current workstations it is evident the manual stations have a significantly lower stop time than the current automated station. The current automated station does not live up to the desired minimum of 99,5 % uptime either.

Furthermore, in the analysis of the stop time for the different stations it was noted that:

- The average stop is between 8 - 34 seconds for each station.
- Only roughly 1 % (1,35 %) of stops last for more than 3 minutes (more than 2 takt times).

Since the cost is only X+Y+Z per minute when the stop is long enough to also halt production in the previous and following production line (Paint shop and Central Gear) we assumed that the buffer within and between the assembly lines keep them running for shorter stops. Hence the cost at X SEK per minute is relevant when calculating stop time cost.

4.11.5 Lowering the takt time

It is not desirable for Scania to increase the pace of production at Zone 1 due to bottlenecks at other business units of the factory. For instance, if Zone 1 were to lower the takt time by 20 % it would not directly result in an overall higher production output since the previous and following assembly lines would likely still remain at the current production pace. Due to the interconnection of different assembly lines, the takt time needs to be reduced collectively throughout the factory in order for the production rate to be reduced.

However, reducing the takt time at a workstation enables the reduction of the takt time in the future. Furthermore, a workstation which only utilizes a portion of the takt time can be considered to be more flexible. This is due to the fact that it provides space for the introduction of new tasks such as products that require more time.

4.11.6 Reducing the number of workstations

Reducing the number of workstations at the assembly line entirely effectively increases the production rate at Zone 1 by one takt time. However, since the output is limited by the takt time this does not realize significant cost reductions for Scania unless the staffing need of one worker is reduced as a result.

Reducing a workstation only reduces the capital tied up at the assembly line, since there would always be one less rear axle in production at the area. This essentially moves the storage of the rear axle from the assembly line to the logistics department and does not affect the order size of rear axles from the purchasing department. Therefore, the only rationalization resulting from the removal of a workstation is the space in the factory that is made available for other means.

4.12 Construction of the assembly line

4.12.1 Expenditure of time for each task

Scania has a balance chart containing information regarding all current tasks at Zone 1. The times for each task are averages that have been measured during production by a production technician. Using already measured activities as a basis in combination with observations on the current line the time required for newly introduced manual tasks can be estimated. Furthermore, the time new proposed robot stations are needed are limited by the requirements made in the RFI.

4.12.2 Sequencing chart for the chronological order of each activity

All tasks and their respective subtasks in the rear axle assembly were mapped to find all dependencies. Some activities need to take place before others chronologically in the assembly, for example the Central Gear needs to be placed in the rear axle bridge before the screw nuts can be tightened. Other activities can be moved freely throughout the assembly line. By mapping all dependencies and sequencing the assembly tasks, alternative assembly sequences can be identified. This resulted in a number of options to merge tasks into new combined stations.

4.12.3 Spatial requirements for the assembly line

Initially, the size of the existing assembly line was measured using a sketch in LayCAD (figure 8). The total size of the assembly line, excluding the return of material and handover to Zone 2 which takes place between station 10 and station 1, is 16,8y + 8,4x.

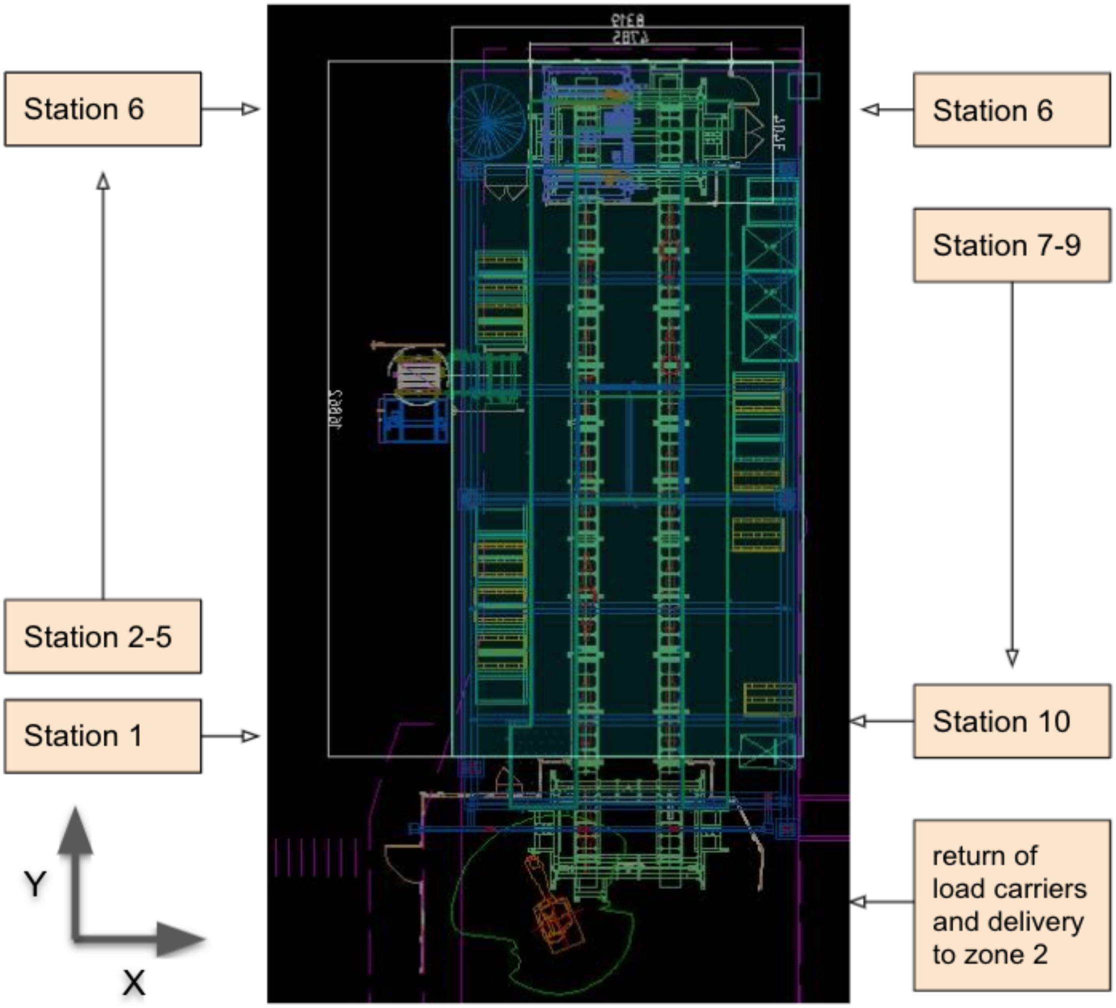

Figure 8 - Snapshot of assembly line layout in LayCAD software with added reference points

Using the size of station 6, 3,4 y + 4,8 x, the average Y-direction length of the current workstations were calculated with the following formula:

- **For station 1 - 5**: (16,8 - 3,4) / 5 = 2,68
- **For station 7 - 10**: (16,8 - 3,4) / 4 = 3,35

In order to calculate the X-direction width of each workstation the storage for materials as well as the required space for workers to move in between stations were calculated. Using the layout sketch in combination with measurements at the assembly line the size of the material storage was estimated to be roughly 1,8 meters, and the area required to walk between load carriers was roughly 1 meter. Using these measurements, the average size of a workstation was estimated to be (8,4 - (1,8 x 2 + 1)) / 2 = 1,9.

4.12.4 Sending out RFIs

Several suppliers of industrial automation solutions were contacted to receive input on the proposed solutions as well as cost estimates. The list of suppliers was created with and vetted by the Scania Purchasing department, as it is important that Scania (or other parts of Traton Group) have a prior relationship with a supplier for a project of this magnitude.

Contact was first made with suppliers to see if they would be interested in replying to a set of four different RFIs, each one covering a different automated workstation. At this stage, it was made clear that the RFIs was part of a Master's thesis project. While the intent of Scania to invest in a new rear axle line is real, the Master's thesis project serves as a pre-study stage and the final decision with an eventual order to a supplier lies ahead in time by a few years.

Following this, four RFIs was sent out to each supplier that replied positively to the first request.
The RFIs sent out were:

- Station 2: Automated screw picking & entering station.
- Station 4: Synchronized screw driving in automated robot cell.
- Station 8: Central Gear pick & place plus silicon application workstation.
- Station 10: Central gear final screw tightening station.

Each RFI was proofread by both the thesis supervisor at Scania as well as a Sourcing Manager from the Purchasing Function before it was sent out. This was to ensure that the RFIs was detailed enough and that the requirements of each station were specified in a way consistent with how Scania usually formulate requirements to suppliers.

Requirements specified in the RFIs covered spatial constraints, required operational reliability, the intended takt time and how many different product variants that each station needs to be able to handle. The exact requirements can be seen in table 7 below.

Table 7 - requirements for each station and RFI sent to suppliers

Requirements / station	**Station 2**	**Station 4**	**Station 8**	**Station 10**
Spatial constraint [m]	5,4 y + 1,9 x	3,4 y + 4,8 x	4 y + 1,9 x	4 y + 1,9 x
Takt time [s]	78	78	78	78
Uptime	Min 99,5 %	Min 99,5 %	Min 99,5 %	Min 99,5 %
# Of job variants	60+	25+	13+	12+

5. Proposed new assembly line design

The fifth chapter contains the results - which can be summarized as the proposed new assembly line's layout, carrier system, MES system and assembly stations. The cost estimates for the new line, the expected effects on ergonomics, stop times and cost reductions in the assembly are also presented.

5.1 Overview of the designed assembly line

Figure 9 represents an overview of the proposed assembly line. Each workstation is numbered according to the chronology of the current assembly line. The main changes regarding workstations include the automation of station 2, 4, 8, 10 and 7. This resulted in station 7 and 4 being removed or merged with another station.

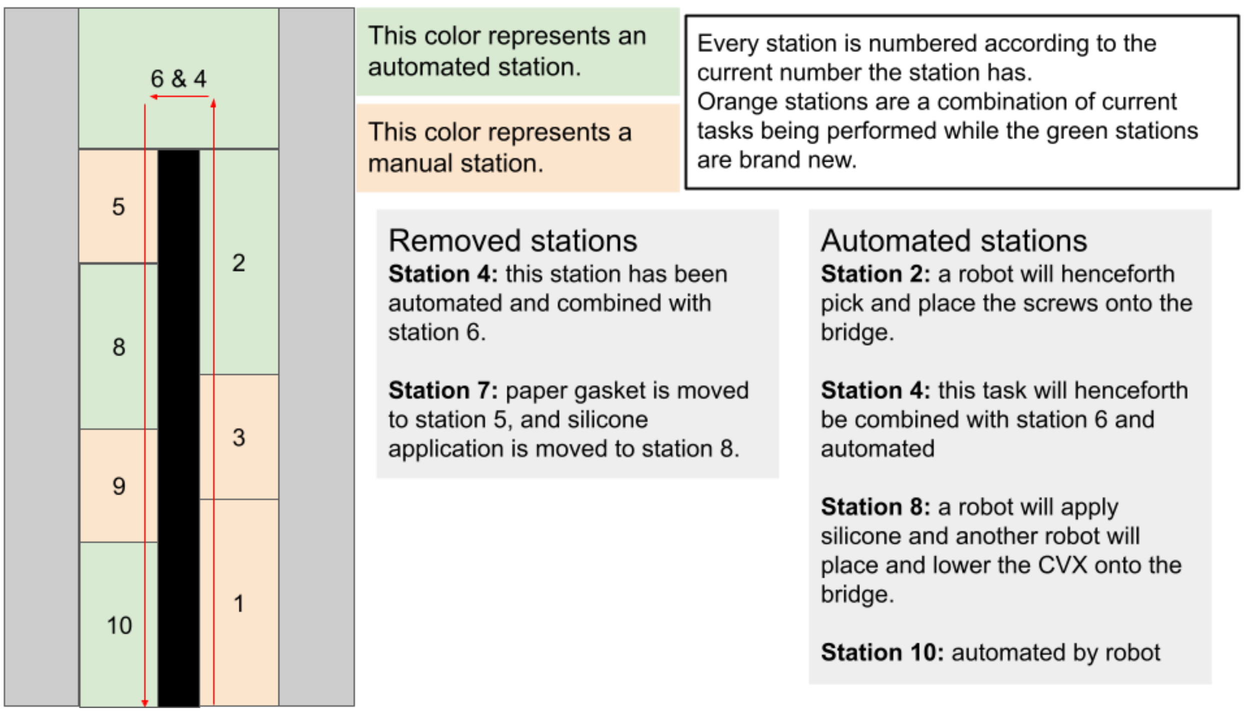

Figure 9 - Schematic overview of suggested next generation's rear axle assembly

5.2 Size and dimensions of the new assembly line

Figure 10 represents a detailed overview regarding the size of the entire assembly line, as well as the measurements of each workstation, the area where workers can move in between stations and the area intended for storage of material.

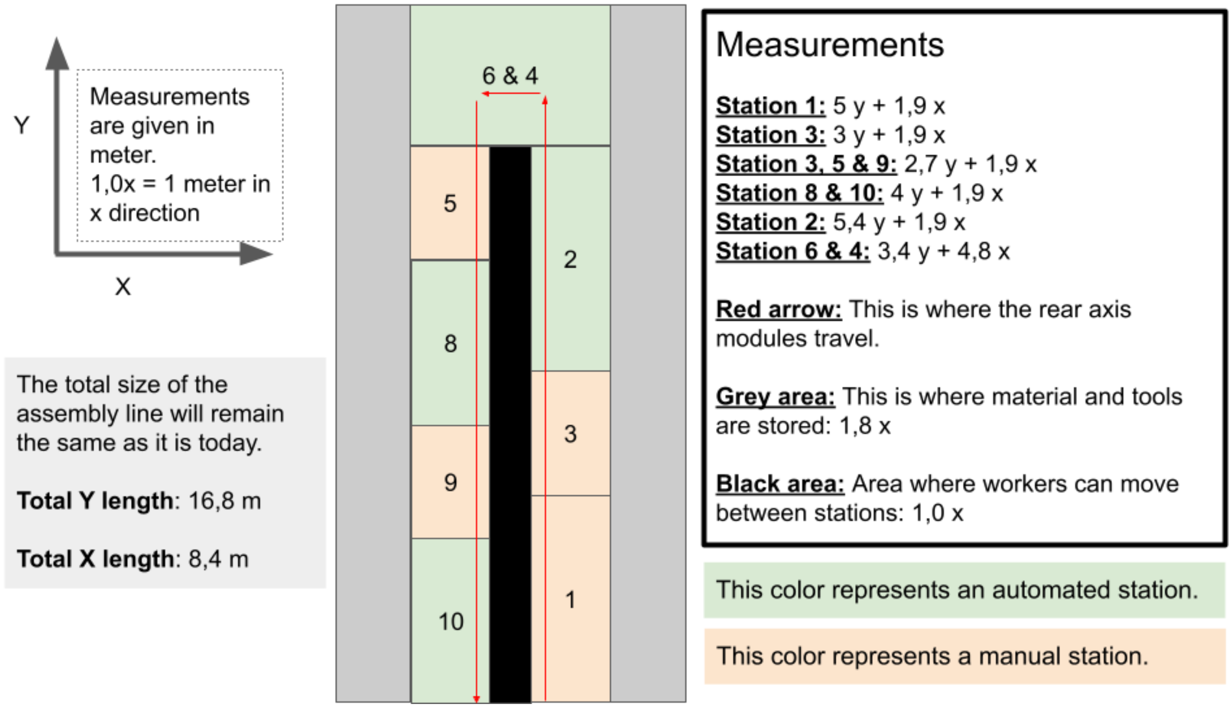

Figure 10 - Dimensions of suggested next generation's rear axle assembly

In order to give as much space as possible to the automated stations the manual stations were designed to remain their existing size. The space freed up as a result of the removal and consolidation of stations 4 and 7 was instead allocated to the automated stations. The reasoning for this decision was based on the fact that the price for an automated station increases if the supplier has to deal with space scarcity.

The reason why station 1 is significantly longer than the other stations in the Y-link has to do with synergy with the logistics department. There is a case to extend the length of station 1 at the assembly line with 1-2 m (in the Y-direction). The current length of the station is roughly 2,7 meter, and in our proposed solution it will be about 5 m long. This is to allow for storing of special support axles directly at station 1 of the line. The supporting axles are delivered from Luleå, just like the normal rear axle bridges, but they are delivered outside the main sequence. This is because the support axles only account for about 5% of the total number of axles.

These supporting axles are currently repicked within the logistics area at the Södertälje factory. If they could be delivered to and placed at the assembly line next to the normal rear axles at station 1, this could bring several benefits. According to a Scania logistics developer, the main benefits are to free up valuable time and potentially an operator at the logistics team who is currently tasked with repicking of support axles.

5.3 Staffing required for the new assembly line

5.3.1 Staffing requirement for regular of takt

Figure 11 depicts the staffing requirements for the old and new line when operating at 100 % of planned takt time. This takt time is customary during the day shift.

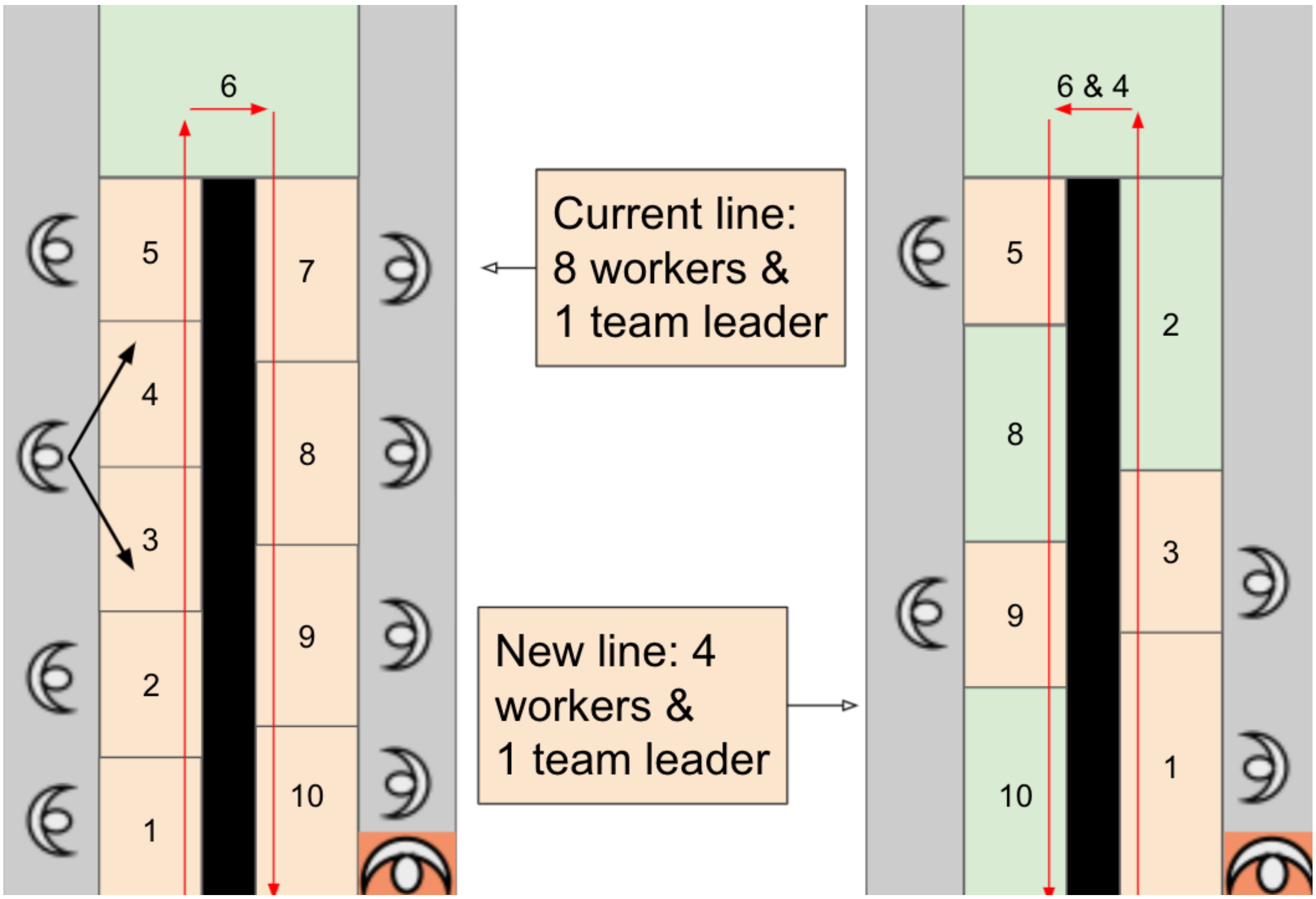

Figure 11 - Comparison of staffing requirements during 100% takt time shifts for current and proposed assembly line.

Since station 3 has a high proportion of no-job variants, it is also possible to appoint the team leader to take care of all the work at station 3, reducing the number of workers even more down to 3.

5.3.2 Staffing requirement for double takt

Figure 12 depicts the staffing requirements for the old and new line when operating at 200 % of planned takt time. This takt time is customary during the night shift.

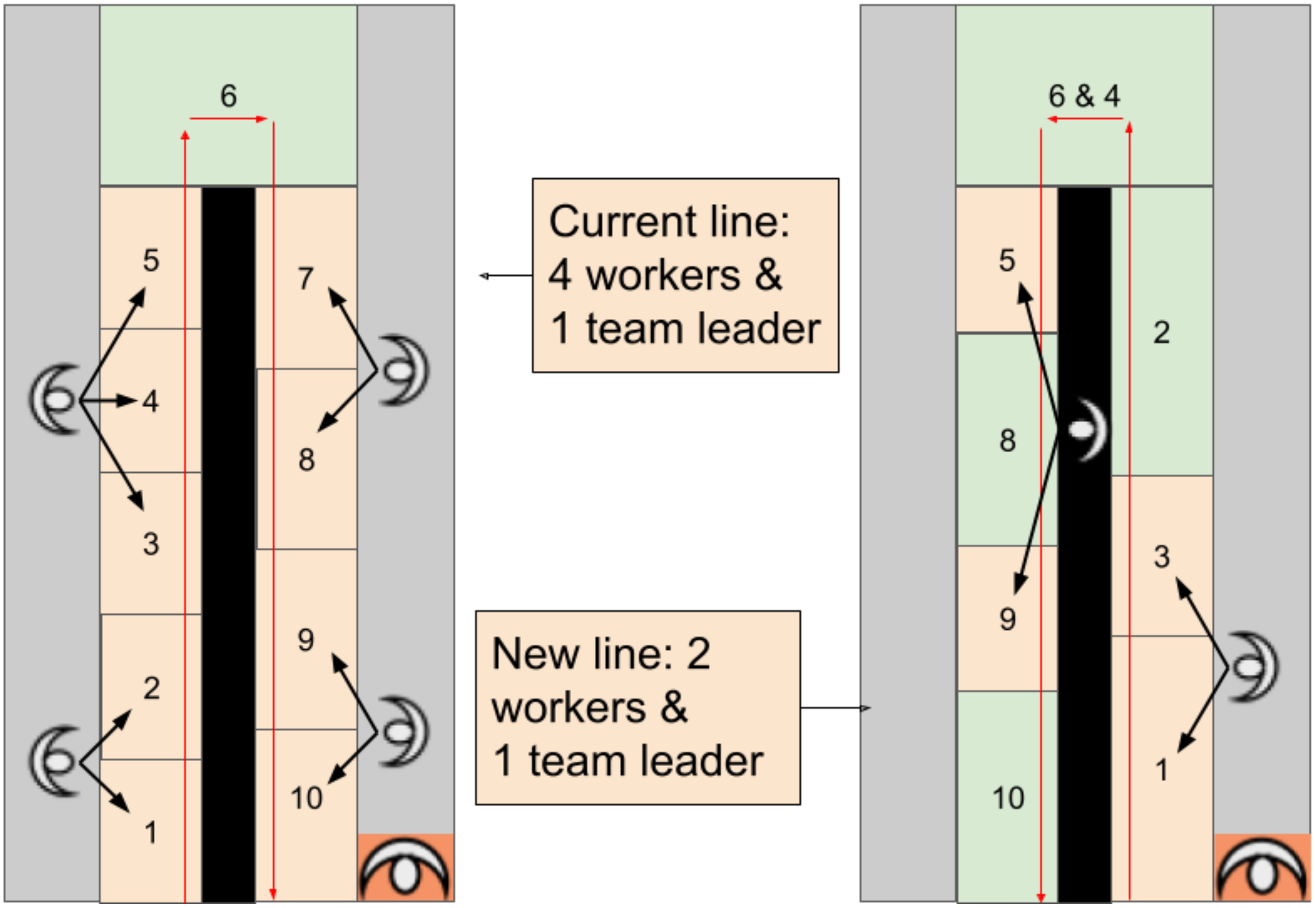

Figure 12 - Comparison of staffing requirements during 200% takt time shifts for current and proposed assembly line.

5.4 Results of RFI

For the RFIs, 7 suppliers all vetted by the Scania Purchasing department were contacted. Of these 7 suppliers, 4 suppliers returned with a full or partial price estimate. In total, 13 RFIs was answered with a price estimation out of the 28 RFIs sent out. The results of the price estimations are presented in table 8.

The suppliers asked different follow-up questions, and as a result, received slightly different levels of information about the assembly line and the intended new station concepts. Two of the suppliers followed up the RFI with digital workshop meetings.

Out of all answers received, only one questioned the spatial constraint or the takt time limitation. In follow-up conversations with the suppliers, the overall message was that each station is realistic to build within the given space and takt time requirements.

However, one supplier raised concerns regarding the merger of station 4 into the existing station 6 robot cell. The supplier mentioned that the carrier system holding the bridge needs to be extremely rigid to not run the risk of the bridge moving slightly during mounting and assembly of torque rod bracket screws from the side or the pin screws from above. The robot cell area will also be crowded with robots, potentially hindering maintenance teams to access parts of the cell. This supplier did not respond with a price estimate for this station and advised against the solution within the given spatial constraints.

Table 8 - Price estimation results from contacted suppliers

(Prices in MSEK)	**Station 2:** Automated screw picking & entering	**Station 4:** Screw driving in automated robot cell	**Station 8:** CVX pick & place plus silicon application	**Station 10:** CVX screw tightening station
Low price est.	3,75	3,2	4,3	3,25
High price est.	6,5	4,1	5,95	6
Average price est.	4,85	3,65	5,1	4,2
# of responses	4	2	3	3

A note on the received price estimations is that they to some extent might include different levels of site material and necessary installation costs between different suppliers. Suppliers were asked to provide an estimation of the total cost of buying and installing the workstation. Some costs, for testing the station and educating operators for example, might increase the total cost of some suppliers. Other costs, such as costs for dismantling the existing line, are not included in the responses at all.

5.5 Takt time of new assembly line

Table 9 summarizes the maximum (bottleneck) takt times for each new station. The summary covers both the most time-consuming rear axle variants with disc brakes as well as the ones with drum brakes.

Table 9 - Estimated required takt time of new assembly stations

Station	**Takt time [s] (disc brake)**	**Takt time [s] (drum brake)**
1	60,6	73,7
2	Max 78 (robot)	Max 78 (robot)
3	79,8	79,7
4	Max 78 (robot)	Max 78 (robot)
5	74,1	53,4
6	Max 78 (robot)	Max 78 (robot)
7	Removed	Removed
8	Max 78 (robot)	Max 78 (robot)
9	57,9	59
10	Max 78 (robot)	Max 78 (robot)

The station with the highest takt time, which also sets the lowest possible takt time for the entire station, is station 3. The takt time for the assembly line will therefore be roughly 80 seconds initially.

In contrast to station 8 the other manual stations, 1, 5 & 9, have between 6 - 20 seconds of spare time each takt. Furthermore, it is also important to mention that station 3 has a lot of no-work variants. For the variants where station 1, 5 or 9 have spare time and when station 3 has a no-job variant the workers will be able to either help out co-workers or complete tasks such as filling screw feeders at automated stations with screws

5.6 Carrier system for the new assembly line

The carrier/conveyor system used for the next generation's rear axle assembly introduces both significant changes to the current one as well as keeping some similarities.

5.6.1 Type of carrier system

The transport system to be used could be either one of two options:

1. A rail-based pallet conveyor similar to the current one. For this option the rear axle bridges would be transported on fixtures mounted on moving pallets.

2. A roof-based monorail system which grabs the pallets at the same contact points as the pallet system does today, but from above (see figure 13).

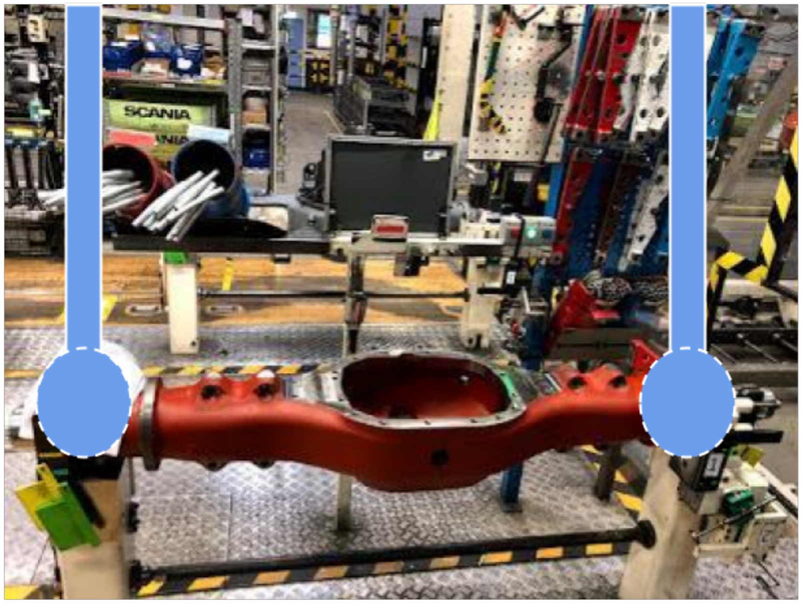

Figure 13 - Sketch of a roof-based monorail system and the two gripping fixtures (marked in blue) station in relation to the rear axle

These two systems were chosen since they are the most compatible with automated workstations, in contrast to for instance AGV carrier systems.

5.6.2 Layout of the carrier system

The first major change to the assembly line is that it has been mirrored compared to the current line. This allows the logistics team to take a shorter and quicker route when delivering rear axles to the line.

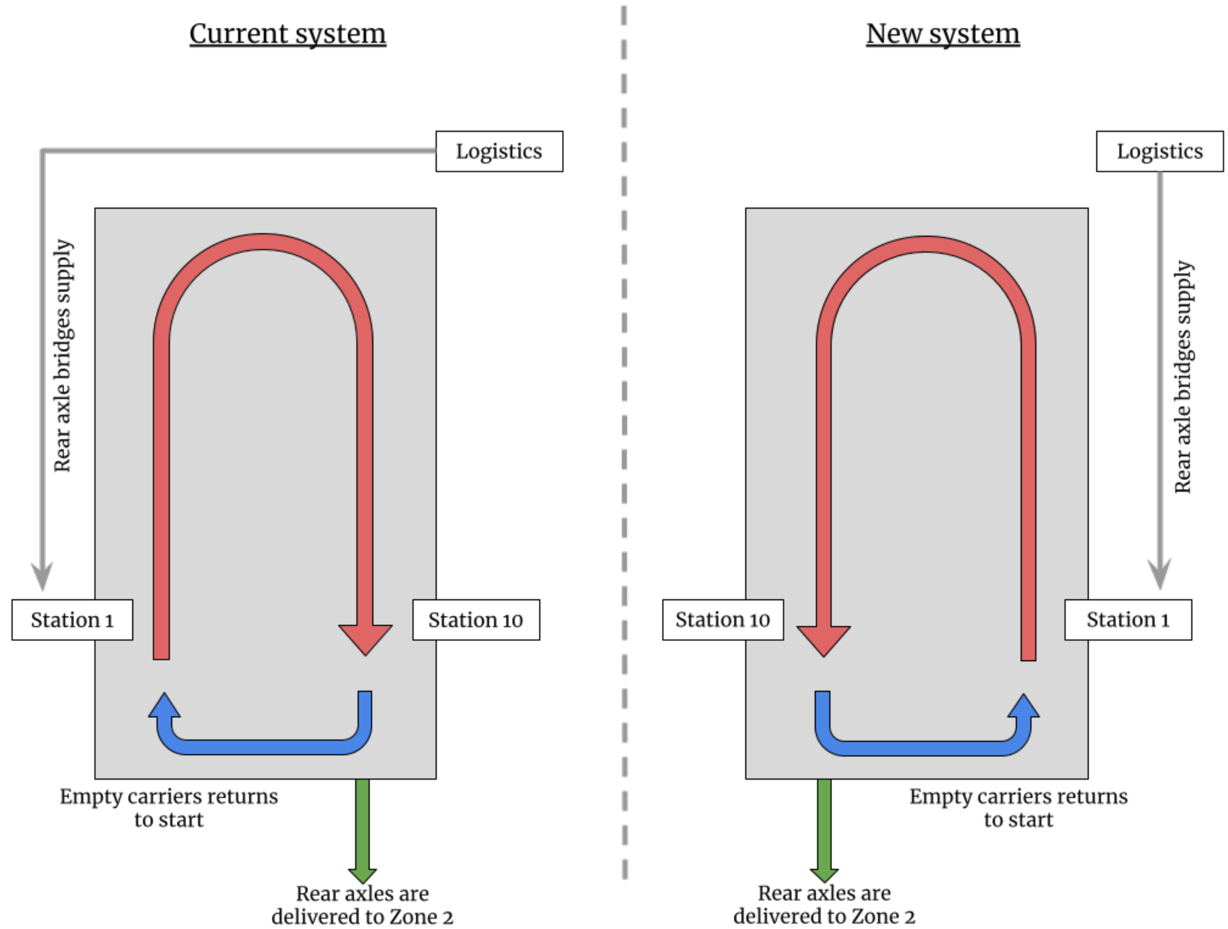

Figure 14 - Schematic overview of current and proposed new assembly line orientation

The pallets (or roof-based carrier system) and fixtures should move in a closed loop in a U-shaped assembly sequence. In addition to the fact that a U-shape layout preserves the current layout which reduces the uncertainty of the development of a new line, a U-shape is often preferred.

Assembly lines where the material flow is straight requiring the load carriers to be transported back to the start again after finishing. This can only be made with either extra space, or if a transport-loop is constructed either in the air or below the floor. These transport-loops are often very costly. A U-shaped line removes this need, and also keeps the workers closer to each other which possibly boosts morale.

The new conveyor system should be either on level with the factory floor or ceiling mounted, hanging above the floor. Compared to the current solution, the new conveyor system should not cause a height difference between the conveyor floor and the factory ground floor. This change is integral to make deliveries easier for the logistics team, who are transitioning from forklift deliveries to AGV based deliveries.

5.6.3 Continuous flow or Stop'n'Go?

Our recommendation is to use a Stop'n'Go flow in the assembly line. The deciding factor for this recommendation is the potential for automation.

We are, for example, recommending a merger of two automated tasks to be performed in the same robot cell. This will be significantly easier to implement at a Stop'n'Go line where the carrier plus bridge can be fixed and held still in a docking station in the robot cell.

Also, all the time required to transport between stations is not considered as a waste of time. Some of this time can be used for operators and robots to adjust tools and settings when switching between drum brake and disc brake variants.

Finally, a Continuous system would have resulted in time required for operators and robots to transport themselves back to the starting station of each takt. This time, spent in transport, cannot be used for adjustments of tools and settings to the same extent as the equivalent idle time in the Stop'n'Go system can be.

Based on the automation potential, the time needed for readjustments and the reduction of non-value-adding time spent on walking, it is our recommendation to opt for a Stop'n'Go-based carrier system.

5.6.4 Precision and docking for automated stations

The choice of carrier system affects the tolerance and thus the need for corrective measures such as vision systems that ensure accuracy in production. In the end, it may be a choice between a very accurate and expensive carrier system and cheaper stations, or a cheaper carrier but more expensive stations as everyone needs vision.

Since vision systems are both very costly and also may cause stop in production a decision to go for an exact carrier system with high precision, where work instructions are fed through the EBBA-system. This was estimated to be the cheapest and most efficient solution by Johannes.

The power should be supplied from the floor or from the roof, and the load carriers should be put in the right place with high accuracy for the robot cells through active docking from under the floor or from the roof (removing the need for a vision system). Active docking means that there should be a system which actively hooks onto the pallets, in contrast to passive docking where the load carrier itself adjusts its station. Active docking is oftentimes more time-efficient than passive docking.

5.7 EBBA - effects of the new order management system

The new MES-system EBBA will be implemented at the new assembly line. The EBBA system eliminates the need for scanning orders completely and speeds up the process of stamping orders after a takt completion. This will free uptime at every station at the line except from station 6, which is already an automated station.

The EBBA system and the new order management routine results in more productive time available at both new manual and automated stations. The time made available varies between the types of stations.

At automated stations, where a currently manual task will be automated, no time will be spent on scanning orders or stamping orders going forward. The automated stations will be fed with assembly instructions directly from the EBBA system and the station will digitally stamp the order upon takt completion. The effect of this is considerable and provides the robot cell with much needed time to perform the required tasks within takt time. Depending on the station, between 7,4 and 16,2 seconds of productive assembly time per takt is made available to the automated station compared to the manual order management routine.

At manual stations, which will be kept manual, the effect is still positive but smaller compared to the automated stations. This is because the EBBA system only removes the need of scanning an order completely, but the need to stamp an order remains. The scanning is replaced by digital communication through the EBBA system, which is presented to the operators on screens.

The stamping process is changed, from a physical stamping of paper to tagging a Scania-employee card on an RFID reader placed next to the EBBA screen. As a conservative measure, the process of stamping and order upon completion is estimated to take 4 seconds. It is likely that the process will require less time from the operator.

As in the case with the automated stations, the additional productive assembly time made available to the operators vary between stations. This time will vary between 4,7 and 11,6 seconds per takt.

5.8 Ergonomics at the new assembly line

Improving the ergonomics of the different stations at the assembly line is one of the main goals when designing and evaluating a new line. One standardized way of measuring the ergonomics at Scania is through the SES-reports. Therefore, the existing SES-report of the line is used to find areas for improvements.

One of the main approaches with the new line was to find areas where there is a strong case for automation. Automating a station removes the involvement of an operator from the station and resolves all the ergonomic issues that the station currently faces.

A secondary approach has been to investigate manual stations which will be kept manual and identify ways to improve these. One clear case has been station 5, where today's lifting tool and way of working is poor ergonomically. This is already being resolved through a redesign of the working station and a new lifting tool. It is assumed that all red marks will be resolved with the new lifting tool, since this is an explicit requirement formulated to the supplier of the tool. The yellow marks are not assumed to be resolved directly with the new tool.

The results of building a new line, through a SES-perspective, are presented in table 10 below.

Table 10 - Number of unresolved SES marks in current and proposed new assembly line

SES levels	Current line	Proposed line	Reduction (%)
# of yellow marks	52	28	46%
# of red marks	58	25	57%

5.9 Summarized comparison between old and new assembly line

The results of the new assembly line are presented in a comparison with the current assembly line in the table below. In *Appendix B: In-depth analysis of each new assembly line station* information on proposed changes, required equipment and required takt times is presented.

Table 11 - Brief comparison of key metrics for current and proposed new assembly line

Factor evaluated	**Old**	**New**	**Comment**
Number of stations	10 + 1	8 + 1	Station 4 & 7 removed.
Number of automated stations	1	4	Automating station 2, 8 & 10
Required workers at 100 % takt	8	4	Station 7 removed + automatic stations
Required workers at 200 % takt	4	2	Station 7 removed + automatic stations
Required takt time	80,9 s	79,7 s*	* 74 s excluding station 3
# of red ergonomic markers	58	25	-
# of yellow ergonomic markers	52	28	-
Required space	16,8 m x 8,4 m	16,8 m x 8,4 m	Remains constant

5.10 Costs and savings for the new stations

As mentioned in section 4.10, reducing the need for one employee at the assembly line results in a cost reduction of roughly 500 000 SEK per year. Currently, Scania runs two shifts each day; day shift and night shift. The day shift almost always runs at 100 % of takt time, resulting in maximum capacity. However, the night shift varies between 100 - 200 % of takt time. Therefore, the staffing often varies between 50 - 100 %.

This means that automating one station would reduce the need for 1,5 - 2 workers depending on which time the night shift is producing at. A conservative estimation indicates an automated station saves roughly 1 000 000 SEK per year, while an optimistic estimation indicates an automated station saves roughly 750 000 SEK per year.

5.10.1 Station 2 - financial info

As mentioned in section 5.4 station 2 was estimated to cost between 3,75 - 6,5 M. Moreover, automating station 2 reduces the need for one worker (present station 2). The potential payback time for this investment is displayed in table 12.

Table 12 - Payback time calculations as a function of investment cost and cost savings for station 2.

	Lowest price: 3,75 M	**Highest price: 6,5 M**
Saving 750 000 SEK / year	5 years	8,7 years
Saving 1 000 000 SEK / year	3,75 years	6,5 years

For this station to have a desired payback time of roughly 2 - 3 years the price for the robot needs to end up in the lower range of what the suppliers offered, while the takt for the night-time shift needs to be 100 %.

Furthermore, automating station 2 eliminates 2 yellow and 0 red ergonomic markers. Since reducing red ergonomic markers is a priority, this does not motivate the automation.

5.10.2 Station 4 - financial info

As mentioned in section 5.4 station 4 was estimated to cost between 3,2 - 4,1 MSEK. Moreover, automating station 2 does not reduce the need for one worker since the current assembly line requires one worker for station 3 and 4 simultaneously. However, since the current station 3 & 4 have a large portion of no-job variants, if the Team Leader would tackle the new station 3 tasks, one employee would be reduced as a result of automating station 4. That would give the payback matrix as presented in table 13.

Table 13 Payback time calculations as a function of investment cost and cost savings for station 4.

	Lowest price: 3,2 M	**Highest price: 4,1 M**
Saving 750 000 SEK / year	4,3 years	5,5 years
Saving 1 000 000 SEK / year	3,1 years	4,1 years

However, automating station 4 eliminates 2 yellow and 6 red ergonomic markers. Since removing red ergonomic markers is a priority at Scania, this motivates the investment. Furthermore, including station 4 at station 6 would remove one workstation, which saves both space and reduces the capital bound up at Zone 1.

5.10.3 Station 8 - financial info

As mentioned in section 5.4 station 8 was estimated to cost between 4,3 - 5,95 M. Moreover, automating station 2 reduces the need for two workers (present station 7 + 8). The potential payback time for this investment is displayed in table 14.

Table 14 Payback time calculations as a function of investment cost and cost savings for station 8.

	Lowest price: 4,3 M	**Highest price: 5,95 M**
Saving 1 500 000 SEK / year	2,9 years	4 years
Saving 2 000 000 SEK / year	2,15 years	3 years

The only scenario where the required payback time is not met is where both the price and yearly cost reduction is conservative. Therefore, one can conclude this is an attractive investment from an economic perspective.

Furthermore, automating station 8 eliminates 11 yellow and 5 red ergonomic markers by removing manual labour from the previous station 7 and 8. Since removing red ergonomic markers is a priority at Scania, this motivates the investment.

Moreover, automating station 8 removes one workstation (previous station 7), which saves both space and reduces the capital bound up at Zone 1.

5.10.4 Station 10 - financial info

As mentioned in section 5.4 station 10 was estimated to cost between 3,25 - 6 M. Moreover, automating station 2 reduces the need for one worker (present station 10). The potential payback time for this investment is displayed in table 15.

Table 15 Payback time calculations as a function of investment cost and cost savings for station 10.

	Lowest price: 3,25 M	**Highest price: 6 M**
Saving 750 000 SEK / year	4,3 years	8 years
Saving 1 000 000 SEK / year	3,25 years	6 years

For this station to have a desired payback time of roughly 2 - 3 years the price for the robot needs to end up in the lower range of what the suppliers offered, while the takt for the night-time shift needs to be 100 %. Furthermore, automating station 10 eliminates 6 yellow and 10 red ergonomic markers. Since removing red ergonomic markers is a priority at Scania, this motivates the investment.

5.10.5 Automation may increase cost of stop time

As calculated in section 4.10.4.1, the cost for a short stop at the Rear Axle is roughly X SEK per minute. Furthermore, the current manual station had a stop time of 0,02 - 0,08 %. If the automated workstations that replace the manual station have an uptime of 99,5 %, which is a normal requirement, that will result in a significant increase in overall stop time.

Below is a calculation showing the increased cost per month when stop time per station is increased from today's 0,1 % to 0,5 %.

Table 16 - Working hours per month at the assembly line

Number of uptime hours per month	
Number of days [Mon - Thu] -days per month	17
Total working time per day during Mon -Thu	14:29:00
Total working time on [Mon - Thu] -days per month	246:13:00
Number of Fridays per month	5
Total working time per day during Fridays	10:57:00
Total working time on Fridays per month	54:45:00
Total working time per month	**300:58:00**

Table 17 - Increased cost per month as a result of stop time increasing from 0,1% to 0,5%

Cost allocation	**Increased cost of stop time per month**
Cost per automated station	300:58:00 h x [0,5 % - 0,1 %] x X SEK / min = XYZ SEK

The cost of increasing stop time from 0,1 % to 0,5 % would be about XYZ SEK per month per station compared to the average stop time of today.

One way to put this number into context is to compare it with the labour costs.
If the cost XYZ SEK per automated station comes close to the cost savings of reducing one operator at a station, it is worth considering setting the uptime requirements even higher, for instance 99,9 %.

During discussions with suppliers, it was brought up that requiring a higher uptime is likely to increase the cost. There is likely a trade-off between demanding a high uptime and paying a premium for this, or settling for a lower uptime and cost, and running the risk of increasing stop time costs in production.

Furthermore, it is of interest to Scania to further investigate if the estimated cost above for stop time per minute is valid in practice.

6. Analysing the results

The sixth chapter contains comments on the results, risk assessments for investing in a new line, a discussion of the results in context of the research questions and an evaluation of the project methodology.

6.1 Comments on the result

6.1.1 No clear recommendation for carrier system

In our recommended solution we proposed either a rail-based pallet- or a roof-based monorail carrier system. However, due to lack of resources and price estimates no in-depth comparison was made between the two. Therefore, this report needs to be complemented with:

a) An in-depth comparison between the two alternatives.
b) RFP:s or RFIs to compare the cost of the two alternatives.

When comparing these two solutions there are two advantages with the roof-mounted carrier system which need to be considered. Firstly, a roof-mounted system would not require investments for immersing the carrier system into the floor. Such an investment would as previously mentioned require roughly 1 - 5 MSEK according to a senior engineer at Scania. Secondly, it is very likely the cost of maintenance will be significantly lower for a roof-mounted carrier system than an immersed carrier system.

6.1.2 Station 3 is a bottleneck for lowering the takt time

The current bottleneck for lowering the takt time at Zone 1 is station 3, where the takt time is unchanged at nearly 80 seconds. The second most time-consuming station is currently station 5, which requires roughly 74 seconds. This means that if station 3 could be optimized to be compatible with a takt time of 74 seconds, the overall takt of the assembly line would be reduced by roughly 5 %.

It is possible however that the takt time for this station may turn out to be lower than 80 seconds in practice. The reason for this is the implementation of the new MES-system, EBBA. For the old sequencing chart, the task of tamping with the work order varied between 5 - 12 seconds for all other stations. However, for this station it was specified to take 4 seconds only (the same amount of time we estimated stamping work orders with the EBBA system would take). It is safe to assume that stamping work orders with the new digital system will be faster than manually handling paper orders, and therefore the takt time should be lowered if all else is equal.

Furthermore, this station is identified as the one station with the most potential for improvement outside the stations we have optimized due to its low ergonomic rating. Therefore, it is not only interesting to optimize this station from a takt time perspective, but also from an ergonomic perspective.

6.1.3 An alternative may be to combine station 6 & 2 instead of 6 & 4

An alternative solution to combining station 6 & 4 at the turning point of the assembly line is to instead combine station 6 & 2 at a station prior to the turning point. Due to time constraints, it was not possible to receive RFIs for this solution. However, it was orally discussed with one of the suppliers who believed such a solution was both possible and reasonable.

There are two main reasons why this solution could be preferred.

Firstly, the automated robots at station 6 and 2 would perform very similar tasks. If the robot tasked with picking and placing pin screws could also tighten them with required torque, two separate assembly tasks could be combined into one.

Secondly, the automated pin screw station currently requires a large portion of the takt time to complete its tasks due to the fact that the palettes also need to alter its direction. If this station would be moved prior to the turning point this would free uptime which could make the combination of station 6 & 2 possible.

This change could be implemented in two ways:

1. Where station 4 is instead moved to the turning point
2. Where station 4 is kept as a manual station (if the ergonomics improvements are not considered to compensate for the cost of an additional station).

Both solutions are illustrated in figure 15.

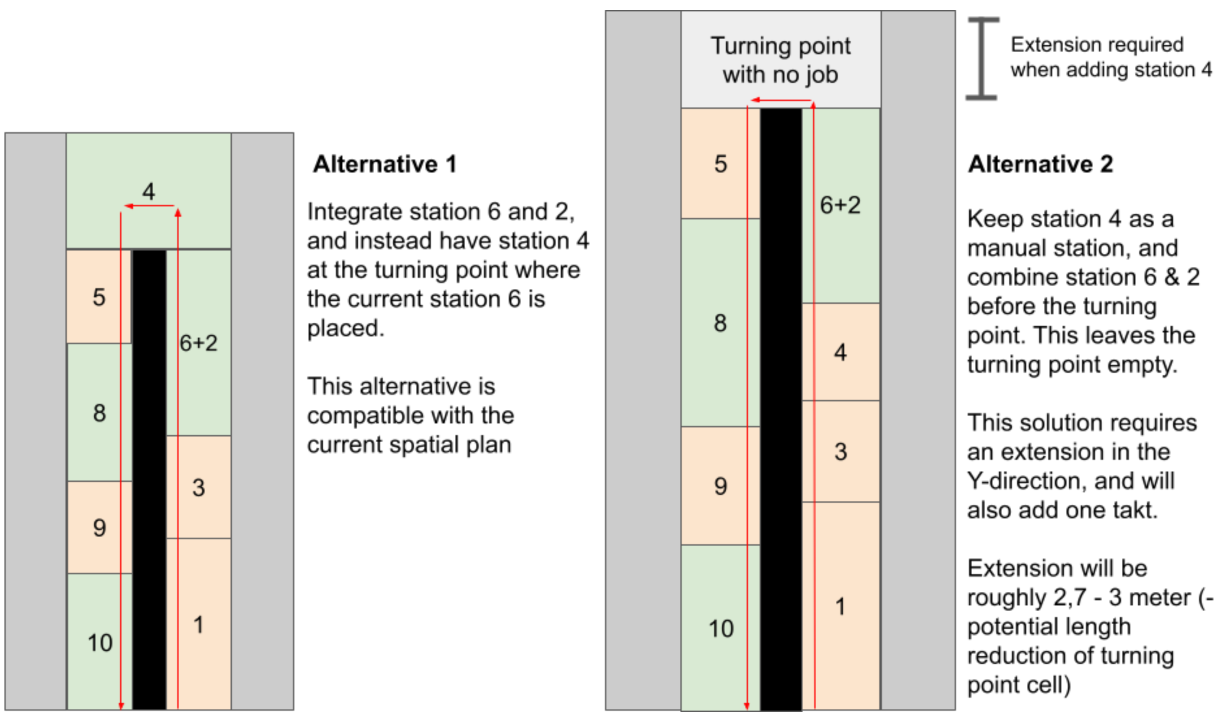

Figure 15 - Schematic overview of proposed alternatives to the new assembly line

Alternative 1 would be the most space-efficient solution, since the current assembly line would not need to be extended. Moreover, alternative 1 would be a full takt faster than alternative 2 which results in less capital bound in the assembly line.

However, in regards to investment costs alternative 2 would be significantly cheaper since station 4 would not be automated at all, which would save Scania roughly 3,2 - 4,1 M SEK. The decision should therefore mainly be based upon if the ergonomics wins, the freed-up space and the removed takt offsets the investment cost of automating station 4.

6.1.4 Cost savings for the logistics department are unclear

In addition to the cost savings at Zone 1, the proposed new assembly line facilitates the job at the logistics department. These savings have not been calculated, and therefore it is of interest to Scania to calculate the value of them. The concerned savings are:

- The extension of station 1, which results in the possibility of storing special axles adjacent to the assembly line.
- The mirroring of the assembly line, which reduces that travel distance for material delivery.
- Having a floor-level assembly line, enabling the delivery of materials from AGV:s.

6.1.5 Physical size of the assembly line - expansion and shrinking potential

When planning the new assembly line, the primary approach has been to keep the new line's dimensions similar to those of the existing line. To the extent it is possible, increasing the size of the line has been avoided. This is to have as little effect as possible on other parts of the Scania factory, such as delivery- or walking routes.

At the same time, opportunities to reduce the size of the line have not been sought after either. Reducing the size of the line could potentially free up space for other activities. On the other hand, to comply with security regulations each automated cell requires its own designated space in the line which is marked by security fences. The more available space that Scania can provide suppliers of automated solutions with, the lower the total cost of an automated solution can be. This is since suppliers, when given sufficient physical space to work with, do not have to put effort into reducing the size of existing solutions or standardised equipment.

When developing the layout of the new assembly line further, there are three possible outcomes.

1. The automated stations, the carrier system and/or the manual workstations require more space than anticipated. In this case, the assembly line needs to be expanded. The line width could be extended by about 0,7 m and the line length by about 1,5 m at a reasonable cost. These expansions would not require any significant changes in delivery routes around the line. More significant expansions than this will require changes to the delivery routes and the way in which material is transported today.

2. The automated stations, the carrier system and/or the manual workstations require less space than anticipated. In this case, the space could be used to increase the storage capacity of the adjacent materials facade. This option should be explored together with the logistics division.

3. The automated stations, the carrier system and/or the manual workstations require precisely the space as anticipated.

6.2 Risk assessment for proposed solution

There are naturally several risks to consider when investing in and implementing a completely new assembly line.

6.2.1 Installing the line is costlier and time consuming than anticipated

There is always the risk that the project will have larger installing costs than expected. Reasons for this might be underestimating the complexity of installing the line, technical malfunctions or human error in both the planning and installing phase.

Apart from higher direct installation costs, there is a risk that the installation process takes longer time than planned. The current plan is to build the assembly line in the same space as the current line, requiring a planned full stop of rear axle assembly. This can cause a bottleneck in the overall truck production process, resulting in considerable indirect costs.

According to Johannes at Scania, the time required to install a new carrier system should not be underestimated, and it is likely that the scheduled production stop during summer breaks won’t be sufficient time for the project.

6.2.2 The run-in period has a longer lower uptime than planned

When installing a line, a run-in period with lower uptime and increased levels of unscheduled stops should be accounted for. Even when accounted for, there is a risk that these levels will be higher than planned.
Multiple employees at Scania have communicated that especially when implementing automated cells there are often difficulties reaching a mature and fully efficient stage with low down time.

6.2.3 The new assembly line does not capture needs of future rear axles

Electrification is increasing the uncertainty on what future generations of trucks will look like. This can lead to different needs in the rear axle assembly line. For example, today the lifting gear at station 8 at BAX is dimensioned to lift a ≈ 325 kg central gear for axles on trucks with internal combustion engines. In the up-and-coming electrified trucks, the central gear will be replaced by a new combined drive module weighing 600+kg, which also will be lifted and mounted at station 8 at BAX.

There is always a risk that e.g., changes in customer demand can lead to changes in the truck designs and the corresponding rear axles. If the rear axle assembly line is planned and purchased during a period of uncertainty, there is a risk that the line will have to be revamped much sooner than expected to meet new customer demand.

6.2.4 The new assembly line affects the operators work environment

Our proposal will introduce several new fully automated cells. This will lead to reduced staffing at the assembly line. Going from a team of 10 operators plus 2 team leaders to roughly half the size will affect the psychosocial work environment.

Changing the group size, and the group dynamics subsequently, can both improve or impair the working environment. One risk is that more automation will create more distance between operators and impair the group dynamics. This could lead to reduced productivity, enhanced long term stress and higher employment turnover.

6.3 Discussion

6.3.1 Challenges at Zone 1

The main challenge for Zone 1 at the rear axle assembly line is to develop a more efficient and ergonomic assembly line that will enable a seamless introduction of electric powertrains.

There is currently a lot of uncertainty regarding the design and construction of the coming electrical powertrains. If the new powertrain keeps the design of the rear axle similar to the current design, it is possible many tools and robots may be able to remain at the assembly line with no or only minor adjustments. Therefore, it is important for Scania to continuously communicate with the product development team responsible for the development of electrical motors in order to plan necessary assembly line challenges.

Furthermore, it is important to learn from the mistakes and challenges of the past. One of the major setbacks with the current assembly line is the complexity of introducing new product variants in the assembly line. The problems are a result of decisions taken on the basis of existing challenges, not taking future changes into consideration. The possibility to customize a truck according to one’s needs is one of Scania’s main competitive advantages which drives the profit margin. Therefore, it is important to have a long perspective whenever implementing changes to the assembly line. This includes the possibility to introduce more material to the material facade, expand the size of the assembly as well as choosing tools and robots that are not only compatible with the current products.

During interviews with Scania employees, it was evident that other business units had previously solved a wide range of problems of similar nature as the problems at Zone 1. The main source of inspiration for solving the problems identified during the project was through interviewing experts within various subject matters at Scania. The fact that Scania is a multinational company with 17,000 employees with multiple production and assembly lines worldwide makes it unlikely problems and challenges that arise in Zone 1 are unique. Using the skills and experience that already exists at Scania is a great advantage that saves both time and effort when approaching a challenge.

Furthermore, being a large company also poses multiple challenges. It was clear that other existing systems and production units at Scania make it difficult to design an efficient production line. An example of this is the broad product portfolio, which complicates the introduction of robots that perform standardized tasks. The task of optimizing the efficiency of an assembly line is easier given the possibility of making adjustments to the productions in order to facilitate the assembly process. Since the design of the existing products are complex to alter it is important for the product development unit to collaborate with the production unit via Design for Assembly (DfA) when developing new rear axles.

In addition to carrying through a harmonious transition to power train every assembly line at Scania constantly faces challenges regarding efficiency and ergonomics. The main drivers causing need for improvements are inflation, salary growth and increased competitiveness of the market. Without continuous improvements the profit margins will diminish over time. It is therefore pivotal to revise which workstations, working methods and tools can be replaced, combined or adjusted in order to improve ergonomics and efficiency. There are many ways of doing this, such as appointing projects that evaluate potential for improvement and creating an atmosphere where employees at Scania are urged to suggest ideas for improvement.

6.3.2 Increasing flexibility, production efficiency and ergonomics at Scania

6.3.2.1 Increasing the ergonomics of the assembly line

There are three principal approaches to improving ergonomics of a task at an assembly line; altering the product being assembled, the way of working or removing the human involvement completely by performing a task completely through automation. During this project no improvements of the working method or adjustments and replacements of working tools were considered. Furthermore, the limitation of altering the products of the assembly line only left automation as a possible option for ergonomics improvements. That being said, altering tools and the way of working at the assembly line can improve the ergonomics substantially. As previously mentioned, the project aiming to replace the lifting tool at station 5 is expected to remove all the red ergonomics markers at that station. Therefore, it is suggested Scania should further evaluate the possibility to improve the ergonomics at the manual stations, especially station 3.

Looking at the results, it is evident multiple improvements can be made at Zone 1 through automation. The proposed automated stations would eliminate between 0 - 17 red and 2 - 14 ergonomic yellow markers per station. However, in comparison to efficiency improvements and cost cuts, ergonomics changes are hard to attribute to economic gains. Therefore, it will sometimes be hard to evaluate if the cost of automating a workstation solely for ergonomic improvements is motivated.

6.3.2.2 Increasing the efficiency of the assembly line

When it comes to increasing production efficiency the main goal of Scania is to reduce the cost of production. Since one limitation for this project was to not adjust the material used or the product being assembled the main way to reduce assembly cost is through reducing the number of workers at the assembly line, hence resulting in lowering employment costs. Reducing the number of workers at the assembly line can either be realized through automation or through a more efficient way of working where a higher portion of the takt time is utilized.

The new proposed assembly line mainly suggested improvements through automation. Because Scania runs two shifts, with a takt time that can vary each day, it is important to consider them both. Currently the Zone 1 assembly line usually runs at 100 % takt during the day and 200 % takt during the night. This means that the proposed solution needs to have a number of workers that is divisible by four during 100 % takt time in order for reductions of workers to be applicable for both day and night shifts. Furthermore, the total reduction of workers needs to be divisible by two in order for the rationalization to be beneficial for both 100 % and 200 % takt time shifts.

The most common method used when evaluating the profitability of the automatization of a workstation is the payback time of the investment. The payback time is calculated through dividing the investment cost by the yearly cost reductions in employment costs. This method considers the investment as a replacement which will likely not be the case when creating a new assembly line. In many cases there would be a cost for keeping the current tools and working methods when building a new assembly line. For instance, instead of automating station 8 it is possible the station would require a renovation of the current tool or even a brand new one. Therefore, it is likely the real investment cost of all automatic stations would be lower in practice when the cost of keeping the current equipment has been taken into account.

The price estimations received from the different suppliers turned out to vary greatly. In some cases, the highest precise estimate is more than double the lowest estimate for the same station. There are several possible explanations for this. The first and most obvious one is that suppliers will often have different prices for stations solving the same tasks, due to the fact that they use different equipment. Another reason could be that suppliers interpret the RFIs and the described tasks differently. Different suppliers can either over- or underestimate the complexity of an assembly task described, which is likely to result in significant differences in their price estimations. A third reason could be that suppliers have different approaches to negotiating a price estimate, where some start with a high asking price and are willing to go lower after a negotiation, while others are less inclined to negotiate on the final price.

Differences in price estimates aside, all the suggested automated assembly stations are designed to result in cost savings. One important effect or risk of automation, which runs the risk of cancelling out the cost savings realized, is the increased cost of stop time for the automated stations. Scania do not take cost of increased stop time into consideration currently, which made it difficult for them to verify if the estimations regarding increased stop time cost at section 5.10.5 were correct or not. If they are correct, every suggested workstation would need to have an uptime of nearly 99,9 % in order to keep the payback time that was suggested in the results section. Demanding such a low downtime from suppliers is likely to have an impact on the price.

It is also worth mentioning that the case for automation in Sweden is very different from automation in other countries where salaries are lower. This is because the price of an automated assembly station solution is very similar between countries. For instance, Scania also has production facilities in Brazil where the wage for installers at the assembly line is significantly lower. This means that in order for automation to be economically justifiable in Brazil the number of workers it reduces the need for has to be higher than in Sweden.

Implementing smarter working methods is the most difficult way of reducing workers. It can however be the most profitable since the investment cost may be very low. One example of how this is realized at Zone 1 is through exchanging the paper-based order system with digital screens using the MES-system EBBA. This entirely removes the need for scanning work order since they instead appear automatically on digital screens at every workstation. Furthermore, it also reduces the time it takes to stamp a work order to confirm that the work is complete. The new MES-system reduces the required working time by several seconds at every station. Even though this does not remove the need for an entire workstation it enables every station to take on more tasks, for example from other stations.

6.3.2.3 Increasing the flexibility of the assembly line

The shift towards electrification of heavy trucks and buses is the primary driver for Scania's need of increasing the flexibility on the assembly line. To a larger extent than before, Scania needs to have the flexibility of being able to introduce new rear axle variants faster on the assembly line. There are two primary ways in which Scania can achieve this increased flexibility in a new assembly line.

Scania can increase the size of the line and increase the storage capacity next to the line which is known as the material facade. This is because new rear axle models are likely to require new tools, assembly material and assembly processes. Increasing the material facade allows for storing of more different screws and tools at the same time.

Another way of achieving flexibility is by creating a time margin between the required time to perform the tasks during a takt and the actual takt time. If current tasks can be performed faster, more time is freed up for steps such as an industrial robot changing its end effector between work on old and new rear axle variants. By doing this, Scania can introduce new variants and assembly steps without increasing the takt time.

6.3.2.4 The conflict between efficiency and flexibility

Through the work of increasing efficiency and flexibility at an assembly line in this project, a conflict between these two focus areas as end goals have been identified. Expanding the size of the assembly line to achieve more flexibility is an example of this conflict. Yes, the flexibility to assemble more rear axle variants at the same time period increases with the increased size of the line. But the cost of this is reduced efficiency. A larger assembly line requires more space, which today is used for other purposes. Since available space in the factory is a limited resource in high demand at Scania, this expansion comes at a great cost. Most likely, an increase in size of the line reduces the storage space for inbound logistics deliveries to the assembly line. With all else being equal, this will require deliveries more frequently and this drives cost.

Another example of the conflict between efficiency and flexibility becomes apparent when exploring the option to create a gap between the takt time and the actual time required for an assembly step. As in the previous example, purposely creating this gap increases the flexibility of the line. But the cost is reduced efficiency. The gap can be created in two ways, increasing takt time or reducing the actual work time. Increased takt time reduces efficiency by lowering the output of rear axles while maintaining the same production cost. The same amount of work time and resources used now results in a lower output.

Reducing the work time also reduces the efficiency, while it might be less obvious why. If the working time per takt is reduced but the takt time is unaltered, the operators will essentially be paid to stand still or work slower. This is a form of direct waste, since all operators are paid on a direct hourly basis. The aggregated sum of time that the operator worked slower or paused entirely is a valuable resource that Scania is paying for and which could have been used in other ways.

6.4 Evaluating the project methodology

Creating an assembly line is a complex task. First, one needs to define what creating an assembly line means, and what level of detail is required to result in a complete creation. The level of detail can range from a concept of an assembly line to a complete blueprint solution ready to be built and implemented.

Secondly, when the scope of the creation and the level of detail is set, objectives and key requirements of the new assembly line need to be formulated. Deciding these objectives and key requirements can be quite a different process depending on if the new line will replace an existing line or if it is a completely new line for a range of new products. When replacing an existing line, the new line will likely need to outperform the existing in performance metrics already measured in the production. When introducing a new assembly line without a predecessor, benchmarking is a less straightforward process.

In either case, when the assembly line is to be optimized for various different variables, it is desirable if the variables have certain minimum acceptable values and mutual valuation. The project of designing a new assembly line at Zone 1 included optimization of variables such as area usage, production efficiency, ergonomics and flexibility. Due to the inability of a mutual valuation, there was no way of translating the monetary value of removing one yellow or red ergonomic marker at Scania. This resulted in a conflict between various variables such as ergonomics and efficiency improvements. Furthermore, the only benchmark that could be used was improvements in each variable in comparison to the same variable for the current assembly line.

Furthermore, there is also a conflict when looking at the interaction of different business units. The most apparent one at Scania is the interplay between offering a varied product portfolio with the possibility of tailor-made orders and at the same time being efficient in the assembly work. The possibility of closer collaboration between product developers and the production department where products can be changed to facilitate assembly and production. One example of this would be the possibility to alter product designs in order to facilitate assembly and production, for instance through DfA-product development.

It is apparent that developing a brief concept of an assembly line or designing a complete blueprint solution and setting the objectives of an assembly line are two very different processes. And often, a first brief concept can serve as a foundation for an in-detail design of a complete assembly line. But regardless of which process and what type of assembly line that shall be created, there are actions within the method of this project that are appropriate to take.

The greatest source of inspiration, insights and information during this project was communication with employees at Scania. Utilizing the possibility of absorbing the knowledge and insights of subject matter experts with years of experience enabled a steep learning curve which would be difficult to achieve through solely a literature review. By interviewing various experts, solving already solved problems was avoided.

With that being said, designing a completely new assembly line is a complex and time-consuming task. Due to these reasons many assumptions, simplifications and delimitations were made in order to deliver a final product within the time frame. Future projects with a similar holistic perspective that have access to more resources would likely be able to deliver a more actionable result. For instance, by appointing responsibility to people for smaller niche areas of the assembly line, a more detailed and substantiated result with fewer uncertainties could be produced. An example of such work could have been to investigate various lifting tools that can improve ergonomics, which was overlooked in this project.

7. Conclusions

In the seventh chapter the research questions are answered in a summarized and more concise way. This is followed by future considerations and important next steps for the new rear axle assembly line.

7.1 Research questions

The purpose of this project, as initially stated in section 1.3, is to develop, describe and evaluate possible solutions for the future of the rear axle assembly line in *Zone 1* at Scania. To do this, and to understand how the method used to do this can be applied in another context in the future, three research questions are formulated. Based on the findings in this report, an answer to each of the three research questions is formulated in a concise way below.

7.1.1 Research question 1

Present challenges at Zone 1 of the rear axle assembly line includes significant areas of needed improvements ergonomics at several assembly stations, rising maintenance costs for the assembly line carrier system and inefficiencies causing unnecessarily high labour costs built into today's assembly routines.

Future challenges at Zone 1, anticipated by Scania management, are a result of the company’s shift towards electrified heavy trucks and buses. Uncertainties in the design of future rear axles, in the demand pattern between ICE and electric trucks as well in the total demand all pose their own challenges for Scania.

Present and future challenges at Zone 1 can successfully be met by Scania through a new rear axle assembly line. Through automation of some currently manual workstations, ergonomics can be significantly improved. This is achieved by removing tasks unfit for the assembly operators to perform. Automation can also help reduce labour costs heavily and increase the efficiency of the staff working at the line.

Further challenges related to the uncertainty on new rear axle variants can be met by preparing for an expansion of the assembly line and a potential reduction of takt time. The storage capacity of assembly material and tools can be increased by expanding the material facade, leaving room for flexible introduction of future axle variants. By rearranging the order of assembly tasks and requiring a lower completion time for robot stations than the current takt time, a flexibility to handle production capacity increases is created. This is because the takt time of the new line then can be lowered without further investments and changes.

7.1.2 Research question 2

The assembly line presented in section 5 introduces several design features which increases the production efficiency, the ergonomic rating and the production flexibility of the rear axle assembly line at Zone 1.

The proposed assembly line reduces costs for the logistics department. The cost reductions are realized through minimizing the transporting distance of rear axle bridges through mirroring the material flow, allowing the storage of special axles at station 1 and by facilitating AGV delivery through having a factory-level assembly line floor. However, the logistics department was not able to determine the exact cost savings of the measures.

Depending on the total investments needed for the various workstations and the future takt time for the night shifts, the automated workstations had a payback time of between 2 - 9 years. In reality the payback time is likely to be lower since it does not take the opportunity cost of carrying out potential repairs needed to instead maintain the existing production equipment. Furthermore, the payback time does not take the cost of increased stop time into consideration as Scania does not use that metric as a decision basis for investment assessment. If the calculations made in section 5.10.5 were to be considered to be correct, the automated stations would need to have an uptime of 99,9 % in order to achieve the aforementioned payback time.

As a result of automating the majority of the tasks being performed at station 2, 4, 7, 8, 9 and 10 the ergonomic grading of the proposed assembly line is significantly improved. The amount of ergonomic red markers is reduced from 58 to 25, and the amount of ergonomic yellow markers is reduced from 52 to 28.

The flexibility at Zone 1 is also improved. First of all, the takt time is reduced from 80,9 s to 79,8 s. However, as a result of the new MES using digital screens instead of paper orders the takt time is expected to be lowered by a few more seconds at station 3, which currently acts as the bottle neck. Furthermore, if the required working time of the activities at station 3 were to be lowered the assembly line could have an even lower takt time at 78 seconds, alternatively 74,1 seconds if the automated stations would allow it.

Finally, it is also possible to consider the possibility of constructing the assembly line on both a smaller and larger surface than what was stated in the result as an improvement in flexibility. The reason is that it enables the expansion and extension of new workstations and activities which facilitates the introduction of new product variants.

7.1.3 Research question 3

The method used in this project can be used by other companies in order to identify and generate improvement ideas when renovating or developing new assembly lines. Due to the fact that the internal knowledge, insights and e-learning presented in section 4 accounted for a large portion of the knowledge gathering process, the method is best suited for companies of similar stature as Scania. The size and stature of the organization is important for two reasons. Firstly, the organization needs to be large enough to be able to absorb enough valuable information and experiences to allow for this method to be properly utilized. Secondly, for this method to provide the most value, the organization should be large enough to have a lot of decentralized knowledge and experience collected.

If the method were to be used by companies with fewer and less experienced employers to consult with and therefore insufficient levels of knowledge and experience, an alternative approach of finding interviewees would need to be developed.

Regarding areas of improvement, if given sufficient time, enough available resources and cooperation with other business units several suggestions of improvements can be made to the method. Firstly, initiating the project by defining the relative value of the various improvement variables, for example by estimating their economic value, facilitates the decision-making process. Secondly, if it is possible to work from a larger and more holistic perspective, for example by involving nearby production lines and the product development department through DfA, that is desirable. This is because the larger scope of project can allow for more powerful courses of action to be taken, increasing the opportunities and potential improvements. At the same time, it should be mentioned that a larger scope can lead to more difficulties overseeing the project and, which will require strong project management and prioritization. Thirdly, by allocating more resources on the project it would be possible to reduce the number of uncertain estimates and provide more accurate predictions.

The contribution of this project for further study and work in the area of assembly line concept generation and design is the method developed and used in this project. This method is later in the report refined and summarized in a more generic way to allow for easier understanding and overview. The result of this refining and summary is presented as a standalone chapter in the report, which is called *Chapter 8. Contribution.*

7.2 Future considerations

7.2.1 Estimating costs

There is, of course, a lot of work still needed to estimate the total costs of investing in a new line. The quotes from the RFIs are loose estimates from the suppliers and in no way final. The RFIs are also individual for each proposed workstation.

The possible effects of volume discounts and limitations of centralized sourcing within the Traton Group has not been considered at this stage.

7.2.2 Improved ergonomics of current and new lifting tools

Station 1 has not been considered a prioritized station to change or automate. However, there are clear needs to improve the ergonomics for the operators at the station. The current lifting tool requires work outside of the body's normal working area and it puts too much strain on both the hands and the back of an operator.

It is recommended to improve the ergonomics of the lifting tool at station 1. With an ongoing and similar project to upgrade the lifting tool at station 5, the findings from that project could serve as a basis for investigating station 1.

Station 3 currently involves a heavy lift when mounting the 11+ kg reaction rods. This is currently considered a double red value (DRV) according to the SES-reports and is an area needing improvement. While it is a complex station to automate, the introduction of a manual lifting tool should be investigated.

Furthermore, station 3 is interesting to improve from more perspectives than ergonomics. For instance, it is currently a bottleneck station which prevents the assembly line from the possibility of lowering the takt time. Moreover, since we have proposed to automate station 4, automating station 3 would also reduce the need for one worker.

7.2.3 Changes in stop-time characteristics with automated cells

We are proposing a heavy emphasis on fully automated cells in the next generation's assembly line. It is important to further look into and consider how this will affect the overall uptime and the stop-time behaviour.

For example, today the manual stations lead to many but short stops. It is easy for an operator to make a small mistake, but they're often very quick to resolve the problem they cause. The operators are agile in their movements and can easily involve a fellow operator or team leader to get assistance when needed.

One significant difference with an automated cell lies in physical accessibility. The automated cells are enclosed within fences. Due to the safety of the operators, entering an automated cell is a time consuming and demanding process. This means that the same amount of stops for a manual station and an automated station can lead to significantly higher total stop time for the automated stations.

Looking into the crash routines, how an automated cell can resolve problems on its own and how an operator can enter an automated cell is an important work to be done. The required time to resolve each stop needs to be balanced with the amount of stops that are allowed to occur. Therefore, internal crash routines are just as important as requiring a high operational reliability from a supplier of automated solutions.

Furthermore, it is of interest to Scania to further investigate if increasing the stop time actually causes such a high cost as our estimations indicate (roughly XYZ SEK per month when increased from 0,1 % to 0,5 %).

7.2.4 Investing in a new carrier system vs. renovating the current

To allow for several fully automated stations and ensure quick and stable operations, we are proposing a static rail-based conveyor/material handling system. This is contrary to our initial hypothesis that an AGV system would be the most suitable.

When proposing a new and very costly conveyor system which operates in a similar way as the current system, one obvious question needs to be answered: what is wrong with the current system?

One drawback of the current system is that it is elevated above the factory floor, providing a difficult challenge for logistics in their ongoing transition from forklifts to AGV based deliveries.

Other than that, concerns have been raised that the current transport system will have quickly increasing maintenance costs over the coming years.

With all boiling down to a cost problem in the end, we suggest an investigation on what it would cost to fully renovate the current conveyor system or use parts of it as a foundation for an updated system. Investing in a new system will probably result in an expensive and fully tailor-made solution.

If renovating the current system is a viable and cost-efficient way to improve the technical life length by a few years, this might allow for the AGV-based conveyor technology to mature into a feasible option for the next conveyor system.

7.2.5 Emerging technologies

The assembly line concept in this pilot study is based on technologies that are mature and well known to Scania as of today. This is intentional, and it is done to focus on a concept that practically could be implemented in the Scania factory in just a few years' time.

There are rapid developments in assembly technology taking place today. Depending on when the assembly line will be installed, new technologies might have matured into considerable alternatives.

AGV conveyor systems is one of the interesting areas. With improved stationing accuracy of the AGV:s and centralized emergency stop signals wirelessly distributed, AGV:s can work well with fully automated workstations. Improvements in Computer Vision systems can i.e., help reduce the needed station tolerance of an AGV.

Future advancements in wearable technology can improve both ergonomics and quality levels of operators. Wearable sensors that can help improve posture and identify risks of strain injuries already exist today. However, the integrity aspect of monitoring operators so closely needs to be addressed both legally and ethically.

Improved Augmented Reality (AR) solutions can improve the quality by always providing the operator with the right instructions at the right time. Intelligent AR can also help detect errors, both from the operator and work done at the previous station, faster and with higher precision. One significant problem with AR today is that it often causes headaches and dizziness when tested on operators in industrial settings. Solving these problems can make AR an interesting investment.

8. Contribution

In the eighth chapter the contribution of the study, a method for designing assembly lines, is presented. An overview of the method is outlined followed by detailed explanations of each ingoing step.

8.1 Method overview

The project method is divided into three parts, the prephase, the main study and the proposal & evaluation. An overview of the method can be seen below.

Prephase

- System definition
- Background & problem definition
- Objective & identification of key variables
- Context & delimitations

Main study

- Knowledge acquisition
- Identification & sequencing of activities
- Identification of challenges
- Generation of conceptual solutions
- Estimation of feasibility
- Requirements engineering
- Request for quotas
- Creation of balance sheet & layout

Proposal & Evaluation

- Workshop with focus group
- Presentation of final proposal
- Project evaluation

8.2 Description of ingoing steps

8.2.1 Prephase

The purpose of the prephase is to understand the scope, delimitations, goals and objectives of the assembly line design project. The prephase is divided into eight steps.

8.2.1.1 System definition

The purpose of 8.2.1.1 is to define the scope of the assembly line design project. The goal of the system definition is to decide upon the desirable level of detail for the final product. The level of detail of the final product can vary from a more general pre-study to a turnkey fully complete assembly line during production.

8.2.1.2 Background & problem definition

The purpose of 8.2.1.2 is to understand the underlying reasons for the project. The goal is to clarify the intention of the project, and whether it is a basic investment, renovation or replacement investment.

8.2.1.3 Objective & identification of key variables

The purpose of 8.2.1.3 is to understand the main goal and the requirements for the end product. The goal is to clearly define which variables the end product should focus on improving or developing. This includes defining their minimum allowable value and their relative valuation. The relative value of variables could for instance include valuation of cost reductions in relation to improved ergonomics, safety, takt time, number of stations and claim of area within the factory.

8.2.1.4 Context & delimitations

The purpose of 8.2.1.4 is to understand the interdependence of the assembly line and the overall production system of the company. The goal is to define which parameters are modifiable in order to improve the variables to be optimized. Example of relevant parameters to examine the modifiability of is takt time, the product appearance, the area in the factory, the shape & layout of the assembly line, IT systems, MES systems, storage of material & material facade, carrier system, various types of technology, elevation of the factory floor and the flow of material.

8.2.2 Main study

The purpose of the main study is to generate solutions for how the various tasks at the assembly line can be carried out based on the objectives identified in the preliminary phase. The main study is divided into eight parts.

8.2.2.1 Knowledge acquisition

The purpose of 8.2.21 is to obtain knowledge and insights in areas related to the parameters (8.2.1.4) that can be corrected to optimize the target variables for the project (8.2.1.3). The goal is to procure sufficient knowledge to develop solutions for the end product. Depending on the project scope and delimitations knowledge could be acquired both internally (work shadowing, site visits, interviews, observations, internal documents) and externally (literature study, external site visits and interviews).

8.2.2.2 Identification & sequencing of activities

The purpose of 8.2.2.2 line activities is to obtain an understanding of the work being performed at the line and the interdependency between the activities. The goal is to map all the different tasks performed on the assembly line, as well as the chronological order in which they can be performed in relation to each other.

8.2.2.3 Identification of challenges

The purpose of 8.2.2.3 is to highlight activities of interest with either improvement potential, activities that are challenging to execute or activities that are likely to change in the future. The goal is to identify the tasks and activities that will create the most value to develop or improve.

8.2.2.4 Generation of conceptual solutions

The purpose of 8.2.2.4 is to produce possible solutions to solve the challenges identified in 8.2.2.3. The goal is to produce at least one solution for every identified challenge identified.

8.2.2.5 Estimation of feasibility

The purpose of 8.2.2.5 is to assess if the conceptual solutions generated in 8.2.2.4 are viable in practice. The estimation could be done in collaboration with experts in the industry, suppliers or internally. If no solution is deemed feasible for a critical challenge that is pivotal to solve for the assembly line, then step 8.2.2.4 needs to be iterated. The goal is to prevent excessive amounts of time spent on developing solutions that are not feasible.

8.2.2.6 Requirements engineering

The purpose of 8.2.2.6 is to define what requirements the generated solutions need to meet. The goal is to compile a complete list of the required attributes each solution needs in order to solve the challenges identified in section 8.2.2.3, while still optimizing the variables identified in section 8.2.1.3.

For industrial robots this could include requirements such as minimum uptime, maximum space requirements, torque capacity, ability to handle different materials, ability to identify different products, maximum time limit for completing tasks, ability to handle objects of certain weights. For manual tools this could include requirements such as the ability to handle objects of certain weights, maximum size and weight requirements, ability to complete certain tasks within a set timeframe, ergonomic standards and torque capacity.

8.2.2.7 Request for quotas

The purpose of 8.2.2.7 is to obtain qualified estimates of the price of the feasibility of the various solutions based on the requirements set in section 8.2.2.6. The goal is to acquire a minimum of two quotes for each solution considered feasible in section 8.2.2.5.

8.2.2.8 Creation of balance sheet & layout

The purpose of 8.2.2.8 is to map out a balance sheet with activities and layout for the assembly line based on the quotes on the solutions provided by different vendors. The goal is to utilize the basis for the various solutions for constructing a proposal for an assembly line that fulfills the level of detail set at section 8.2.1.1, while still optimizing for the variables identified in section 8.2.1.3 and meeting the limitations in section 8.2.1.4.

8.2.3 Proposal

The purpose of the proposal is to present the generated solution and guide decision makers in implementing it. The proposal is divided into three parts.

8.2.3.1 Workshop with focus group

The purpose of 8.2.3.1 is to obtain a second opinion on the proposal generated at step 8.2.2.8. The goal is to receive feedback in order to improve the proposal by covering for potential mistakes and gaps in the solution.

8.2.3.2 Presentation of final proposal

The purpose of 8.2.3.2 is to present the designed assembly line to decision makers within the company. The goal is to highlight the various problems that the assembly line solves and how they justify the investment cost.

8.2.3.3 Project evaluation

The purpose of 8.2.3.3 is to evaluate how successful the project was. The goal is to generate improvement ideas for future projects, risks with the proposal and important factors to consider when implementing the solution.

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Appendix

Appendix A: In-depth analysis of each assembly station in Zone 1.

Station 1 - lifting bridges from logistics onto line

Factor evaluated	**Value**	**Comment**
Takt time	71,1 - 79,9	High utilization of takt time
Type of station	Manual	Complex station to automate
Red erg. markers	6	Room for improvement
Yellow erg. markers	9	Room for improvement
Priority for improvement	Low	See below

A.1.1 Ergonomics

This station has a high number of red and yellow ergonomic markers. Hence it is interesting to evaluate how this station could be improved from an ergonomic perspective.
However, we noticed it is a very detailed oriented task to investigate how different lifting tools can improve ergonomics. Our understanding is that this requires an in-depth discussion with different suppliers. For instance, various projects at Scania (like the one investigating a new lifting tool for Station 5 have run over multiple weeks.

A.1.2 Automation potential

Station 1 was evaluated to be a very complex task to automate, due to the weight of the bridges as well as their placement when coming in from logistics.

A.1.3 Utilization of takt time

At station 1, almost the entire takt time is required to complete the task. Therefore, it is unlikely this task can be included or combined with another station. However, just switching out the MES system and manual paper handling to EBBA/DIDRIK/MONA would spare sufficient time to enable this station to handle a shorter takt time. Therefore, this station is not interesting to improve from the perspective of its active working time.

A.1.4 Final remarks

Due to this fact it was decided station 1 would not be a prioritized station to investigate.
This decision is based on the current logistics solution of delivering the rear axle bridges on transport pallets with forklifts. However, new delivery methods such as transporting the bridges with AGV:s could potentially open up a new case for automation.

Station 2 - entering pin screws onto the bridge

Factor evaluated	**Value**	**Comment**
Takt time	41,6 - 80,9	Low utilization of takt time for some models
Type of station	Manual	Medium automation complexity
Red erg. markers	0	No room for improvement
Yellow erg. markers	2	Little room for improvement
Priority for improvement	Medium	See below

A.2.1 Ergonomics

From a purely ergonomic standpoint, station 2 is performing relatively well. Solely from an ergonomic perspective the station should not be a priority for improvement.

A.2.2 Automation potential

The task of picking up and entering screws is a standardized task which Scania already uses automated solutions for today. With the assistance of screw feeders and either information from a vision system (or preferably from the MES) this task could be automated.

A.2.3 Utilization of takt time

Workers at station 2 rarely utilize the full takt time.

A.2.4 Final remarks

This station is currently performing quite well in regards to ergonomics and stop time. However, the tasks being done at this station are not estimated to be complex to automate. Therefore, the station could be interesting to automate if possible and economically profitable.

Station 3 - Mounting torque rod brackets

Factor evaluated	**Value**	**Comment**
Takt time	0 - 79,7	Many no-work models
Type of station	Manual	Very high complexity for automation
Red erg. markers	4 + 2 double red	A lot of room for improvement
Yellow erg. markers	4	A lot of room for improvement
Priority for improvement	Low	See below

A.3.1 Ergonomics

Station 3 is one of the stations which performs the worst from an ergonomic perspective. Purely ergonomics could motivate significant improvements at this station.

A.3.2 Automation potential

Potential for automation at this station is low without making product changes. The reason for this is that there are too many complex movements, lifts and tasks being performed. The assessment was made with help from Fredric and Johannes at Scania.

A.3.3 Utilization of takt time

There are many no-work jobs at this station which leaves a lot of inefficient working time for the workers. Simultaneously this time could be utilized as Andon, helping others at their stations.

A.3.4 Final remarks

Due to the high grade of complexity for automation this station has not been a focus for improvement. It is however very likely that a new way of working including a new lifting tool could improve the ergonomics at this station.

However, we noticed that projects for new lifting tools are very complex and take a long time to complete. Therefore, we recommend that a project is launched to improve this station - the same way it was launched for improving station 5.

Station 4 - Tightening screws onto torque rod brackets

Factor evaluated	**Value**	**Comment**
Takt time	0 - 79,6	A lot of no-work models
Type of station	Manual	Low complexity for automation
Red erg. markers	6	A lot of room for improvement
Yellow erg. markers	2	Room for improvement
Priority for improvement	High	See below

A.4.1 Ergonomics

The screwdriver tool puts a lot of physical strain on the workers and therefore this station is interesting to improve from an ergonomic perspective. 6 red markers are in the higher end of the current Zone 1 solution.

A.4.2 Automation potential

This station is estimated to have a low complexity for automation. Therefore, it is interesting from an automation perspective.

A.4.3 Utilization of takt time

A lot of variants have no work for this station. This causes the installer who works here to do nothing for a big portion of the time. Therefore, it is interesting to automate or remove this station.

A.4.4 Final remarks

Because of the bad ergonomics, the low utilization of the takt time and the low complexity for automation this station is interesting from an automation perspective.
However - removing this station does not save the employee cost for an installer since station 3 and 4 are conjoined currently. The advantages with removing the station as a separate unit are:

- Reduce production time at Zone 1
- Reduce capital tied up in the assembly line
- Improve ergonomics of the workers
- Enable the removal of one worker if station 3 is automated in the future

Station 5 - fastening transport yokes

Factor evaluated	**Value**	**Comment**
Takt time	71,2 - 80,5	High utilization of takt time
Type of station	Manual	High complexity for automation
Red erg. markers	9	A lot of room for improvement
Yellow erg. markers	9	A lot of room for improvement
Priority for improvement	Low	See below

A.5.1 Ergonomics

From an ergonomic standpoint this station is not performing well, making it a priority for improvement.

A.5.2 Automation potential

The station involves multiple different and demanding tasks which makes the complexity for automation high.

A.5.3 Utilization of takt time

Workers at this station have little to none idle time and the workstation even requires Andon/team leader assistance for some variants.

A.5.4 Final remarks

<u>This station is already being investigated for improvement</u>. It is assumed that ergonomics will improve as a result of the new lifting tool being introduced.

Station 6 - tightening of pin screws by automated robot

Factor evaluated	**Value**	**Comment**
Takt time	78	
Type of station	Automated	-
Red erg. markers	-	-
Yellow erg. markers	-	-
Priority for improvement	Medium	

A.6.1 Ergonomics

Station 6 is a fully automated station and therefore ergonomics cannot be improved there.

A.6.2 Automation potential

Station 6 cannot be automated further. However, new tasks could be included in the cell.

A.6.3 Utilization of takt time

The station today utilizes 77 seconds of the takt time. Of this time, 37 seconds are used for the transport and turning of the carrier and its bridge. Once the bridge has stopped in its assembly station, it takes 40 seconds for the automated screwdriver to perform its task.

A.6.4 Final remarks

This station requires the most time for transporting the bridge, because the station is placed at the turning point of the U-shaped line, and all carriers are therefore led from one straight line to the other. Because there is a lot of space in this automated cell, and the screwdriver only performs work from directly above the bridge, other tasks could potentially be performed here simultaneously as the pin screws are entered.

Station 7 - placing paper gasket or silicone onto the rear axle bridge

Factor evaluated	**Value**	**Comment**
Takt time	26,8 - 79,4	Low utilization of takt time
Type of station	Manual	Low automation complexity for silicone
Red erg. markers	7	A lot of room for improvement
Yellow erg. markers	3	Room for improvement
Priority for improvement	High	See below

A.7.1 Ergonomics

Applying the silicone puts a lot of physical strain on the workers which makes this station a priority for improvement.

A.7.2 Automation potential

Automating the application of silicone is not a complex task, and similar solutions already exist at Scania. However, automating the placement of the paper gasket is very complex. Hence that task would need to be moved to another station.

A.7.3 Utilization of takt time

When only a paper gasket is put on the rear axle bridge the utilization of the takt time is very low. This is the case for most variants which makes the workers at this station ineffective at most times. Therefore, this station is interesting from an efficiency point of view.

A.7.4 Final remarks

Ergonomics can definitely be improved. The utilization of the takt time is low for most product variants (which are the products using paper gasket instead of silicone). Because of the difference in complexity between placing a paper gasket (complex task) versus applying silicone (not a complex task) it is interesting to split this station into two different tasks. Placing the paper gasket can instead be done at a station where takt time utilization is low. Applying silicon can be automated at a more reasonable cost and be kept at the current station.

Station 8 - lifting and mounting central gear onto bridge

Factor evaluated	**Value**	**Comment**
Takt time	76,6 - 78	Not much room for improvement
Type of station	Manual	Medium automation complexity
Red erg. markers	4	A lot of room for improvement
Yellow erg. markers	2	Room for improvement
Priority for improvement	High	See below

A.8.1 Ergonomics

This station performs decently in terms of ergonomics in comparison with other stations at Zone 1. However, since there are still multiple red markers it is needed to improve this station solely from an ergonomic standpoint.

A.8.2 Automation potential

It is estimated that automating the tasks of picking up and placing heavy central gears onto the bridges with good enough precision to fit the screws is doable and not overly complex.

A.8.3 Utilization of takt time

This station utilizes almost the entire time. However, since the current lifting tool does not manage to lower the central gear onto the bridge with perfect alignment, another station is needed for solely that task. If an automated lifting tool could both lift and lower the central gear with sufficient precision that would save a lot of time.

A.8.4 Final remarks

Because of the red ergonomic markers, the medium automation complexity and the possible synergy with other stations when automated this station is highly interesting for automation.

Station 9 - lowering the central gear onto the bridge

Factor evaluated	**Value**	**Comment**
Takt time	67,1 - 79,6	Little room for improvement
Type of station	Manual	Low automation complexity
Red erg. markers	10	A lot of room for improvement
Yellow erg. markers	15	A lot of room for improvement
Priority for improvement	High	See below

A.9.1 Ergonomics

This station is the one with the highest amount of red ergonomic markers, making it a priority to improve from an ergonomic standpoint.

A.9.2 Automation potential

Entering screws is something that is not complex, and lowering the central gear could be done at station 8. The complexity for automation is therefore estimated to be low.

A.9.3 Utilization of takt time

The workers utilize a large portion of the takt time, but it can be discussed if this takt is needed or if it could be included at another station.

A.9.4 Final remarks

Because of the ergonomic as well as time improvements that can be made this station is highly interesting to improve through automation. It should be noted that screws are pre-entered at station 9 to allow the full entering of screws at station 10 to be completed within the takt.

Station 10 - tightening screws on the central gear

Factor evaluated	**Value**	**Comment**
Takt time	79,6 - 80	Not a lot of downtime
Type of station	Manual	Low to medium complexity for automation
Red erg. markers	10	A lot of room for improvement
Yellow erg. markers	6	A lot of room for improvement
Priority for improvement	High	See below

A.10.1 Ergonomics

This station performs poorly from an ergonomic perspective which in itself motivates an improvement. Station 10 has the highest amount of red ergonomic markers, sharing the lead together with station 9.

A.10.2 Automation potential

The task of tightening screws is not a complex task. However, the tightening of hidden screws is a more complex task - but still doable - to automate.

A.10.3 Utilization of takt time

This station utilizes a large portion of the takt time. As mentioned in station 9, screws are also pre-entered at the previous station to save time for the entering at this station. However, this is also not very positive since it makes it more difficult to lower the takt time. Therefore, room for improvement exists.

A.10.4 Final remarks

This station is highly interesting to automate since it performs poorly on ergonomics, is medium-complex to automate and requires a lot of time now.

Appendix B: In-depth analysis of each new assembly line station

Station 1

At station 1, the main task taking place is lifting and placing the rear axle bridge onto the carrier system. This will remain unchanged. The way in which the bridge is lifted can change depending on the design of the new carrier system. This could potentially create a need for modifications on the current lifting tool or a new lifting tool. There are also two changes in tasks currently performed at station 1.

B.1.2 New tasks to be completed here

For drum brake models the instalment of oil pipes will be done here instead of at station 2.

B.1.3 Existing tasks to be moved or removed

Tasks connected to the old MES such as printing, stamping and handling paper orders will be removed.

B.1.4 New equipment and tools needed

- New lifting tool with improved ergonomics in the way of working.

B.1.5 Utilization of takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	60,6	Time difference because the carrier system will need to readjust in between drum and disc brake variants.
Drum brake	73,7	

Station 2

Station 2 will be fully automated, removing the need for an operator at this station.

A robot with six different screw feeders (one for every variant) will pick and place the screws onto the bridge. After picking the screws the robot will enter them into the bridge by screwing them 360 - 720 degrees. The screws are each covered at one end with a glue called Loctite. The Loctite is chemically activated when the screw is entered more than 720 degrees into the bridge. Therefore, the screw cannot be entered completely at this point to prohibit the Loctite to be activated too early in the assembly process.

The robot will be given product information and instructions from the EBBA-system (MES) and therefore won't be dependent on a vision system to know in which pattern the screws should be placed.
If the carrier system delivers the bridge with high precision and the station is known within a fine tolerance, no vision system is needed at all. If the carrier system delivers the bridge with lower precision, a vision system still might be needed to guide the robot to the screw holes.

In order to place the screws with the Loctite-covered end the correct way an optical sorting system needs to be in place within the screw feeders.

B.2.2 New tasks to be completed here

No additional task will be included in this automated station.

B.2.3 Existing tasks to be moved or removed

The instalment of oil pipes will be moved to station 1.
Manually marking the area where silicon should be applied with a pen has been removed since the application of silicone will be automated at station 8.

B.2.4 New equipment and tools needed

- 6 Feeders to present robot with correct screws types
- 1 Industrial robot to pick screws (including end-effector tool)
- 1 Industrial robot to enter screws (including end-effector tool)
- Control and communication system
- Safety fencing and system for secure entry into robot cell
- (Potentially vision system depending on carrier's precision)

B.2.5 Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	78	Takt time sets the required time
Drum brake	78	

Station 3

Station 3 will remain the same for the tasks that will still be performed here with the exception of the removed order management tasks.

B.3.2 New tasks to be completed here

No new tasks added.

B.3.3 Existing tasks to be moved or removed

Tasks connected to the old MES such as handling and stamping paper orders.

B.3.4 Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	79,8	Takt time sets the required time
Drum brake	79,7	

Station 4

Station 4 as a standalone station will be removed and the tightening of screws for the seat suspension system will be automated and performed at station 6 simultaneously as the pin screws are entered. This will be possible since the pin screws are entered from above the bridge, and the torque rod brackets are mounted to the side of the bridge.

Since the tasks performed at station 5 will be moved to after station 6 the current lifting yoke will not be in the way for a robot to tighten these screws from the side.

B.4.2 New tasks to be completed here

No new tasks added.

B.4.3 Existing tasks to be moved or removed

Tasks connected to the old MES such as handling and stamping paper orders. The task performed at what is station 4 today will be performed later in the assembly process at station 6.

B.4.4 New equipment and tools needed

Will be specified at station 6.

B.4.5 Takt time: Disc brake and drum brake variants

The required time will be set to the takt time at station 6.

Station 5

Station 5 will be changed in several ways. The main tasks at this station are to mount transport yokes and to mount ventilation pipes. These tasks will be performed in the same way as before, but the station will be moved chronologically later on in the assembly process, and take place after today's station 6.

This station currently performs poorly from an ergonomic perspective, much because of the lifting tool used to lift the transport yokes. There is already a project running today to change the lifting tool to a new, and more ergonomic one.

Since the tasks performed at station 5 will be moved to after station 6, the current lifting yoke will not be in the way for a robot working at station 6 to tighten the torque rod bracket screws from the side.

B.5.2 New tasks to be completed here

For the disc brake variants, the paper gasket which today is mounted at station 7 will be mounted here instead.

B.5.3 Existing tasks to be moved or removed

Tasks connected to the old MES such as handling and stamping paper orders.

B.5.4 Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	74,1	Mounting ventilation pipes is only done on disc brake variants.
Drum brake	53,4	

Station 6

This is currently the only automated station on the line. At station 6, pin screws will still be entered by a linear robot from above. Additional to this, the torque rod brackets mounted at station 3 will be screwed at this station. This will be done by two screwing and gripping robots operating from opposite sides of the rear axle bridge.

The added complexity of performing two different tasks simultaneously at the same station will require modifications to the linear screw driving robots currently in place.

B.6.2 New tasks to be completed here

Two industrial robots will be added in order to complete the tasks that were previously performed at station 4.

B.6.3 Existing tasks to be moved or removed

No task will be removed at this station.

B.6.4 New equipment and tools needed

- 2 linear Gantry robots to handle screwdrivers (including end-effector tool)
- 4 screw drivers, 2 per Gantry robot
- Control and communication system
- Modifications to existing equipment and programming
- (Potentially vision system depending on carrier's precision)

B.6.5 Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	78	Takt time sets the required time
Drum brake	78	

Station 7

Station 7 will be removed as a separate station. All tasks performed at this station will be moved to other stations. This frees up both an operator and available space at the assembly line. This is also one of the stations where the operator is utilized the least during the takt.

B.7.2 New tasks to be completed here

No new tasks.

B.7.3 Existing tasks to be moved or removed

The mounting of the paper gasket packing will be moved to station 5.
The application of silicone will be done at station 8.

B.7.4 Takt time: Disc brake and drum brake variants

Removing this station removes one takt, or 78 s, of total assembly time for each rear axle produced.

Station 8

Station 8 will be an automated cell with two industrial robots which has two main tasks:

1. To lift the central gears (CVXs) and place them onto the bridge (without leaving a gap between the CVX and the bridge).
2. For models that require application of silicone, this will be performed by a silicone applying robot before mounting the CVX within the same takt time.

One of the main features of the CVX-lifting robot is that it can place the CVX into the bridge without a gap. The robot can use applied force plus the weight of the CVX to do this.

Lowering the CVX is currently a problematic process with the manual lifting tool, because of the gap that often occurs between the bridge and the CVX. Since there will not be a gap between the CVX and the bridge, the need for lowering the CVX at station 9 will disappear. However, entering of nuts onto the pin screws will still need to be performed.

B.8.2 New tasks to be completed here

Application of silicone which was previously done at station 7.

B.8.3 Existing tasks to be moved or removed

Fetching mutters and entering them onto the pin screws.

B.8.4 New equipment and tools needed

- 1 6-axis Industrial robot to apply silicone (including end-effector tool)
- 1 linear Gantry robot to lift and lower CVX (including end-effector tool)
- Control and communication system
- Safety fencing and system for secure entry into robot cell
- (Potentially vision system depending on carrier's precision)

B.8.5. Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	78	Takt time sets the required time.
Drum brake	78	

Station 9

Station 9 will be a quality check/crash routine area for station 8 as well as entering mutters onto the pin screws.

B.9.2 New tasks to be completed here

Fetching mutters and entering them onto the pin screws.

B.9.3 Existing tasks to be moved or removed

Eliminating the gap by lowering the CVX into the bridge with a screwdriver.
Tasks connected to the old MES such as handling and stamping paper orders.

B.9.4. Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	57,9	Very similar process for both disc and drum brake variants.
Drum brake	59,0	

Station 10

Station 10 will be a fully automated station where both hidden and visible screws will be tightened by industrial robots. Unlike the current station, where the nuts are already lowered into station, the robots will have to first lower the nuts so that they go from the screw head to the root of the pin screw, before tightening them with torque.

Lowering the nuts requires very little torque, but is a time-consuming process. Tightening the nuts requires more torque but takes less time since fewer rotations are needed. Therefore, the screw driving robots need to be able to switch between high speed, but low torque to low speed, but high torque, during the screwing process.

Furthermore, the station will need two different robots to be able to handle screws that are both visible and hidden from above.

B.10.2 New tasks to be completed here

Fetching mutters and entering them onto the pin screws.

B.10.3 Existing tasks to be moved or removed

Lowering the bridge onto the rear axle.
Tasks connected to the old MES such as handling and stamping paper orders.

B.10.4 New equipment and tools needed

- 2 linear Gantry robots to enter screws
- 2 screw drivers for entering visible screws from above in pairs
- 1 angular head screw driver for entering hidden screws
- Control and communication system
- Safety fencing and system for secure entry into robot cell
- (Potentially vision system depending on carrier's precision)

B.10.5. Takt time: Disc brake and drum brake variants

Variant group	Required time [s]	Comment
Disc brake	78	Takt time sets the required time.
Drum brake	78	

Appendix C: Interview guide - Scania employees

Introduction

Presentations, purpose of interview.

Q: What is your name and your role at Scania?

Purpose of our thesis - Next generation rear axle assembly.

Purpose of this interview:

1. Learn about how Scania is working with this technology today. Current project and future plans within Scania
2. Get your thoughts: Wild ideas and suggestions on how this technology can solve the challenges we have identified in Zone 1?
3. Get your opinions: Present our own suggestions and ask for your direct feedback on it.

Your area of expertise and experience with it

Q: What are some current and future applications of the technology/field that you are working with?
Q: In your opinion, what is the maturity level of this technology as of today?
Q: What are the main challenges and areas of improvement for this technology to be useful within Scania?
Q: How are Scania working with this technology today? Can you think of one or several projects where this technology is being/going to be used?

Q: What current or previous methods/processes/technologies are you replacing?
Q: What alternatives did you consider before choosing this solution?
Q: What was the main rationale behind this project/change
Q: What were the objectives and metrics that you used to measure the outcome of this project?
Q: What are the costs related to this project?
Q: (If the project has been implemented) What has been the outcome of the project so far? What are your thoughts on it?

> Q: Were there any surprising results?

Our challenges within Zone 1 & where do you see this technology helpful

Explain our Zone 1 area and the challenges we have identified. Focus on describing areas relevant to the specific field.

Our suggestions on new solutions in Zone 1 - your direct feedback

Suggestions are specific to the interviewees area of expertise.

Q: We have thought about this solution #1 (...) what are your thoughts on it?

> Q: Specific follow-up

Q: We have thought about this solution #2 (...) what are your thoughts on it?

Summary & Wrap-up

Q: Can we follow up on some of these questions with an email or Teams meeting in the future?
Q: Based on our questions and challenges we’ve targeted; can you think of any other employee that we should talk to?
Q: How are we allowed to use/cite your input and suggestions into our thesis?

> Q: Can we use your name as a general interview source in the thesis?