CHALMERS
UNIVERSITY OF TECHNOLOGY

Minimising required driving in internal logistics

A Case study on tow train logistics at Volvo Penta, Vara Operations

Master's thesis in Production engineering

CARL WITT and FREDRIK LINDÉN

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

Master's thesis 2024

Minimising required driving in internal logistics

A Case study on tow train logistics at Volvo Penta, Vara Operations

CARL WITT & FREDRIK LINDÉN

Department of Industrial and Materials Science
Chalmers University of Technology
Gothenburg, Sweden 2024

Minimising required driving in internal logistics
A Case study on tow train logistics at Volvo Penta, Vara Operations
CARL WITT & FREDRIK LINDÉN

Supervisor: Steven Shamoun, Volvo Penta
Supervisor: David Lind, Volvo Penta
Examiner: Peter Hammersberg, Department of Industrial and Material Science

Master's Thesis 2024
Department of Industrial and Materials Science
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2024

Minimising required driving in internal logistics
A Case study on tow train logistics at Volvo Penta, Vara Operations
Carl Witt & Fredrik Lindén
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

This thesis conducts a case study at Volvo Penta, a production facility in Vara, Sweden. The purpose is to evaluate their internal logistics and increase the understanding of its efficiency. Specifically the tow trains, supporting the assembly line. In order to do this, the research questions for this project are:

- *Is the current logistics solution for the tow trains delivering standardised results? If not, how can deviations in the results be minimised?*
- *How can the utilisation degree of tow trains and drivers be measured and how can it be improved?*
- *What is required to consider within the internal logistics of the D4/D6 flow when restructuring the production layout?*

In order to answer these questions the data has been gathered in three different ways. From interviews, material requirements measurements and position tracking of the tow trains. The results shows a higher work load on one of the two tow trains, both when it comes to boxes delivered and distance travelled, which is supported by the interviews with the tow train drivers.

When responding to the first research question, this project found a noticeable variation in the results, which indicates that the delivered results are not standardised. The interviews indicated that the workers have different ways of completing their tasks, and can be a reason for the variation in results.
The utilisation degree has been defined in this project as the meters travelled per box delivered for each tow train. This is based on the data from both the position tracking and materials requirements measurement. In order to improve this, a more efficient way of driving needs to be performed.
When restructuring the production layout, it would be beneficial to even out the work loads for the two tow trains. Since Tow Train 2 is currently driving longer distances each route, and longer distance per day.

Hence the recommendations from this thesis is to rework the work instructions, introduce a digitalised kanban system and centralise the supermarket location in a possible, future production layout.

Keywords: Production, lean, kanban, logistics, supermarket, industry 4.0

Acknowledgements

We would like to thank our examiner and academic supervisor, Peter Hammersberg. His expertise and guidance has helped us throughout this thesis and its completion. Thanks to his guidance we have been able to aim the project in a direction that has beneficial to everyone included.

At Volvo Penta we would like to thank our supervisors Steven Shamoun and David Lind as well as the management with Lovisa Nygren and Tom Jörgensen Björk. They have helped us to feel welcomed at the company and their guidance and expertise helped us significantly on our way to perform our measurements and data gathering. An extra thank you to Lovisa for help with transportation to the facility.

Finally we want to thank all of the employees that has contributed to the thesis with interviews, position tracking and the material requirements measuring. Without their participation this would not have been possible to do.

Carl Witt & Fredrik Lindén, Gothenburg, May 2024

Contents

List of Figures

List of Tables

1
Introduction

The first chapter will provide an understanding of the issue that this project is dealing with. It will also introduce the reader to the aim and delimitation's that has been set for this project.

1.1 Background

In today's increasingly competitive market companies need to be able to respond to the customers needs. In order to maintain a competitive advantage it is important to maximise the utilisation of all company assets, as well as being able to handle new challenges that may arise, for example due to market fluctuations and economical changes [1]. The organisations depend on reorganisation and adaptation of new knowledge to survive in such an environment. Therefore, there is a need of innovative ideas and continuous learning [1, 2]. One manufacturing strategy that encourages continuous learning is lean manufacturing, which comes from the Toyota Production Strategy (TPS). A strategy that made Toyota very successful despite slim resources and low demand [3, 4].

1.1.1 Problem background

Volvo Pentas production plant in Vara is producing diesel engines for both land and maritime applications, they are also used as diesel generators for example hospitals. The smallest and most common products today is the D4-engine and the D6-engine, which both are produced on the same assembly line. This production line is called the *light flow* and is supported with materials by two tow trains. These tow trains has to be planned well, so that the assembly line never has lack of materials. Furthermore the utilisation of the tow trains and the workers driving them, has to be optimal in order for the company to maintain efficient operations. This is the main reason for the project and a focus for Volvo Penta going forward.
Currently, the existing data regarding their tow trains and their internal logistics at Volvo Penta is limited. They do not know how well they are utilising their tow trains nor the staff. If the tow trains could provide the same results with less driving, the dust levels would decrease and thereby ease the work at some of the assembly stations. If the drivers could provide the same results in less time, they would get more time for additional tasks and hence a more efficient operation.

1.2 Sustainability aspects

Historically the Swedish manufacturing industry has been on the forefront of developing positive work environments. But today it is often prioritised lower and handled later than production efficiency [5]. Despite this, a positive work environment has a good impact on the workers performance and improving the performance of human resources is key for the sustainability in relation to the company's performance [6]. In addition to this, improved production performance can strengthen the job security and economical sustainability within the company.

The environmental sustainability is highly prioritised in Swedish companies, which is reflected in Sweden's first place in the global sustainable competitiveness index by *solability* [7]. To ensure fulfilment of these sustainability aspects, the resource efficiency is important going forward.

1.3 Aim and research questions

This project aims to provide Volvo Penta with a better understanding of their internal logistics, supporting the light flow. It lies in the company's interest to be more resource efficient. Hence this project aims to assist Volvo Penta when planning future production layout which the company is planning to rearrange at some point in the future. Furthermore a suitable way to measure the utilisation of tow trains and workers will be part of this project. This will be called *utilisation degree* in this report. In order to achieve this they need more data and a better understanding than they currently have regarding the tow train utilisation. Thereby this project will answer the following research questions:

- **Research question 1:** Is the current logistics solution for the tow trains delivering standardised results? If not, how can deviations in the results be minimised?
- **Research question 2:** How can the utilisation degree of tow trains and drivers be measured and how can it be improved?
- **Research question 3:** What is required to consider within the internal logistics of the D4/D6 flow when restructuring the production layout?

By answering these questions the project aims to provide a better understanding of the current effectiveness and find areas of improvements. In addition to this the affected areas of Volvo Penta will be recommended actions for future implementations in order to reach an overall more efficient operation.

1.4 Delimitations

In this project some delimitations are made. The project only considers the internal logistics for the light flow. This means the tow trains that supports the D4/D6-engine assembly line and not the tow train supporting the *heavy flow*. The data is only collected from two out of three shift parts, due to travel inconveniences.

Therefore there are no data gathered from the earliest shift part (*Morning*). Neither is the utilisation of the forklifts, delivering larger materials from the goods reception, a part of this project. The assembly line is only taken into consideration when analysing the tow trains utilisation in relation to the throughput from the assembly line.

2
Theory

This chapter will briefly explain the theory that is relevant to understand this project and its challenges.

2.1 Industry 4.0

Industry 4.0 is the automatisation of digitalization, data exchange in industries and systems and processes. The concept and goal of industry 4.0 is to create a smart factory with decreased lead times and increased productivity [8]. Industry 4.0 can help a company to improve its supply chain, manufacturing as well as logistics both internally and externally[9].

For a company to implement strategies from industry 4.0 can be hard. One of the reasons why is how the company can implement an industry 4.0 vision into their current business model.[10]

Industry 4.0 also aims to give an overview of how the the company is performing in real time. The benefit is that predictions of for example ordering of goods and shipping can have better estimates. The big data that comes with connecting the plant can be utilised by AI to help with these forecasts and better predict to help with optimisation [11].

2.2 Variation

In order to better understand how processes can behave, it is important to understand variation and its affect on different processes. Variation complicates the company's ability to combine resource efficiency and productivity [12].

Variation has an noticeable effect on processes and there are almost infinite number of reasons behind variation. To better understand the types of variations, they can be split into three types; resources, flow-units and external factors [12].

Resources that vary, can be in the form of machines breaking down or workers with different amount of experience. People as a resource, can also be affected by tiredness from day to day which leads to variation. Variation in flow-units can be described as the difference in each product or cycle time for different products. For example in a car repair, different cars with different problems will require different amount of time to fix. External factors can be varying demand depending on season, or big orders being placed at different times from a production. In all of these cases, variation will affect the process [12].

2.3 Lean Manufacturing

Lean Manufacturing is a manufacturing management methodology mainly derived from the Toyota Production Systems(TPS) [13]. In lean manufacturing it is important to minimise waste of all kinds. Often waste is divided in three different types within lean manufacturing, which is unevenness(Mura), Overburden(Muri) or process related waste that do not add any value(Muda) [4, 14].
According to TPS, waste is any process that do not add any value to the final product [13]. At Toyota the company is known to focus waste reduction on seven wastes, these are:

- Overproduction
- Excess inventory
- Waiting
- Transportation
- Unneccesary motion
- Overprocessing
- Defects

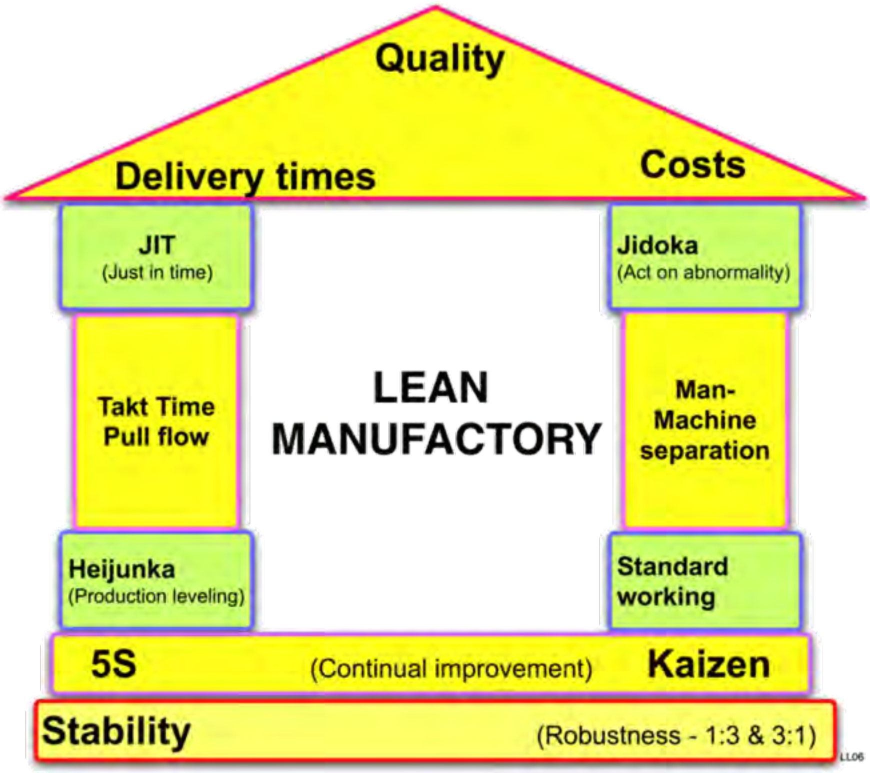

Figure 2.1: House shaped plan visualising the Lean production system [15]

When trying to learn from TPS it is also emphasised that the way of working has to be adapted to your company's culture. There will most likely be problems if the lean methods are implemented in the same way in Europe or USA as they have been in Japan [3]. Thereby an interpretation of lean, called Volvo Production

System(VPS), is being practised at Volvo. VPS is the Volvo groups framework for continuous development and waste reduction [16].

2.3.1 Kanban card

Kanban system is a pull-system used in lean manufacturing to reduce inventory buildup. Kanban cards are used to signal when material is needed to be delivered to stations. Hence nothing is being delivered on schedule, as within a push-system. When the kanban card indicates that material is needed, that is when the logistics are ordered to deliver material to where it is needed. The kanban acts as the limit for the inventory build [13]. With reduced materials in production, there will be less Work In Progress (WIP) which minimises lead times and thereby waiting. Something that is considered as waste within lean manufacturing.

2.3.2 Spaghetti diagram

The spaghetti diagram is one of the tools of lean production and can be used to identify unnecessary motion [17]. A spaghetti diagram is a way of displaying an objects positioning over time. It can give a clear overview of well trafficked areas and routes, as well as non utilised space. An example of a spaghetti diagram can be when logging ones position over time while on a run and saving it to a plot.

2.3.3 Just In Time

JIT (Just In Time) is a concept introduced by the Toyota corporation in 1954 and its aim is to reduce the wasteful overstocking in production[18]. JIT can be described as a planned way to eliminate as much waste as possible while also improve productivity. JIT includes all parts and activities in production that is necessary to produce the final product[13].
It's a way to help minimise unnecessary storage losses. So JIT focuses on a systematised way to provide the right part, at the right time in the right amount. JIT helps the manufacturer with management and organisation their production to be more effective and in turn be more competitive[18].

2.3.4 Supermarkets

A supermarket is a way to decentralise the areas for internal logistics. The area should be in close proximity to the production line where the parts will be used. The idea behind the supermarket is to reduce the amount of parts that are stored at the assembly station while being closer than the main storage. To distribute the parts from the supermarkets to the respective station a series of tow trains is necessary. These trains will deliver parts on a pull-based system when a request from the assembly line is made[19].

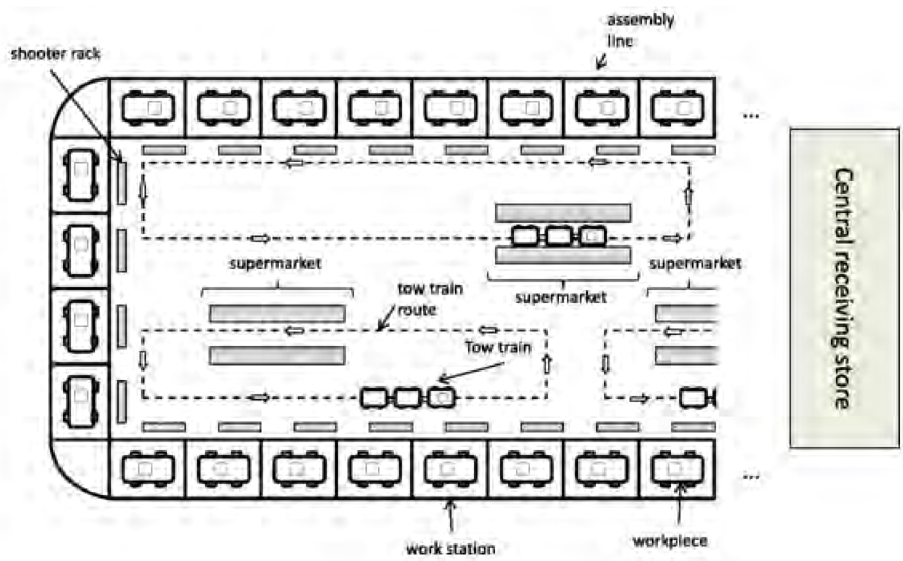

Figure 2.2: Example of how a supermarket can be implemented [19].

3
Case company

In this chapter the production and internal logistics at Volvo Penta Vara will be explained, with a focus on the light flow and the tow trains supporting this flow.

3.1 Production flow

The production at Volvo Penta Vara is divided into two different production lines. The first one is the heavy flow which is handling the largest products and the highest product variety due to low demand on each product model. The second line is the light flow (Figure 3.1) where the D4- and D6-engines are being produced. These are the products with the highest demand from the market and where the focus of this project. The light flow is divided into three different flows, flow 1, flow 2 and flow 3. Each D4/D6- engine has to go through all three flows before completed. At today's production rate the assembly line should produce 20 D4/D6 engines every shift and the shift is split into three parts. The shift parts will be referred to in this report as *Morning* (approximately 06:30-08:45), *Day* (approximately 09:15-11:30) and *Afternoon* (approximately 12:30-14:45).

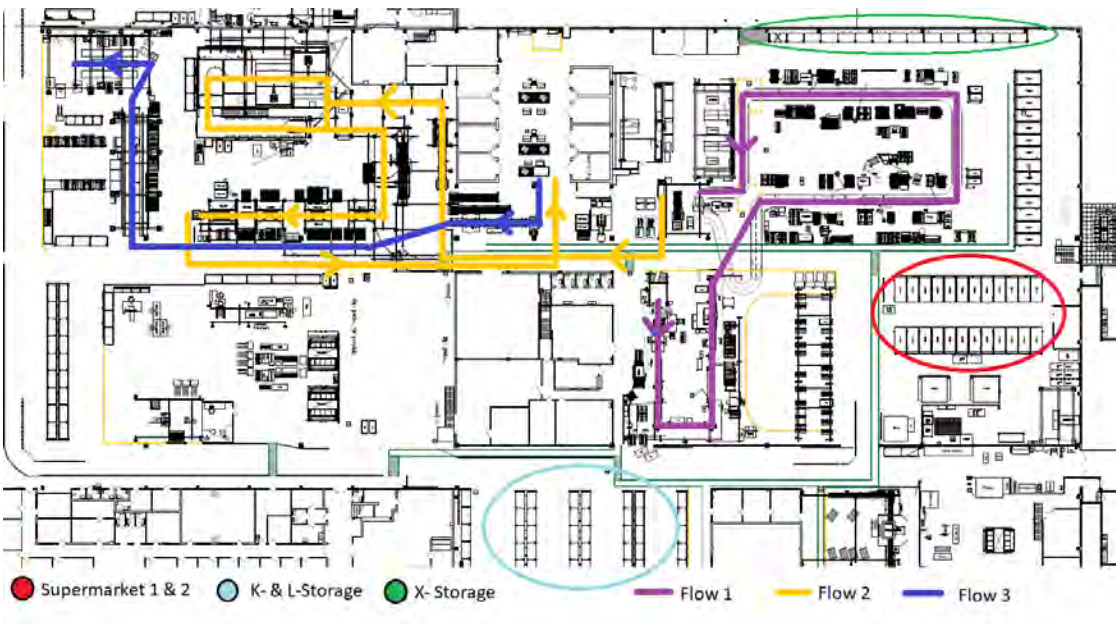

Figure 3.1: Map of the light flow layout at the Volvo Penta production in Vara

3.2 Material flow

The material referred to in this case is only the material delivered by the tow trains to the light flow and not any of the materials delivered by forklifts or to the heavy flow. This material is received at the goods reception (outside of Figure 3.1) and transported by forklifts and trucks across the production to the K-,L-,X- storage or supermarket 1/2, depending on what material.
From the supermarket there are two tow trains supporting the light flow , *Tow Train 1* and *Tow Train 2* and one supporting the heavy flow *Tow Train 3*. Tow Train 1 is supporting flow 1 (purple in Figure 3.1) while Tow Train 2 is supporting flow 2 and flow 3 with materials.

3.3 Operator instructions

The drivers are rotating between the tow trains, which means there can be different drivers handling each tow train from day to day, or week to week. The production follow a kanban card system to indicate that an empty box needs replacing and the cards are placed at each station. This requires the tow train driver to constantly keep an eye out for where materials needs refilling next along the flow that their tow train is responsible to support. The operators of the tow trains is following written instructions of what is requested of them to cover as they drive the tow trains. These instructions are shown in appendix A, along with maps showing the expected route for each tow train.

4
Methods

For the project to be able to successfully reach its purpose, several established research methods is going to be utilised. The research methods will be presented and discussed throughout this chapter. Since the task at hand is to analyse the current logistical solution a case study seems to be adequate and will be conducted for further investigation. This will help to put the project in a proper setting.

4.1 Research Methods

When conducting research it's important to select an adequate method which focus is in alignment with the characteristics of the research subject. Depending on the research question the approaches tend to land in either quantitative methods, qualitative methods or mix of them[20]. The phenomenon that has been observed in this project is how effective the internal logistics are at Volvo Pentas production plant in Vara, Sweden.

4.1.1 Case Study

A case study is a broad empirical investigation of a phenomenon in a natural context. Case studies goes analytically very deep into detail, particularly when the definition between the context and the phenomenon is not clearly stated[21]. A case study is a way to study a phenomenon in a non controlled environment and hence basically the opposite of an experiment. A big advantage with a case study is that it utilises both quantitative and qualitative data to be able to keep the phenomenon in its context[21]. Due to the advantages that a case study gives especially to *how* and *why* questions regarding contemporary situations. This method will also be advantageous due to it utilisation of both quantitative and qualitative methods. With this data a way to triangulate opens, to get a better overview.

4.1.2 Quantitative data

The major strategies for Quantitative data research is to evaluate numeric patterns based on psychological, social and economic processes[22]. The numeric data can have a clear quantitative data structures (ex personal income) while others are on a set scale by the researchers[22]. The gathering of data can be through questionnaires or structured observation, which in this case has been carried out by a material requirements study and will be presented further in section 4.2.3.

4.1.3 Qualitative data

Qualitative research data in comparison to Quantitative data is more suitable when answering questions of *what* and *why* something is being observed or when trying to concentrate on intervention improvements[23]. The paths to collect qualitative data are many and some of the most common is to either perform a document study, informal- or semi formal interviews [23]. In this project informal and semi formal interviews with different stakeholders has been performed and will be further explained in section 4.2.2.

4.2 Information collection

For this project the information collection has been conducted through 2 different ways. The first being theoretical information which was gathered through literature study, the second is data collection. The data collection covers both primary- and secondary data. Following in this section these information collections will be presented.

4.2.1 Literature study

To be able to formulate relevant research questions and objectives within the thesis a literature study has been performed. This to make sure that empirical findings that support the claims can be made. To provide the authors with information searches were made primarily in scientific data bases utilising Google Scholar and Chalmers Library. In addition to this the authors has utilised knowledge from earlier courses and material provided by encouragement from the supervisor.

4.2.2 Interviews

During the project several informal interviews were conducted with both tow truck operators as well as the logistics management team. These interviews gave an insight how management and operators view both the current operation as well as the issues. The interviewees also came with suggestions on how to improve the current logistical challenges. The way the interviews were performed, they provided the project with valuable qualitative data. This because of the openness of the questions requiring the interviewees to consider and evaluate before answering [23].

4.2.3 Material requirements

To be able to get a more detailed understanding on how the logistical solution is functioning currently, a field study in close proximity to the two Supermarkets will be conducted during the project. The study will include how often the tow train comes to the supermarkets as well as how many boxes it has on it's cart. To minimise time delays of the tow train drivers, photos of the corresponding Kanban card was taken. The photo will also help collect timestamps when the tow train has picked

up material for the production line. This data collection will be performed during the day- and afternoon shift parts.
In addition to this there are tasks that the tow train driver performs that doesn't involve Kanban cards and will not show in this data. These tasks are for example a set of carts that are delivered 5 times a day.

4.2.4 Position tracking

Position tracking of the two tow trains has been conducted simultaneously to the material requirements measurement and was done by placing a cellphone in the back of each tow train. The phones were connected to the factory WIFI to be able to get a GPS position. The GPS position was utilised by the app Geo Tracker. Geo Tracker provided data of several interests such as distance, max speed, average speed, duration and movement duration. The app also showed the tow trains movement which was utilised for a spaghetti diagram. This tracking, like the material requirements measurement, took place during the day- and afternoon shift parts.

5

Results

The results are presented in this following chapter and split up into a interview section and a data collection section. The data collection are split up into material requirements and position tracking.

5.1 Interviews

When interviewing the tow train drivers it became clear that there are variations in solutions to the task performed. Some of the drivers believed this is due to different introductions and mentors when learning the different tasks. The most noticeable differences between workers are the driving intervals. Some drivers prefer to continuously drive around looking for empty material boxes to replace. While others drive more scarcely and collect more boxes at a time.

The drivers that were interviewed also discussed the work load between the two tow trains. All of the seven drivers unanimously felt that Tow Train 2 has a higher work load, including longer drives and more materials to refill. They believed that this is due to the fact that Tow Train 2 supports both flow 2 and 3.
The interviews pointed out two major things when it comes to driving and their workload. Firstly they explained that drivers tend to drive around to make the time pass which affects the interval between pickups and the amount of boxes per pickup. Secondly they mentioned that the work load is the heaviest during the morning shift out of the three parts.

Although the experienced difference in work load, they felt that there are no issues getting their tasks done in time. This view is also shared with the logistics management, who confirmed that there are very rarely any problems with the timing of material deliveries.

When discussing the benefits of minimising the driven distance of the tow trains, production management mentioned minimised dust being pulled up from the floor. This is currently an issue at a few stations along the assembly line, where clean surfaces are needed and dust creates a requirement of an additional cleaning task for the operators.

Interviwee	Description	Occurence	Estimated Length
Logistics Management	Discussion of how the current state of the logistics work and it's challenges to get at comprehension of where to focus the project	1	45 min
Production Management	Discussion on how the production works and the challenges it faces, both production wise as well as material wise	1	45 min
Operator- Tow Train	Discussion with drivers about the tasks and how a new employee learns to perform it, also what influences the difference in driving style of each driver	6	10 min
Operator- Packing Station	Discussion of the packing of parts works, it's challenges and that the packing staion/supermarket is on the other side of where the material reception is.	6	10 min
Logistics Engineer / Project Supervisor	Discussion with the logistics engineering team about the focus of the project and what data to collect	1	45 min

Figure 5.1: Performed informal interviews

5.2 Data collection

In this section the findings from the data collection will be presented. The data collection has been split up into *Material requirements* and *Position tracking*. These results will be presented separately.
In order to relate this data to the production rate, the throughput is presented in Table 5.1 for each day that data has been collected.

Date	Engines that began production	Engines that finished from production
Jan 16	25	25
Jan 29	17	0
Feb 2	18	17
Feb 5	21	19
Feb 6	21	21

Table 5.1: Number of produced engines each day that data was collected

Due to the fact that there is no collection of how many engines start/finish from each of the sub-flows, only the total number of engines started/finished can be shown.

5.2.1 Material requirements

The material requirements results will be presented for each tow train. This include the number of boxes picked up by the tow trains, each time they stop at the supermarket as well as the interval between each stop. In order to highlight the variation, max- and min values will be presented in all data sets.

5.2.1.1 Tow Train 1

In total Tow Train 1 has collected 47, 71, 73 and 82 boxes each day. The 47 boxes is from 29th of January when the production had to stop early due to production issues and the data has thereby been collected during a shorter time period. As seen in Table 5.1 the production rate is more similar between 2nd, 5th and 6th of February. This means an average of 75,33 boxes per day, these three days. The 16th of January has not been included for Tow Train 1 due to incomplete data.

Date	Average number of boxes per pick-up	Max boxes	Min boxes
Jan 29	2,76	5	1
Feb 2	1,73	5	1
Feb 5	2,15	6	1
Feb 6	1,91	5	1

Table 5.2: Number of boxes picked up by Tow Train 1

In order to highlight the differences, the staple diagram of picked up boxes from the 2nd and 5th of February are shown below. This since these were the days with highest and lowest average of collected boxes per pick-up (excluding the 29th of Jan due to less production time). All of the staple diagrams can be seen in Appendix B.

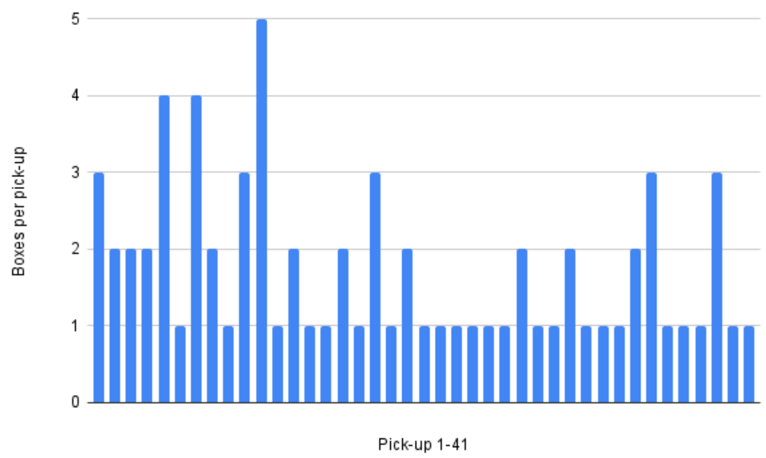

Figure 5.2: Staple diagram of boxes picked up by Tow Train 1 from Feb 2

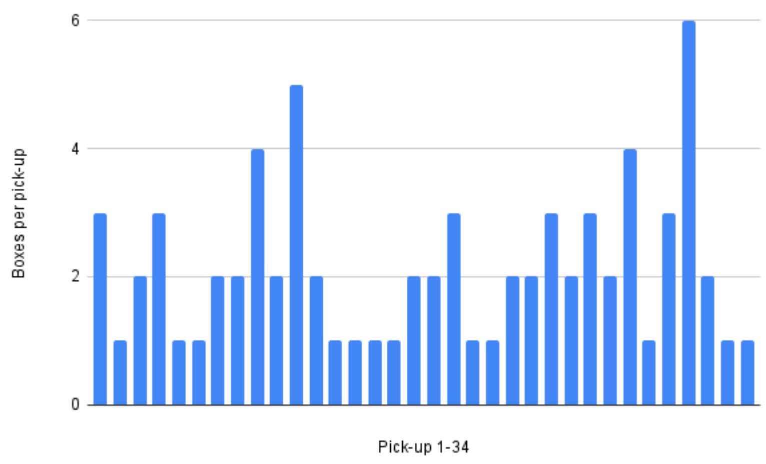

Figure 5.3: Staple diagram of boxes picked up by Tow Train 1 from Feb 5

Date	Average interval (min)	Max interval (min)	Min interval (min)
Jan 29	8	18	3
Feb 2	5,66	26	2
Feb 5	8,19	28	2
Feb 6	6,37	18	1

Table 5.3: Interval between pick-ups for Tow Train 1

Similarly to the boxes picked up, the intervals are displayed in staple diagrams below. In this case the 2nd and 5th of February because of the highest and lowest average interval times. Staple diagrams for all the dates are presented in Appendix B

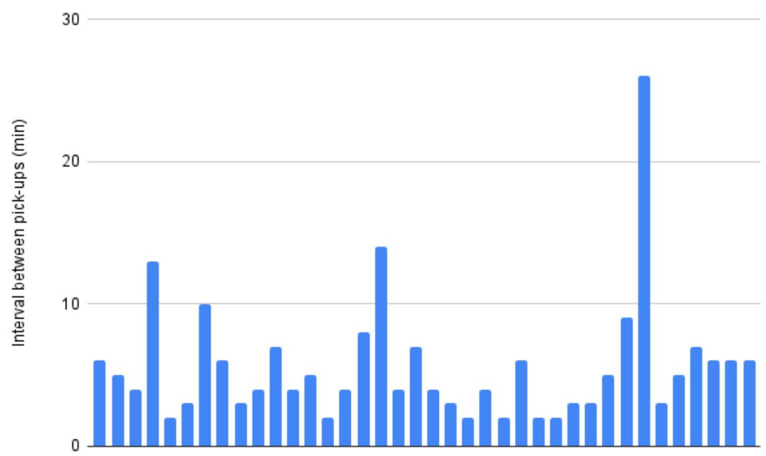

Figure 5.4: Shortest intervals between pick-ups for Tow Train 1, that were collected on February 2nd

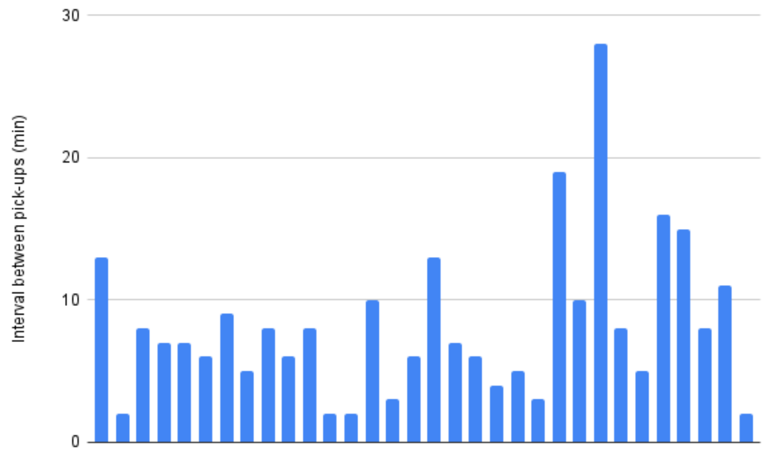

Figure 5.5: Intervals between pick-ups for Tow Train 1 on February 5th

5.2.1.2 Tow Train 2

Tow Train 2 did collect a total of 69, 68, 76, 76 and 93 boxes per day. The 68 boxes is from the 29th of January, when the production had to stop early, as explained for Tow Train 1. The average number of boxes for the other four days was 78,5.

Date	Average number of boxes per pick-up	Max boxes	Min boxes
Jan 16	2,46	6	1
Jan 29	2,65	5	1
Feb 2	2,17	7	1
Feb 5	3,30	7	1
Feb 6	6,64	14	3

Table 5.4: Number of boxes picked up by Tow Train 2

Similarly to the Tow Train 1 section, the staple diagrams from the days of production with highest and lowest average boxes per pick-up are highlighted. The remaining staple diagrams are shown in Appendix B.

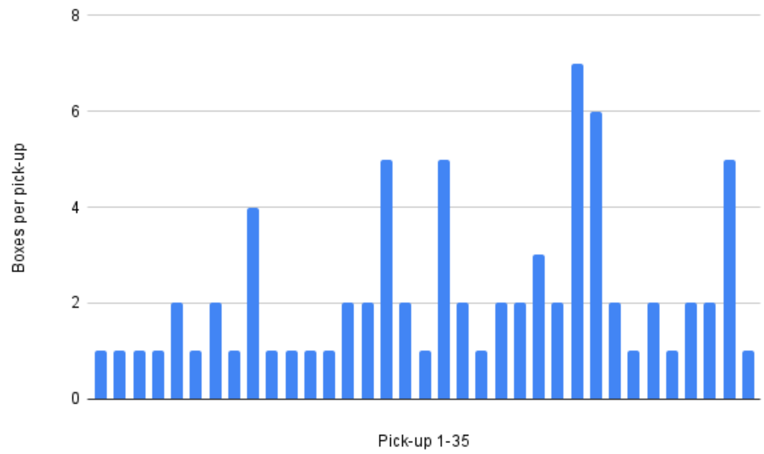

Figure 5.6: Staple diagram of boxes picked up by Tow Train 2 from Feb 2

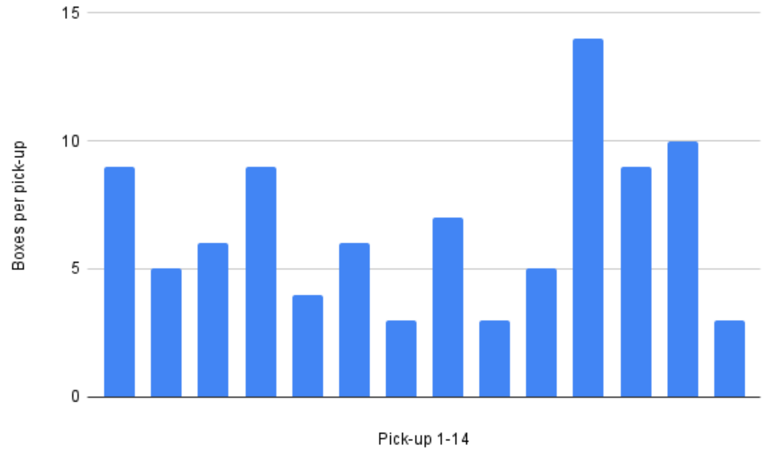

Figure 5.7: Staple diagram of boxes picked up by Tow Train 2 from Feb 6

Date	**Average interval** (min)	**Max interval** (min)	**Min interval** (min)
Jan 16	7,81	26	2
Jan 29	6,75	12	3
Feb 2	6,84	16	3
Feb 5	10,5	27	3
Feb 6	17,33	37	7

Table 5.5: Interval between pick-ups for Tow Train 2

Below the staple diagrams with the highest and lowest average intervals are shown (when excluding the half production day 29th of January). Remaining diagrams are shown in Appendix B

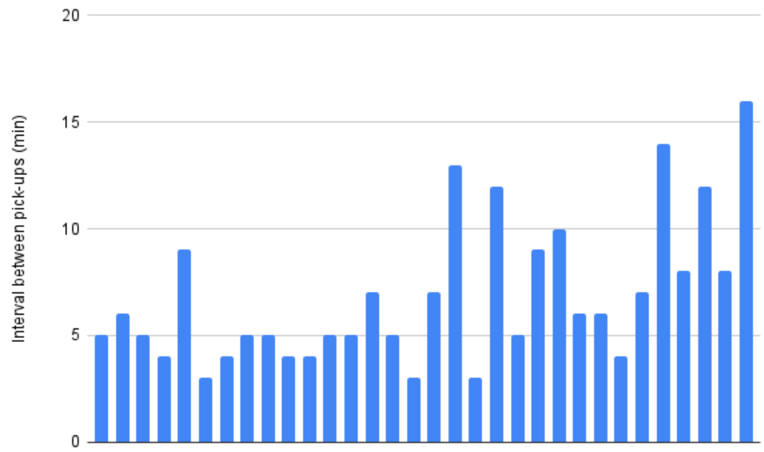

Figure 5.8: Intervals between pick-ups for Tow Train 2 on February 2nd

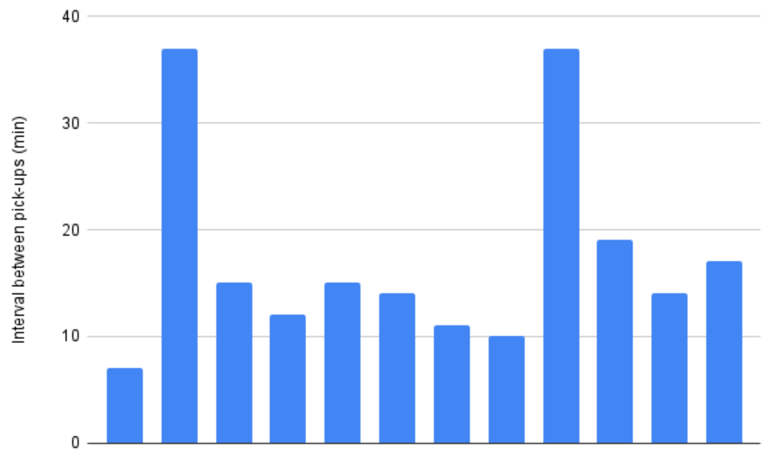

Figure 5.9: Intervals between pick-ups for Tow Train 2 on February 6th

5.2.2 Position tracking

The results from the position tracking is presented below for each of the tow trains. These results are how each of the tow trains approximately moved throughout the factory, the distance driven as well as the duration the tow train has been moving. For each tow train a picture of the spaghetti diagram will be shown in this chapter, while the rest can be seen in appendix C. Furthermore the data from the spaghetti diagrams are presented in tables and plotted in figures to highlight variations in the data collected.

5.2.2.1 Tow Train 1

Figure 5.10: Spaghetti diagram of Tow Train 1

The spaghetti diagram in 5.10 shows where the tow train has been during the recording. During this measurement we can clearly see that the tow train has completed a route to the processing, which is to the left of the stopmarker.

	Avg Movement (min)	Std Deviation (min)	Max Duration (min)	Min Duration (min)
Day	104	5,6	109	96
Afternoon	91	8,45	102	83
Total	97,5	9,61	109	83

Table 5.6: Movement times of Tow Train 1

	Avg Distance (km)	Std Deviation (km)	Max Distance (km)	Min Distance (km)
Day	3	0,49	3,62	2,56
Afternoon	3,15	1,15	4,81	2,23
Total	3,08	0,82	7,81	2,23

Table 5.7: Distance driven by Tow Train 1

5.2.2.2 Tow Train 2

Figure 5.11: Spaghetti diagram of Tow Train 2

	Avg Movement (min)	Std Deviation (min)	Max Duration (min)	Min Duration (min)
Day	63,75	8,85	76	55
Afternoon	60,25	6,65	66	51
Total	62	7,48	76	51

Table 5.8: Movement times of Tow Train 2

	Avg Distance (km)	Std Deviation (km)	Max Distance (km)	Min Distance (km)
Day	4,23	1,11	5,21	2,75
Afternoon	3,57	0,94	4,94	2,92
Total	3,92	1,02	5,21	2,75

Table 5.9: Distance driven by Tow Train 2

6
Analysis

In this chapter the data gathered has been analysed further. This to be able to compare data from different days and drivers in a scientific way.

6.1 Utilisation degree

Based on the gathered data, the utilisation degree has been defined by how far they have travelled in relation to the amount of boxes delivered. This is based on a combination of the data from the material requirements and the position tracking. It is presented for each tow train, and measured in *meters per box delivered*, since this would highlight variation in performance. Similar to the previously presented results the 16th of January is not included for Tow Train 1 due to faulty data.

Tow Train 1

Date	**Boxes in total**	**Distance travelled** (km)	**Meters per box**
Jan 29	47	3,96	84,26
Feb 2	71	5,1	71,83
Feb 5	73	4,9	67,12
Feb 6	82	6,17	75,24

Table 6.1: Utilisation degree for Tow Train 1

Tow Train 2

Date	**Boxes in total**	**Distance travelled** (km)	**Meters per box**
Jan 16	69	7,16	103,77
Jan 29	68	6,72	98,82
Feb 2	76	10,15	133,55
Feb 5	76	8,36	110
Feb 6	93	5,67	60,97

Table 6.2: Utilisation degree for Tow Train 2

In general Tow Train 1 has to drive a shorter distance per box delivered than Tow Train 2. Part of the reason for this is that the supermarket is in closer proximity to the stations supported by Tow Train 1. But still the day with best utilisation (least meters per box) is from Tow Train 2 on February 6th.

6.1.1 Relation to throughput

To further analyse the utilisation degree, the number of engines produced has been put in relation to the meters travelled per box. In figure 6.1 the number of boxes per engine produced are shown. Where it is possible to see that each engine requires between 2,8 and 4,2 boxes from tow train 1 and 2,8 and 4,5 boxes from tow train 2.

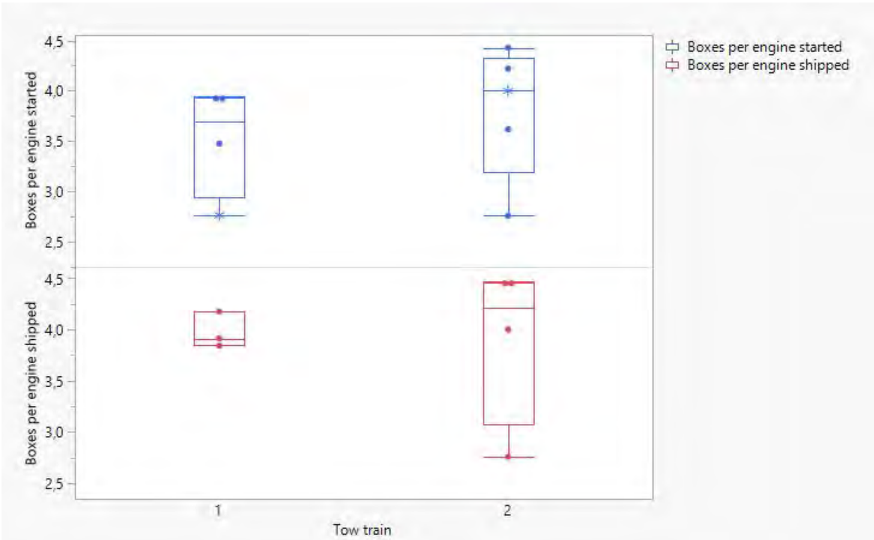

Figure 6.1: Number of boxes being delivered per engine started and finished

When combining this with meters travelled per box delivered we get the total distance travelled per engine produced, as shown in figure 6.2.

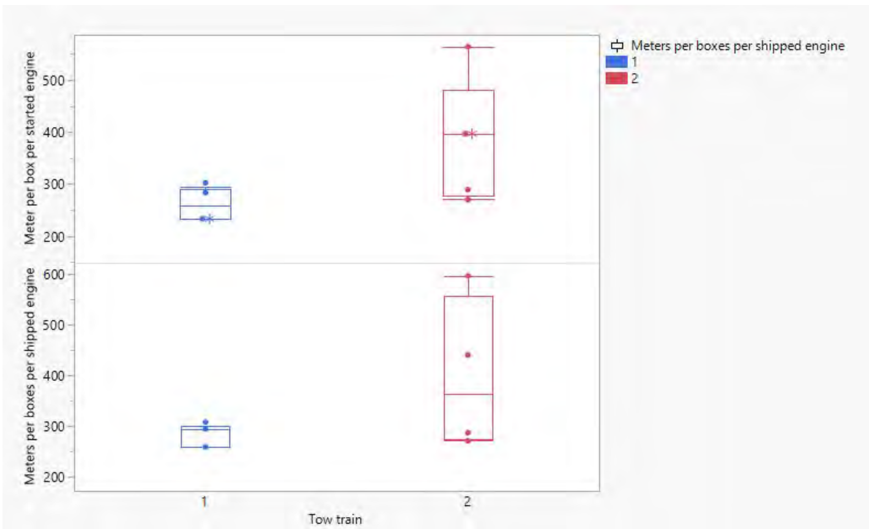

Figure 6.2: Meters travelled per each engine started and finished

This shows a bigger variation in travelled distance for tow train 2 compared to tow train 1, even if it is in relation to the number of produced engines. From figure 6.1 it is visible that part of the reason for this is a larger variation in boxes delivered per engine.

6.2 Driving styles

When analysing the data, variations are noticeable in all data sets. The first big difference is how the routes are driven. The main difference is that Tow Train 1 has the possibility to split the route into 3 smaller routes which would increase the amount of stops at the supermarket.

For Tow Train 2 it is a bit different since the route can not be split like Tow Train 1 can. For Tow Train 2 we can see that the average interval between trips is a bit higher than Tow Train 1 which mainly has to do with that the route is longer. On the 6th of Feb we see that the data differed significantly from the others. The reason behind this was that the driver had the style to drive less often. It is remarkable that all except one of the drivers, drives more than twice as often as the last driver. Even more that the smallest interval is larger than two drivers average interval. This indicates that some drivers are driving more often than necessary, since all drivers were able to complete their task without disturbing the production flow.

While observing the Tow Trains it became evident that a major drawback with the current kanban card system is that each box needs two trips from the tow train to be refilled. This because the driver has no indication of when there are boxes that needs to be refilled.

Further identified differences between the tow trains are the storages locations in relation to their materials supported stations. For Tow Train 2 the K and L storage is located far from the stations that materials needs to go to, which can be seen in figure 3.1. This is one of two reasons identified why they have to drive longer than Tow Train 1, the other reason being where the supermarkets are located in relation to the supported stations. For Tow Train 1 it is the opposite where they have to pass the supermarkets as well as the X storage while they complete their routes. This is supported by the data collected in the spaghetti diagrams as well as in meters driven per box.
Furthermore when analysing the workload differences between the two tow trains and the amount of boxes that each driver needs to pick up, it is noticeable that the averages are similar, but Tow Train 1 has a slightly lower average.

7
Discussion

The discussion has been divided into two main discussion points. These discussion points was derived from the results from the interviews, that can be seen in section 5.1 as well as the analysis of the results. In addition to these we will also discuss the credibility of the data gathered in this project.

7.1 Driving styles

As Mentioned in 6.2 there are some differences in the driving styles between the drivers. This became more evident after the interviews with the drivers since they believed it came down to personal interpretation of the work instructions. This has both negatives and positives for the task at hand. One positive, is that the drivers feels some degree of freedom and can take ownership of the task at hand. The instructions becomes a guideline rather than a set of monotonous tasks that needs to be performed. So information about why the drivers should drive less would help to keep the drivers informed. On the negative side, due to the uncertainty of when the boxes needs refilling, the tow train drivers has to keep a look out for empty boxes and thereby perform a lot of *empty driving* no matter of their stimulation. This can be described as unnecessary motion and be linked back to the framework of Leans different types of waste.

When looking at the result and analysis, variation is noticeable within all data sets. The utilisation degree varies, more than twice the amount of meters travelled per box, from one day to the other. This is of course affected by the different driving styles and the variation in output indicates a need for limited deviations in driving styles.

Although the deviations in output, needs to be minimised, it is important that the workers remain in charge of the task. This can be key to maintain a motivated staff. Since the current kanban system requires two trips for each box, as mentioned in 6.2 there could be a correlation with the dust problem that the management mentioned. This however needs data on dust levels in all stages of production, to confirm if there is a correlation. Less driving has other effects like less resources being used for wear and tear on the tow trains, the amount of charge that the tow train consumes and wear on the production floor.

7.2 Data credibility

When conducting any type of analysis the expectations of data is to be sufficient. However the reality is that all data has some imperfections. For this project there is a limited amount of data collected. Which also is affected by several factors which will affect the credibility. As previously stated in 4.2.3 that the data is only collected during the later two shift parts, and that the drivers said the most work is being done during the shift part not measured. The driver will affect the data as can be seen in 5.2 especially on the 6th of February. These variations needs to be studied to get a representative sample. This while also keeping the drivers anonymous since the union does not allow to measure data that can be tracked back to the driver. So in order to get a sample that gives a fair representation of how the tow train logistics work, the time span measured should be bigger. This would give an indication on if there are patterns based on different weekdays and seasons during the year. This can be linked to the external factors explained in section 2.2, where the demand for products can vary depending on the season.

For the analysis on utilisation degree compared to production throughput, it is important to remember that the started and finished engines are the only throughput data to compare. This means that there are no data on how many engines passed by flow 1, flow 2 or flow 3 individually. This data would make the comparison more representative. For example the 29th of January, there were no engines finished, but this does not mean that no engines where handled in flow 2 or 3. Furthermore when putting the logistics performance in relation to the throughput, there could be an aspect of responsiveness between throughput and work load on the logistics. This means that there could be a set of working hours from an increased throughput to an increased work load on the internal logistics. To find out if this is the case, data would have to be gathered more regularly to catch ups and downs in work load for the logistics, as well as ups and downs in production rates. Specifically data from the different, individual flows 1 through 3.

8
Conclusion

8.1 Research questions

Is the current logistics solution for the tow trains delivering standardised results? If not, how can deviations in the results be minimised?

Despite limited data there is a considerable deviation within the results that indicates that the output from the tow trains is not standardised. In order to minimise these deviations, the work instructions needs to be updated. The workers need to still have ownership of the tasks at hand, but the guidelines should be reworked so that the results would be more standardised.

How can the utilisation degree of tow trains and drivers be measured, and how can it be improved?

Based on the different data sets in this report, the *utilisation degree* has been explained as a combination of the position tracking and material requirements data. This has been measured in *meters travelled per each box picked up*, which highlights possible variation in output. The utilisation degree in this case show that the Tow Train 1 on average has to drive 74,61 meters per box delivered, while Tow Train 2 has to drive 101,42 meters on average. To improve this some sort of replacement for the kanban card system should be implemented, in order to minimise the empty driving without boxes. No data about the utilisation degree of the workers has been made other than the interviews. The workers said that there is no problem to get their tasks done in time, but how much time is spent adding value to the product or should be interpreted as waste, needs further investigation.

What is required to consider within the internal logistics of the D4/D6 flow when restructuring the production layout?

If a future restructuring of the production layout will be made this project found that the location of the supermarkets should be more centralised in the production to even out the required driven distance from the two tow trains. The current position is part of the reason why Tow Train 2 has a higher work load compared to Tow Train 1. Furthermore the position requires forklifts to travel across a big part of the production from the goods reception.

8.2 Recommendations

1. **More data collection**
   This project has been based on data collected from a few dates within three weeks. To be able to notice patterns of certain week days or yearly seasons, data should be collected similarly but on a bigger time span. None of the data in this project, has been collected during the morning shift part, which is where the interviewed workers claimed they had more deliveries to do. This would also be of interest to the company and requires more data collecting in the future. This data would be most useful to the Production Engineers to further improve the efficiency of the production. Thereby they should be in charge of implementing the tools required to collect this data.

2. **Rework work instructions**
   Redesigning the work instructions in order to achieve more standardised results from the internal logistics will be key to work on improvements in the future. The instructions should be like guidelines, so that the workers stay in charge of the tasks at hand. Formulating these guidelines, should be performed by the logistics management and with input from the tow train drivers, in order to be transparent within the company.

3. **Digitalised kanban system**
   This system could be an idea to minimise empty driving by informing tow train drivers when and where materials is required. A digitalised kanban system that can handle requests from the assembly line to the internal logistics team, as well as showing the inventory at each station. This could greatly benefit the tow train drivers who can plan their drives better, deliver multiple boxes each route and between each route spend more time with other supporting tasks. This together with updated work instructions should lead to both a better utilisation degree and better support with additional tasks. This is recommended that the production and logistics management prioritise to invest in.

4. **Centralise the supermarket location**
   Since there will possibly be a future restructuring of the production line, some replacements of stations might occur. With this in mind the results from this project indicates an unevenness between the two tow trains, both from the interviews with workers and from the position tracking data. This shows that Tow Train 2 has a higher work load. In order to even this out the recommendation would be to place the supermarket in a more central location, so that the Tow Train 1 route and Tow Train 2 route would be of more similar distance. This is also supported by the literature study about supermarkets and would reduce the required travel distance for Tow Train 2, which currently has to drive more that 25 meters longer per box delivered on average. This is up to management to consider if the production layout will be rearranged in the future.

8.3 Future work

Since the data samples are few and focused on a short time span it is recommended that for future research that more data is collected on a bigger time span, for example to catch seasonal effects on production. Another addition to the data collection would be to note when a trip with no boxes has been made. This to get a more conclusive view on the current situation.

However the data that has been gathered indicates that changes can be tested to see how it impacts the utilisation degree of the tow train. In the short term new clearer instruction and guidelines for the tow train drivers could be written and tested. This pilot test could then be compared with the data in this project to see if the changes has affected in any way.

In the long term when the plant is going through a reconfiguration it would be beneficial to have gathered enough data to make an informed decision with the logistical aspect in mind.

Bibliography

[1] D. Mendez, P. D. Gaspar, F. Charrua-Santos, H. Navas. *Integrating TPM and Industry 4.0 to Increase the Availability of Industrial Assets: A Case Study on a Conveyor Belt*. (2023). Accessed: Feb. 17, 2024 [Online]. Avalible: https://doi.org/10.3390/pr11071956

[2] A. P. Proenca, P. D. Gaspar, T. M. Lima. *Lean Optimization Techniques for Improvement of Production Flows and Logistics Management: The Case Study of a Fruits Distribution Center*. (2022). Accessed: Mar. 01, 2024 [Online]. Avalible: https://doi.org/10.3390/pr10071384

[3] J. Liker, M. Hoseus. *Toyota Culture: The Heart and Soul of the Toyota Way*. (2007). Accessed: Mar. 01, 2024 [Online]. Avalible: https://mhebooklibrary.com/doi/book/10.1036/9780071712576

[4] J. K. Liker, D. Meier. *Toyota Way Fieldbook, 1st Edition*. (2006). Accessed: Mar. 01, 2024 [Online]. Avalible: https://www.accessengineeringlibrary.com/content/book/9780071448932/

[5] B. Johansson *Work Environment and Production Development in Swedish Manufacturing Industry*. (2010). Accessed: May. 15, 2024 [Online]. Avalible: https://doi.org/10.1080/10803548.2010.11076852

[6] M. F. Lussa, A. Sudiro, R. D. V. Hapsari. *The effect of work motivation and work environment on employee performance through work engagement*. (2023). Accessed: May. 15, 2024 [Online]. Avalible: https://doi.org/10.20525/ijrbs.v12i9.3063

[7] SolAbility *The Global Sustainability Competitiveness Index*. (November,2023). Accessed: May. 15, 2024 [Online]. Avalible: https://solability.com/the-global-sustainable-competitiveness-index/the-index

[8] Maryam Abdirad and Krishna Krishnan *Industry 4.0 in Logistics and Supply Chain Management: A Systematic Literature Review*. (2020). Accessed: Mar. 11, 2024 [Online]. Avalible: https://doi.org/10.1080/10429247.2020.1783935

[9] Yin,Y., Stecke,K. E., & Li, D. *The evolution of production systems from Industry 2.0 through Industry 4.0.* . (2018). Accessed: Mar. 11, 2024 [Online].

Avalible: https://doi.org/10.1080/00207543.2017.1403664

[10] Facchini, F.; Oleśków-Szłapka, J.; Ranieri, L.; Urbinati, A *A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap for Future Research.* (2020). Accessed: Mar. 12, 2024 [Online]. Avalible: https://doi.org/10.3390/su12010086

[11] Astha Raizada *Inventory Management Challenge in the Industry 4.0 Global Supply Chain.* Accessed: Mar. 13, 2024 [Online]. Avalible: https://copperdigital.com/blog/inventory-management-in-industry-4-0/

[12] N. Modig, P. Åhlström. *Detta är lean* 2nd ed. Halmstad, Bulls Graphics AB, 2012. pp. 40-41

[13] J. X. Wang. *Lean Manufacturing : Business Bottom-Line Based.* (2010). Accessed: Mar. 13, 2024 [Online]. Avalible: https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=589949

[14] TWI *What is lean manufacturing and the 5 Principles Used? - TWI.* Accessed: Mar. 13, 2024 [Online]. Avalible: https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-lean-manufacturing#The8WastesofLeanManufacturing

[15] Laurensvanlieshout. *Lean manufactory house.png.* (2006). Accessed: Mar. 14, 2024 [Online]. Avalible: https://commons.wikimedia.org/wiki/File:Lean_manufactory_house.png

[16] Volvo Group. *Volvo Group magazine 2.2017.* (2017). Accessed: Mar. 13, 2024 [Online]. Avalible: https://www.volvogroup.com/content/dam/volvo-group/markets/master/news-and-media/volvo-group-magazine/news-and-media-vgm-2-2017.pdf

[17] N. Daneshjo, V. Rudy, P. Malega, P. Krnáčová. *Application of Spaghetti Diagram in Layout Evaluation Process: A Case Study.* (2021). Accessed: Mar. 12, 2024 [Online]. Avalible: https://doi.org/10.18421/TEM102-12

[18] Atour Taghipour, Phuong Hoang, and Xue Cao *Just in Time/Lean Purchasing Approach: An Investigation for Research and Applications.*(2020) Accessed: Mar. 13, 2024 [Online]. Avalible: https://www.joams.com/uploadfile/2020/0527/20200527052053983.pdf

[19] Daria Battini · Nils Boysen · Simon Emde *Just-in-Time supermarkets for part supply in the automobile industry.*(19 sept 2012) Accessed: Mar. 14, 2024 [Online]. Avalible: https://doi.org/10.1007/s00187-012-0154-y

[20] Carrie Williams *Research Methods. Journal of Business & Economics Research (JBER). 5.*(3 Mar 2007) Accessed: Mar. 14, 2024 [Online]. Avalible:

https://doi.org/10.19030/jber.v5i3.2532

[21] Robert K. Yin *Case study research : design and methods*. 5th ed, London UK,2014

[22] Hancock, D.R. and Algozzine, B. and Lim, J.H. *Doing Case Study Research: A Practical Guide for Beginning Researchers.*(2021) Accessed: Mar. 14, 2024 [Online]. Avalible: https://books.google.se/books?id=e7lLEAAAQBAJ

[23] Sharique Ahmad, Saeeda Wasim, Sumaiya Irfan, Sudarshana Gogoi, Anshika Srivastava, Zarina Farheen*Qualitative v/s. Quantitative Research- A Summarized Review.*28 Oct(2019) Accessed: Mar. 3, 2024 [Online]. Avalible: 10.18410/jebmh/2019/587

A

Appendix A

Moppe 1

Kör för Montering och Prov i Lätta Flödet (A-line)

<u>Rutt 1</u>

1. Börja i Grunddel stn 100-170 (insida, fm & trucksida), hämta tomma lådor och kanbankort.
2. Åk till ställage J-M, Hiss 1/2/3, SM 1, ställage X, måleriet (plugg). Lämna tomlådor och ta med nytt material och kör ut till platserna i samma rutt.

<u>Rutt 2</u>

3. Kör till Mellandel stn 200-250 (trucksida, FM, och insida), hämta tomma lådor och kanbankort.
4. Åk till ställage J-M, Hiss 1/2/3, SM 1, ställage X. Lämna tomlådor och ta med nytt material och kör ut till platserna i samma rutt.

<u>Rutt 3</u>

5. Kör till Slutdel stn 300-350 (insida & trucksida) och hämta tomma lådor och kanbankort.
6. Ta med sekvensvagnar när det finns färdiga att hämta i Sekvensplocket.
7. Åk till Sekvensplocket, ställage J-N, Hiss 1/2/3, SM 1, ställage X. Lämna tomlådor och ta med nytt material och kör ut till platserna i samma rutt.

<u>Rutt4</u>

8. Kör till Läcktest stn 400, hämta tomma lådor och kanbankort.
9. Kör till Provets materialställ och hämta tomma lådor och kanbankort.
10. Åk till ställage J-M, Hiss 1/2/3, SM 1-2, ställage X. Lämna lådor och ta med nytt material och kör ut till platserna i samma rutt.

<u>Rutt5 körs 3x/dag</u> (1 gång på morgon, 1 gång innan eller efter lunch samt 1 gång innan hemgång)

11. Kör in på bearbetningen via gångväg (mellan blockstation & kontor) för att hämta tomma lådor och kanbankort på deckelstation. Hämta tomma lådor och kanbankort på blockstation.
12. Åk till J-M-ställage, hiss 123, SM 1 och lämna tomlådor och kanbankort. Ta med nytt material och kör ut till platserna i samma rutt.

Figure A.1: Current instructions for Tow Train 1

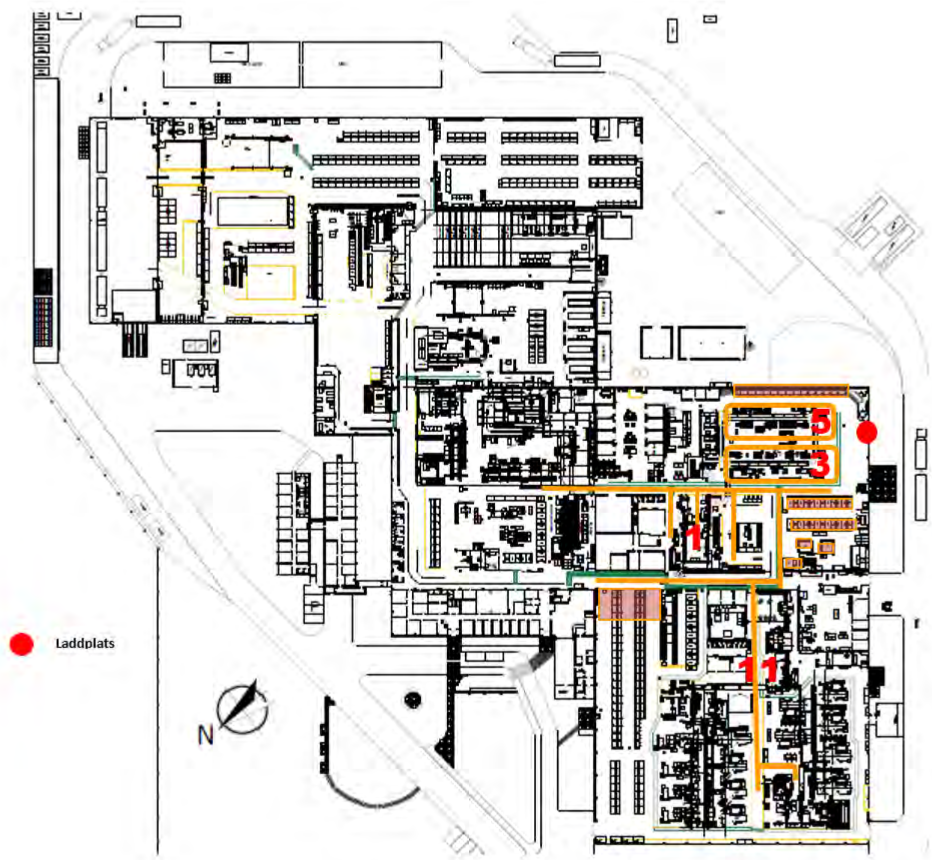

Figure A.2: Map of the Tow Train 1 route

Moppe 2

Kör för Måleri & Satspack i Lätta flödet (A-line)

Rutt 1

1. Börja i Flöde 2, stn 835-858(trucksida och insida), hämta tomma lådor och kanbankort.
2. Hämta tomma lådor och kanbankort i Flöde 3 stn 860-882(insida, FM och trucksida) och stn 685 i Satspacken.
3. Åk till Satspackens materialställ och lämna tomma lådor.
4. Hämta påfyllda lådor som ska till Flöde 2 & 3 i Satspackens materialställ.
5. Hämta tomma lådor från A-vågens retur.
6. Åk till ställage J-M, Hiss 1/2/3, SM 2. Lämna tomlådor och ta med nytt material och kör ut till platserna i samma rutt.

Figure A.3: Current instructions for Tow Train 2

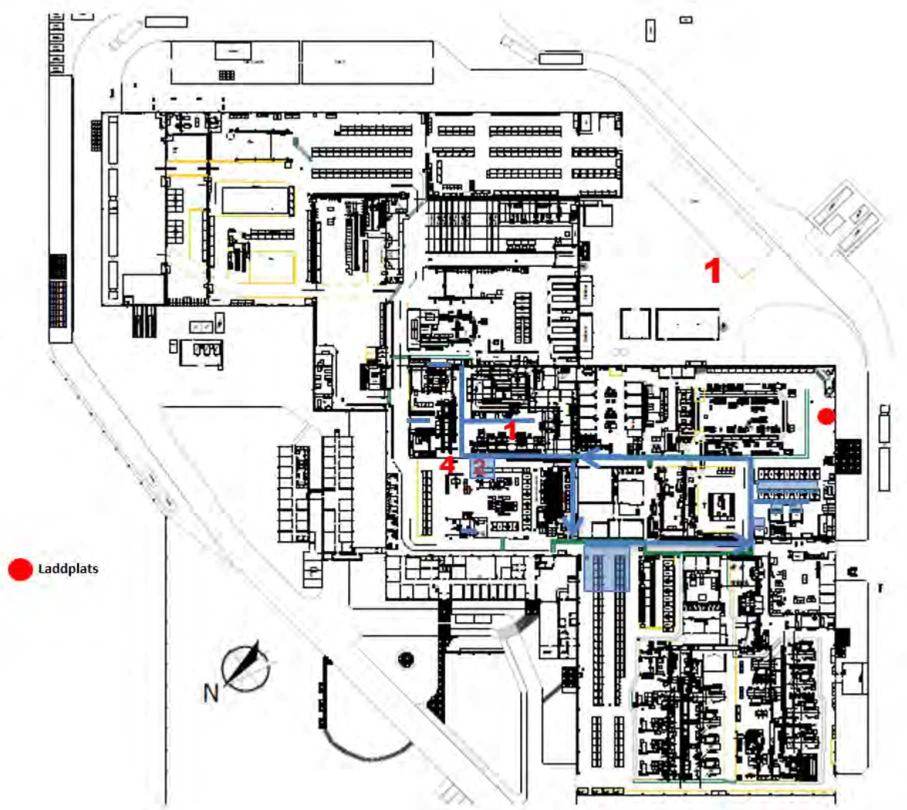

Figure A.4: Map of the Tow Train 2 route

B

Appendix B

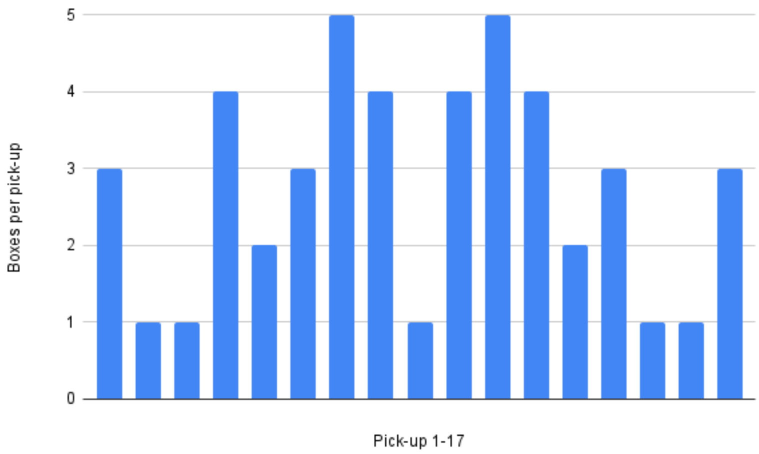

Figure B.1: Histogram of tow train 1 29/1

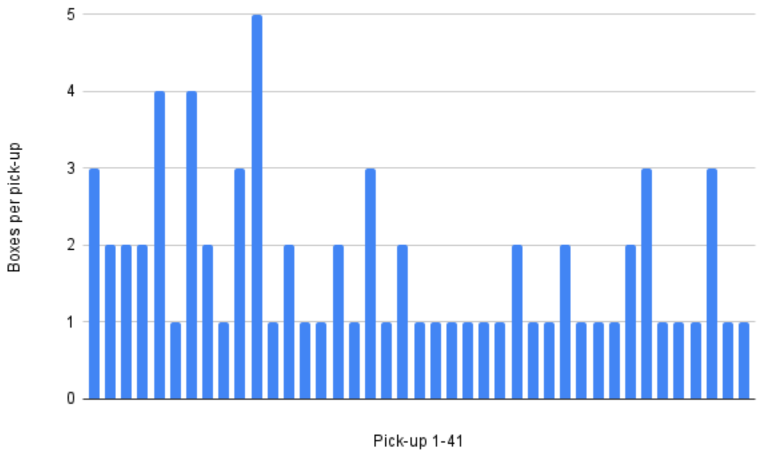

Figure B.2: Histogram of tow train 1 2/2

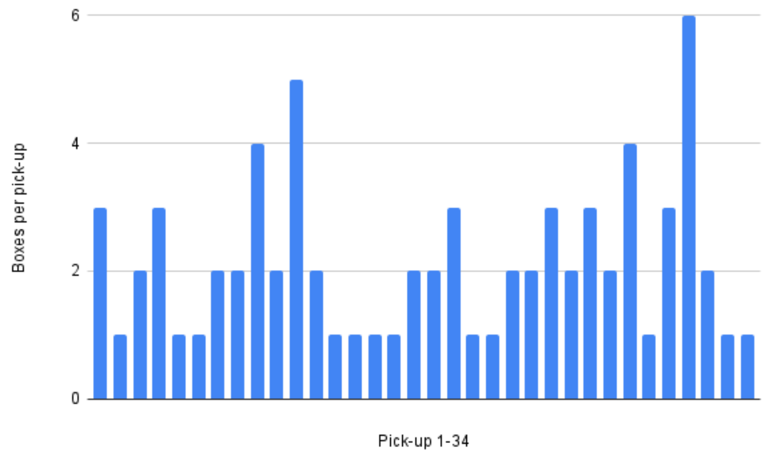

Figure B.3: Histogram of tow train 1 5/2

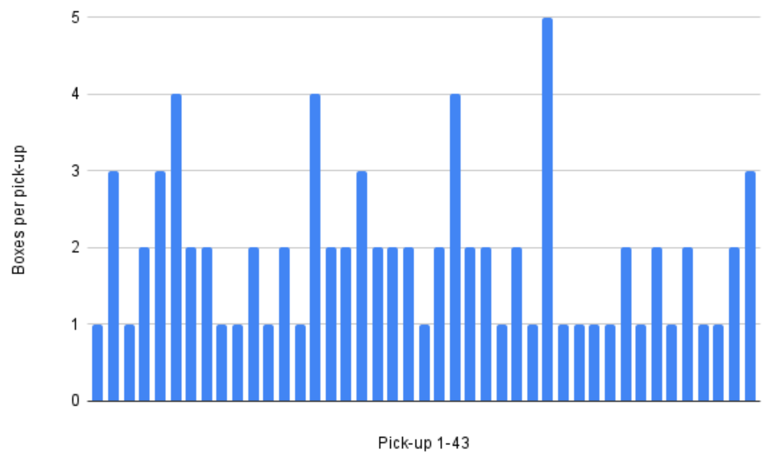

Figure B.4: Histogram of tow train 1 6/2

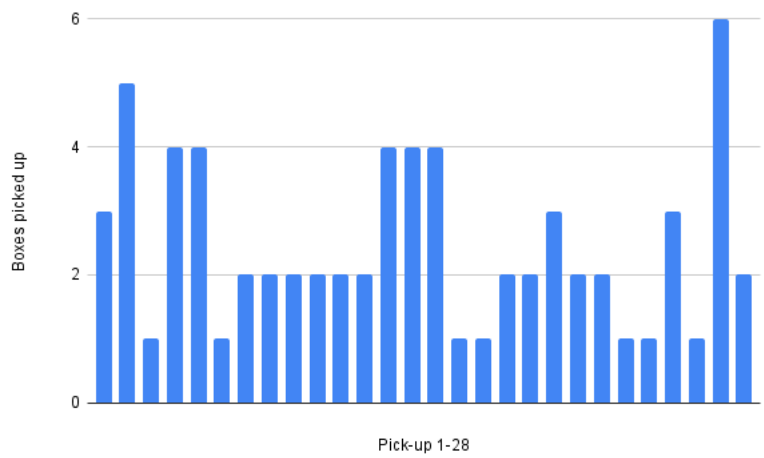

Figure B.5: Histogram of tow train 2 16/1

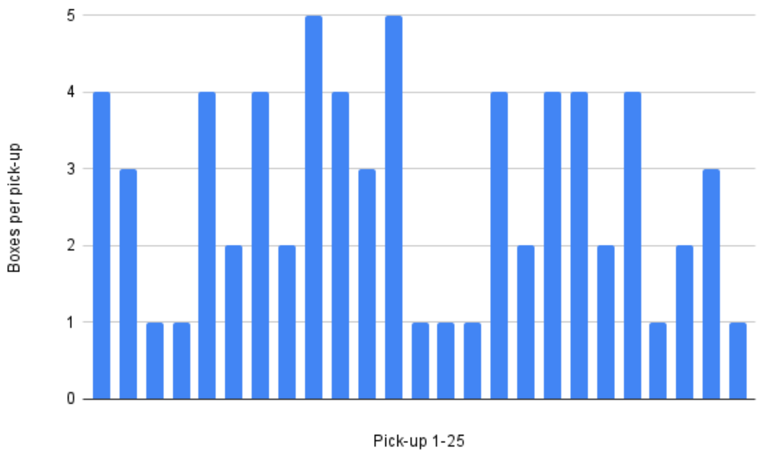

Figure B.6: Histogram of tow train 2 29/1

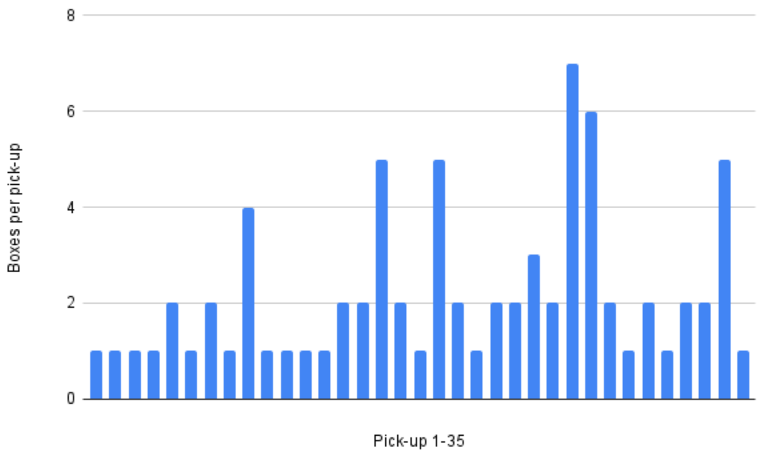

Figure B.7: Histogram of tow train 2 2/2

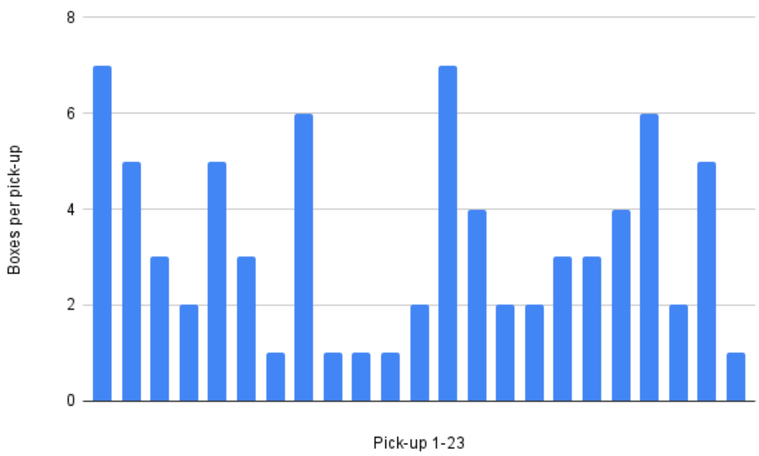

Figure B.8: Histogram of tow train 2 5/2

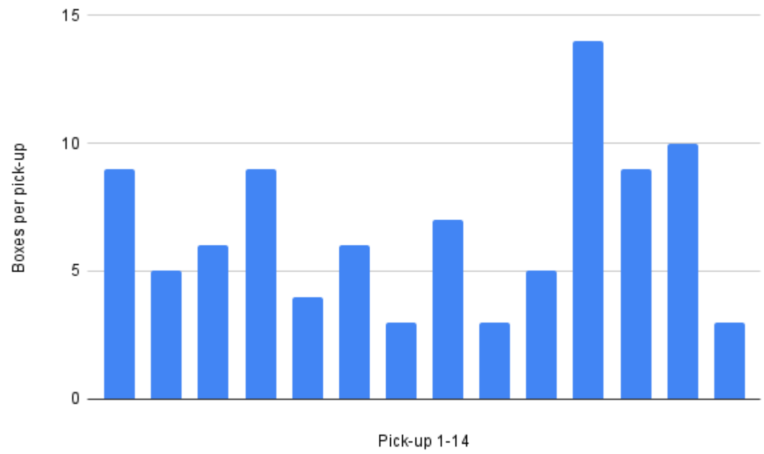

Figure B.9: Histogram of tow train 2 6/2

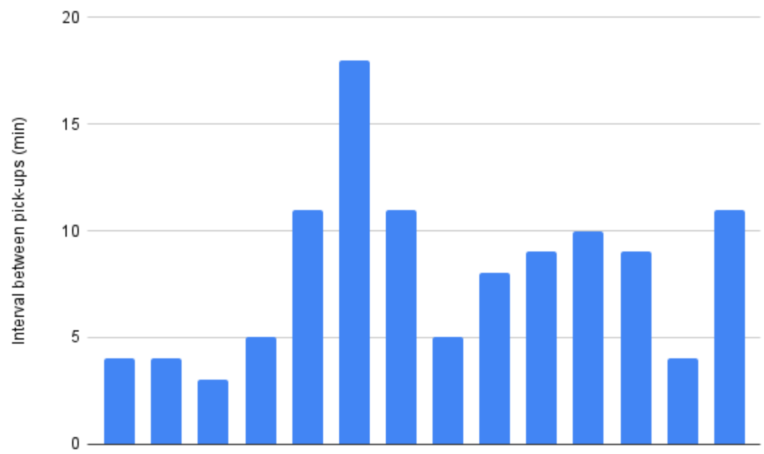

Figure B.10: Intervals of tow train 1 29/1

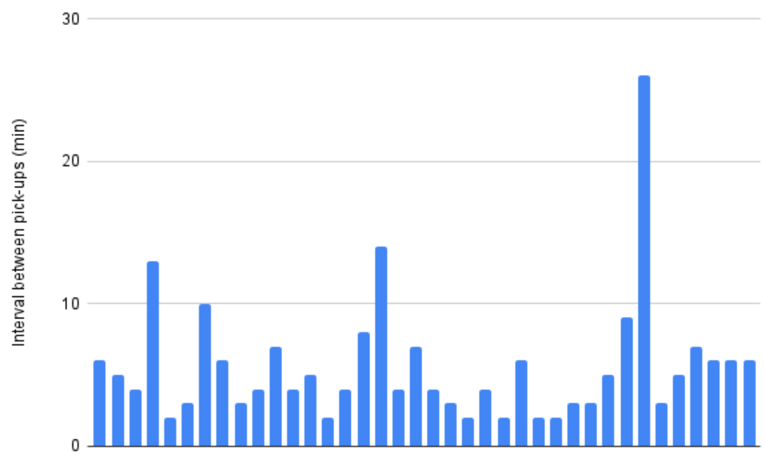

Figure B.11: Intervals of tow train 1 2/2

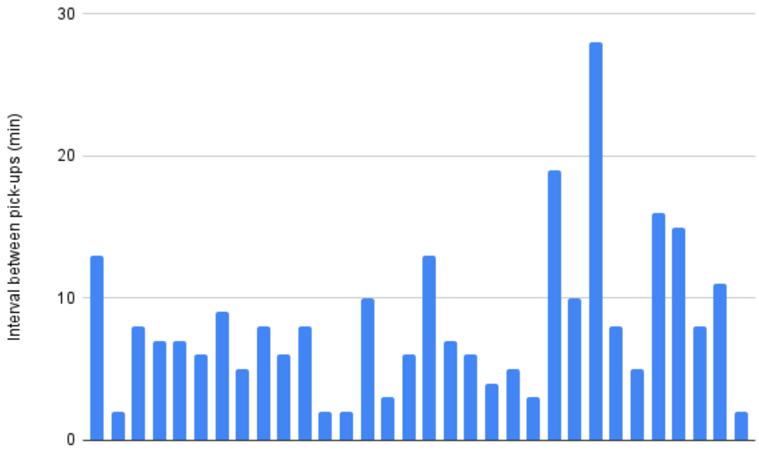

Figure B.12: Intervals of tow train 1 5/2

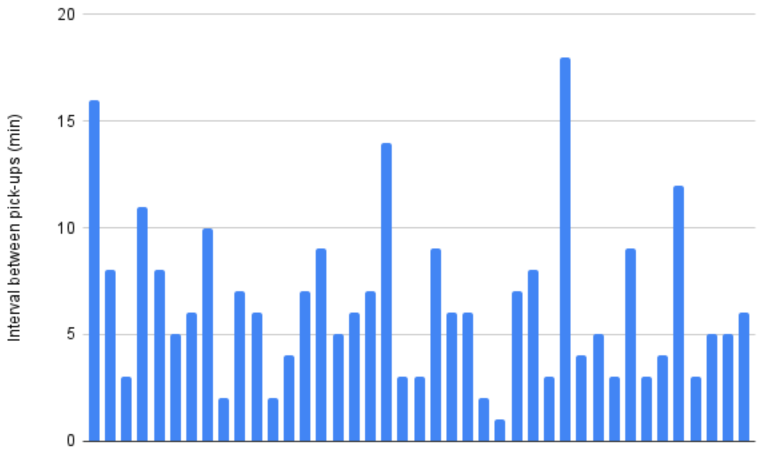

Figure B.13: Intervals of tow train 1 6/2

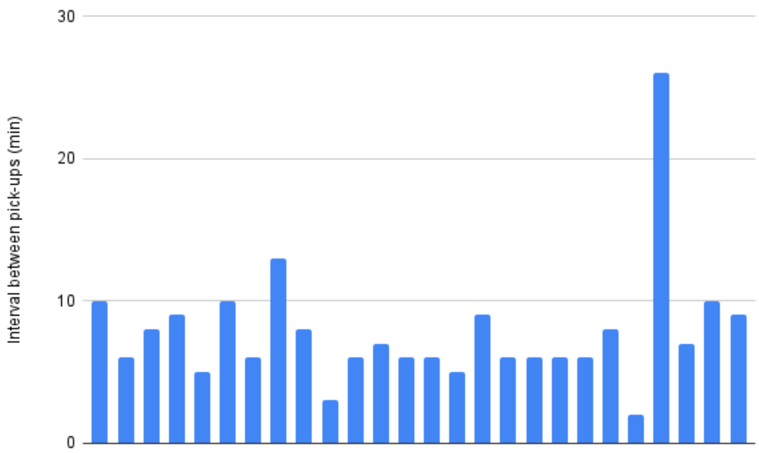

Figure B.14: Intervals of tow train 2 16/1

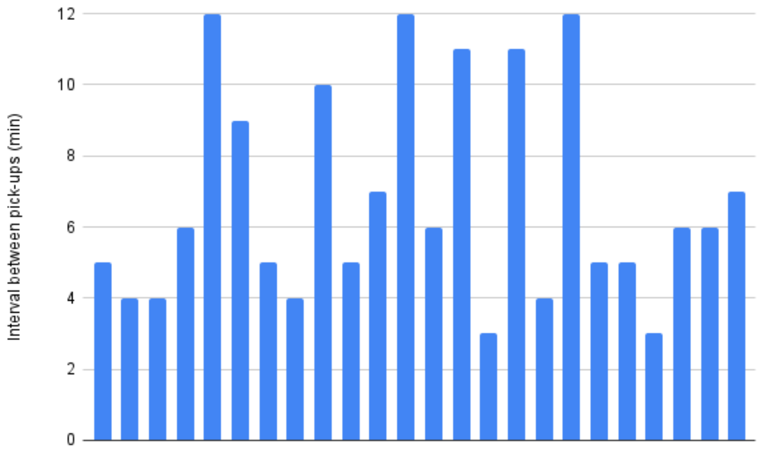

Figure B.15: Intervals of tow train 2 29/1

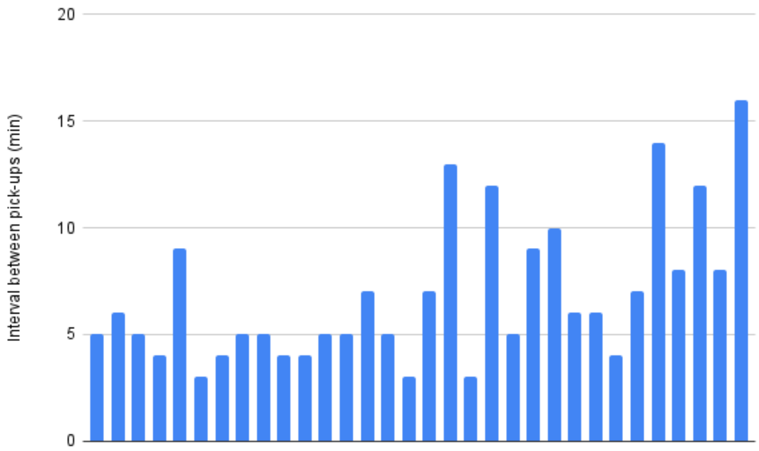

Figure B.16: Intervals of tow train 2 2/2

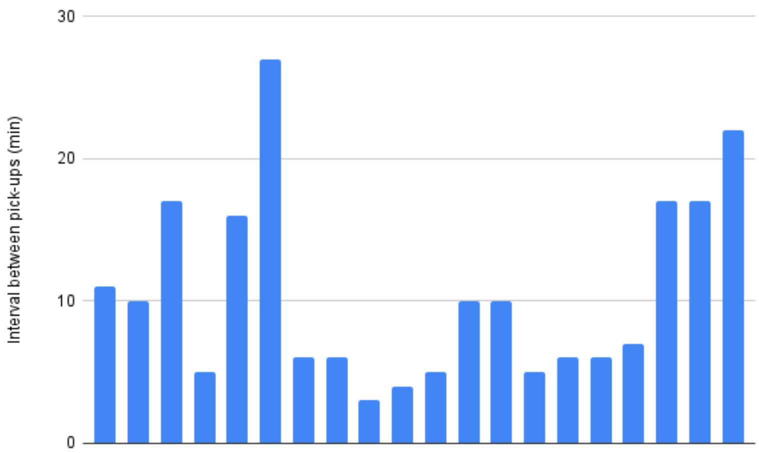

Figure B.17: Intervals of tow train 2 5/2

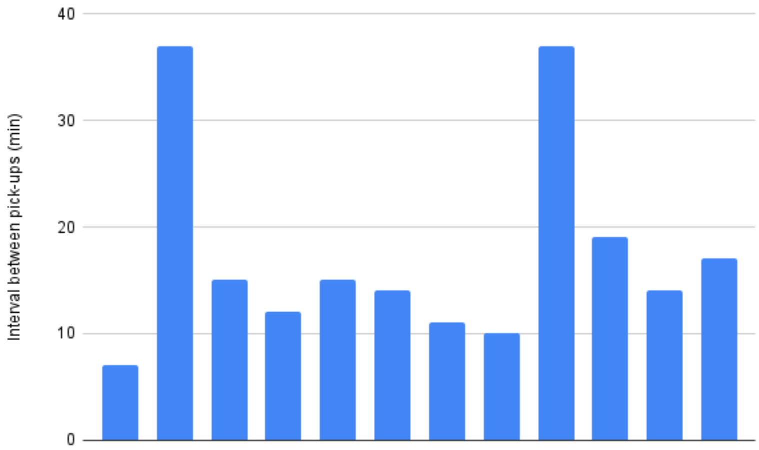

Figure B.18: Intervals of tow train 2 6/2

C

Appendix C

Figure C.1: Spaghetti diagram of Tow Train 1 16/1 Day

Figure C.2: Spaghetti diagram of Tow Train 1 16/1 Afternoon

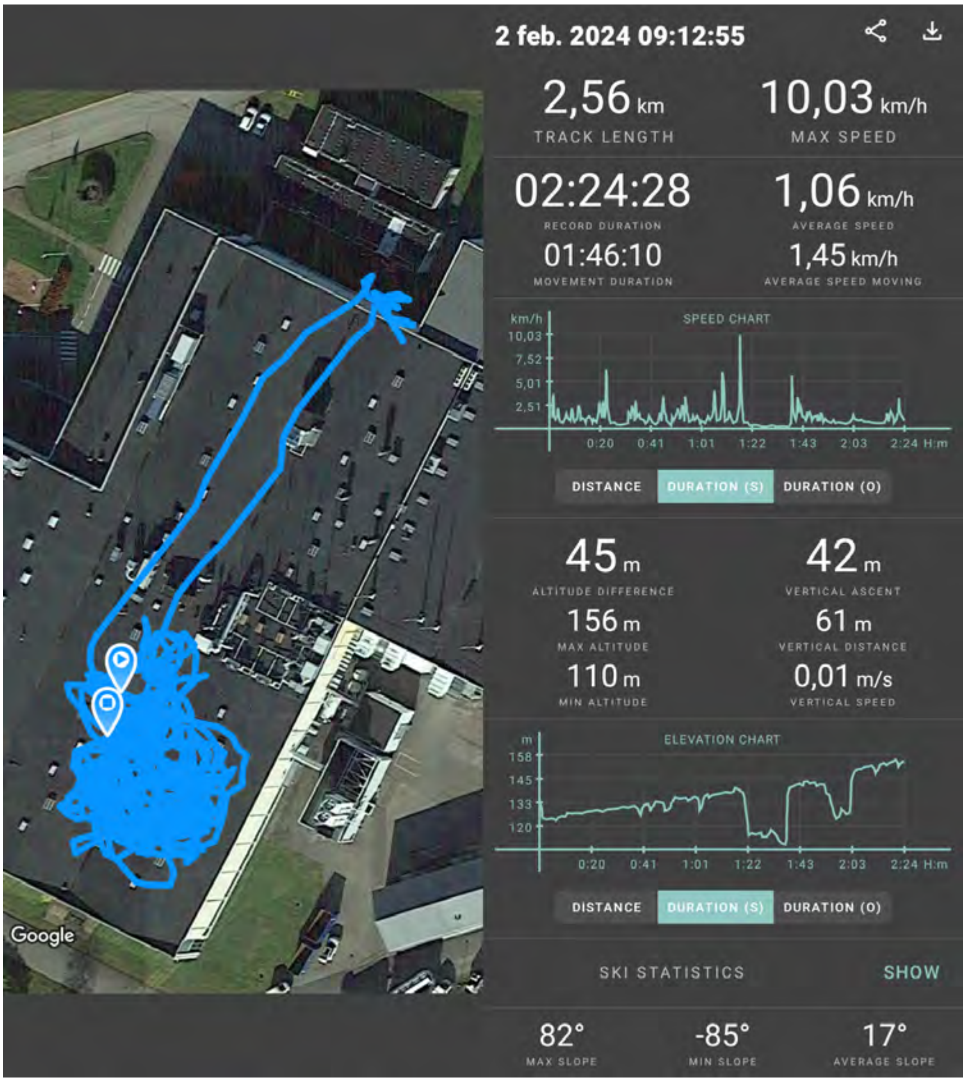

Figure C.3: Spaghetti diagram of Tow Train 1 2/2 Day

Figure C.4: Spaghetti diagram of Tow Train 1 2/2 Afternoon

Figure C.5: Spaghetti diagram of Tow Train 1 5/2 Day

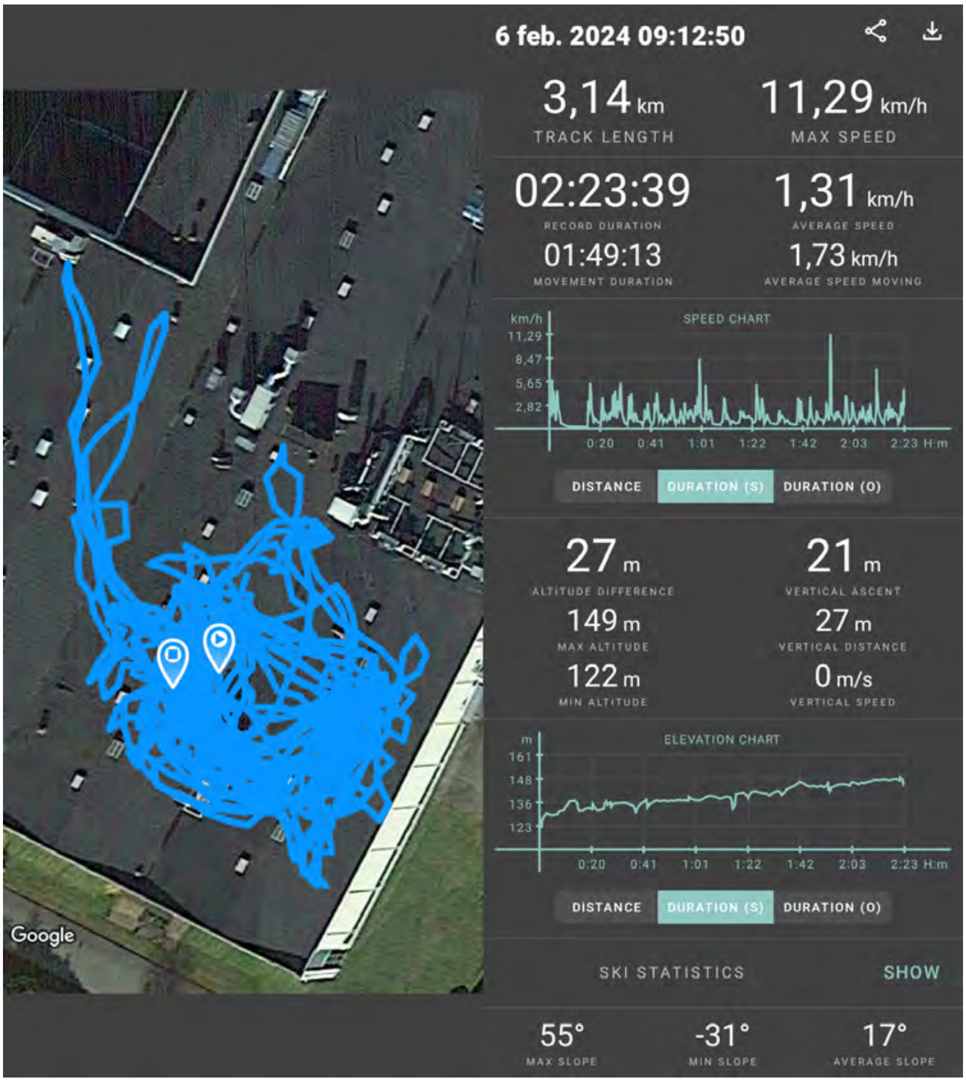

Figure C.6: Spaghetti diagram of Tow Train 1 6/2 Day

Figure C.7: Spaghetti diagram of Tow Train 1 6/2 Afternoon

Figure C.8: Spaghetti diagram of Tow Train 2 16/1 Day

Figure C.9: Spaghetti diagram of Tow Train 2 16/1 Afternoon

Figure C.10: Spaghetti diagram of Tow Train 2 2/2 Day

Figure C.11: Spaghetti diagram of Tow Train 2 2/2 Afternoon

Figure C.12: Spaghetti diagram of Tow Train 2 5/2 Day

Figure C.13: Spaghetti diagram of Tow Train 2 6/2 Day

Figure C.14: Spaghetti diagram of Tow Train 2 6/2 Afternoon

DEPARTMENT OF SOME SUBJECT OR TECHNOLOGY
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY