Enhancing Internal Logistics through Automation

A Case Study at Volvo Trucks Tuve

Master's thesis in Production Engineering

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Cover:
Different truck models presented by Volvo Trucks [Volvo Trucks].

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SUMMARY

This thesis analyzes the internal logistics system at Volvo Trucks' plant in Tuve, with a particular focus on the internal transport system. The main goal of this study is to identify inefficiencies and investigate the potential for automation within two specific transport categories: Synchronous deliveries, which includes the delivery of sequenced, kitted, and subassembled parts, and Pallet on Wheels (PoW) deliveries, which involve transporting pallets using tugger trains to kitting and subassembly stations.

A set of different methods were used to achieve the study objectives, such as on-site observations, supported by time studies, interviews, and internal document analysis. Automation concepts, both from suppliers and used internally at Volvo, were evaluated to assess their suitability to the two transport categories.

Automating the PoW process turns out to be difficult due to many steps that need to be done manually. Even if transport is automated, key tasks such as pallet switching still require human intervention, which limits efficiency gains. The high number of delivery points and the need to integrate with IT systems further increase automation challenges and complexity, thus even implementation cost. Additionally, several inefficiencies related to PoW were identified, including space inefficiency. As a result, the study recommends reconsidering PoW as a delivery method to achieve higher automation potential and space efficiency.

Synchronous deliveries, on the other hand offer higher potential for automation. Challenges with Synchronous deliveries include varying material handover methods and high part variation, which increases the need for customized carts. The study suggests using more AGVs combined with Karakuri mechanisms to enable automated delivery at the point of use.

Keywords: Internal transport, Logistics, Automation, Robots, AGV, Forklifts, Tugger trains, Production.

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Automated Guided Vehicles
AMR	Autonomous Mobile Robot
AS/RS	Automated Storage and Retrieval System
BM	Base module
CAD	Computer Aided Design
ERP	Enterprise Resource Planning
FA1	Final assembly 1
FA2	Final assembly 2
GTO	Group Trucks Operations
MES	Manufacturing Execution System
PoU	Point of use
PoW	Pallet on wheels
WMS	Warehouse Management System

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1

Introduction

This chapter outlines the background, problem formulation, purpose, objectives, and delimitations of the study. The problem formulation and delimitations define the scope of the project.

1.1 Background

The manufacturing industry is facing major challenges, one of which is high competition, especially posed by low-cost countries [1]. There has also long been a trend towards mass customization in the manufacturing industry, where products are customized according to the customer's preferences within a mass production environment [1]. In addition, the increasing importance of sustainability has led manufacturers to become more sustainable, both in terms of the offered products and the manufacturing of those. [2]. These challenges put pressure on production systems, not least on internal logistics, to become more flexible and efficient at the same time [1]. To meet these demands, companies are embracing the fourth industrial revolution (Industry 4.0), which offers a great opportunity for industries to become competitive in terms of quality, productivity, and efficiency by using advanced technology, one of which is automation [3]. Industrial automation has revolutionized the manufacturing industry and has led to a substantial increase in productivity [3].

Volvo Trucks Tuve, a truck manufacturing company whose assembly plant in Tuve has been producing trucks since 1982, faces similar challenges [4]. With approximately 2400 employees, the plant assembles four different truck models with different powertrains (diesel, gas, and electric) according to Mixed Model Assembly. This means that all different models are produced on the same production line. In addition to that, Volvo offers a high level of customization, tailoring each truck to the specific preferences and needs of customers [4]. This level of customization is expected to increase even more as new truck models are expected to be launched in the coming years, with even more customization. In addition, a hydrogen fuel cell powertrain that is under development is expected to be launched in the near future. All of this will lead to an almost doubling of the number of parts in the plant in the coming years, increasing the demand for storage space and placing great pressure on the production system, especially on internal logistics [4]. Volvo Trucks Tuve is seeking to address these challenges, maintain competitiveness, and increase productivity by adopting Industry 4.0 technologies, specifically automation solutions within the plant.

1.2 Problem formulation

There is a push towards more automation within internal logistics in the plant, mainly driven by the desire to be more cost-efficient. Another reason for automation is the ambition to create forklift-free areas along production lines to improve safety.

Internal transports were specifically identified by Volvo Trucks Tuve as an area with significant potential for automation due to its manual nature. Volvo Trucks has also conducted an initial study in which their different internal transport categories have been investigated in terms of automation complexity and potential. It was found that material deliveries to assembly lines, along with attached pre-assembly and kitting stations, show the most promise. Thus, the focus will be on analyzing the categories that are mainly responsible for these deliveries, namely Pallet on Wheels (PoW) and Synchronous deliveries. These categories are further described in Chapter 4.

Volvo aims to implement automation solutions that prioritize simplicity, flexibility, and efficiency. A key challenge is the limited knowledge about how automating existing transport categories will affect the plant, particularly regarding space and process efficiency. This is especially important as the number of parts in the plant increases, intensifying space constraints and the need for improved internal logistics.

1.3 Purpose

The purpose of this project is to analyze and compare two internal transport categories, Pallet on Wheels and Synchronous Deliveries, in order to assess the feasibility of automating these categories and to evaluate the potential consequences of such automation.

1.4 Objectives

- **Analyze the internal transport system**
  Analyze the current state of the internal transport system by focusing on the different transport categories and analyze the inefficiencies that occur during material delivery. This analysis will include an evaluation of the facility layout and activities that constitute the categories.
- **Evaluate automation concepts**
  Gather relevant automation concepts from companies and existing literature to address the inefficiencies identified in the previous step. Analyze how aspects such as space usage, running costs, investment costs, and flexibility are affected by the different concepts, as well as the challenges associated with their implementation.

1.5 Delimitations

The scope of this project is limited to analyzing the previously mentioned transport categories at Volvo Trucks Tuve. Thus, picking processes that occur during kitting and sequencing operations are excluded from the analysis.

The area of focus is restricted to the Cab line, which includes two parallel assembly lines. This focus is motivated by the fact that the Cab line has a large network of Pallet on Wheels and Synchronous Deliveries, involving a high number of deliveries and delivery points.

The focus will not be on the technical details of implementing the identified automation concepts but rather on analyzing their potential impacts and consequences if implemented. The analysis will not include organizational factors such as the company's internal structure, level of knowledge, or openness to automation. These factors may be briefly mentioned where relevant, but they will not be analyzed in depth.

Blue plastic boxes account for a large number of deliveries to the assembly lines, but they will not be considered in this project. This is because they are not part of the identified high-potential automation categories, as Volvo Trucks considers them to be inflexible.

While cost will be considered as one of the evaluation criteria for comparing different concepts, a full investment cost analysis will not be performed for any particular solution.

2

Theory

This chapter presents the theoretical framework relevant for this project. The three main topics covered in this chapter are internal logistics, automation, and lean philosophy.

2.1 Internal logistics systems

Logistics is defined as "a process of planning, implementation, and management of effective flows, goods storing, services, and information from the place of origin to the place of consumption with the target to satisfy customer requirements" [5]. There are mainly two types of flows involved in logistics. A forward flow of physical goods from point of origin to point of use and a reverse flow of information [6].

Internal logistics is defined as all logistics activities that occur within the physical boundary of an enterprise or plant, such as internal transports, material handling, storage, and packaging in a factory [7]. Internal logistics is therefore a subsystem of the logistics system as a whole [7]. In the manufacturing industry, internal logistics is primarily responsible for supplying manufacturing and assembly operations with the necessary materials and components, where any disruptions in that flow could lead to costly downtime [7]. Internal logistics constitutes a major factor in determining a company's competitiveness due to its large share of the overall cost [7].

Internal transport plays a critical and key role in internal logistics and the manufacturing industry, as it supplies production lines with components and material in the right quantity at the right time [7].

2.1.1 Material feeding principles

The number of parts needed in assembly line stations is increasing rapidly [8]. However, the space at those stations is limited. In addition, material handling activities must be kept to a minimum to minimize costs [8]. Different material feeding principles in production lines have different strengths and weaknesses [8]. While presenting parts in pallets results in less costs, it takes more space. Parts presented in smaller boxes and kits require less space at the assembly line but lead to higher material handling costs [8]. Consequently, a trade-off is unavoidable [8]. There are three main modes of material supply to the production line.

- **Line Stocking** Homogeneous parts are transported from local warehouses and delivered to the production line without any intermediate repacking process. Materials can be delivered in pallets or smaller boxes [8].

- **Sequencing** is the process by which different variants of the same part family are ordered in sequence and delivered to production line in a container. The sequence is according to the order in which the products are assembled on the assembly line [8].
- **Kitting** is the process by which different parts are picked and collected in a single container. All parts picked are connected to a specific product [8]. The kit can be stationary or mobile. Stationary kits are delivered to specific stations on the assembly line. Mobile kits, also called follow-lead kits at Volvo, are attached to the moving assembly line. In that way, the kit container passes through different stations together with the assembled product [8].

2.1.2 Performance Indicators in Logistics

A performance indicator is a performance metric that evaluates how successful an organization or a system is in performing its tasks [9]. While some indicators can be formulated to measure a specific metric and can be easily quantified, others are more abstract and general [9]. These following evaluation criteria can be considered as general performance metrics, and are therefore applicable to a wide range of domains, not least internal logistics. Cost, quality and flexibility are among the most important performance indicators in operations management [10]. Efficiency and space are two other indicators that are highly relevant for this projects's purpose and objectives.

Flexibility
Flexibility in operational terms can be defined as "the ability to adopt different states, take up different positions or do different things" [10]. It can also be used to describe the ease with which it can move between different states. Cost and time are two factors that define the flexibility of a system. A system that can change its state with least cost and shortest time is most flexible [10].

Cost
Cost is one of the most important factors in every operation's success [10]. Cost-efficient operations allow companies to provide products at lower cost and achieve competitive advantage or obtain more profits and reinvest in their operations. Operating expenditure, such as labour and material is an important financial category under the broad umbrella of cost [10].

Quality
Contrary to common belief, quality does not necessarily refer to high-end products or services [10]. Instead, it refers to the ability of a product or service to live up to its specifications and meet the expectations of its user [10].

Space
Floor space is an important and often overlooked resource in production and logistics contexts that can contribute to overall productivity [11]. Due to its scarcity, it can be considered a constraint in many cases. For example, space at workstations along assembly lines is a scarce resource and is highly related to material feeding policies; see Section 2.1.1 [11].

Efficiency
Efficiency in general terms can be defined as the ability of a process or system to perform its tasks with the least amount of resources [12]. Resources can be expressed in monetary terms, material, energy use, space, or any other input variable [12].

2.2 Automation

Automation can generally be defined as the process or technology by which a procedure or task is performed without human intervention [13]. Automation is conceptually divided into mechanization and computerization [14]. Mechanization is the process of replacing human physical power by machine power [13] or automating physical tasks [1]. Computerization, on the other hand, is the automation of control and information handling of a process [1]. Many technological advancements within batteries, sensors, computational power, and artificial intelligence have resulted in a significant increase in automation capabilities as costs continue to decrease [15]. These advancements have not only contributed to substantial increase in productivity, but have also opened the door for more intelligent automation systems that can be implemented in complex and dynamic environments [16].

2.2.1 Potential benefits of automation

Automation has been widely used in the manufacturing industry due to the various advantages it offers, such as increased productivity, reduced costs, and improved product quality [13]. Automated systems can also replace humans performing dangerous, tedious and repetitive tasks, thus increasing occupational safety and improving ergonomics and human well-being [13].

Automation does not automatically guarantee advantageous results. Wrong technology or right technology poorly implemented, can instead have negative effects. Successful automation lies in finding, selecting and acquiring and proerply implementing the right type and level of automation with an emphasis on the companies needs, goals and prerequisites [14].

As mentioned in 1.1, mass customization has increased the pressure on manufacturing systems to become more flexible [17], and it has been shown that automation can support this by increasing flexibility in manufacturing processes [13]. It can minimize the extent of labor layoffs and hiring, as well as related concerns when production volumes must be adjusted due to demand fluctuations or during unexpected rapid shutdowns, as was the case during the COVID-19 pandemic. Those issues can be minimized with automation, as automated machines and robots can operate around the clock and be shut down when needed. Automation has the potential to meet the challenge of an aging population and a lack of workers in countries that face these problems [1]. In general, automation can result in increased competitive advantage for an enterprise [7].

2.2.2 Automation in Internal Logistics

Internal logistics activities are very labor intensive. Therefore, they constitute a major part of business costs [14]. Although some areas of internal logistics might be fully automated, such as automated storage and retrieval systems (AS/RS), the degree to which internal logistics activities are automated is less than production-related activities [14]. Many material handling activities, for example, are carried out manually [14]. There are many automation applications that are used to increase overall efficiency in internal logistics. These include systems such as AS/RS, autonomous transport robots, automatic forklift trucks, and robotic picking systems, to name a few [18]. In internal logistics automation, autonomous transport systems play an important role in material transport [16].

Automated Guided Vehicles (AGVs) are mobile industrial robots used to transport materials between different points mainly in industrial environments [19]. They operate by following a pre-defined physical path such as wires, magnetic tapes, or optical lines. Since they follow a predefined path, they can achieve high accuracy. However they are less flexible since changes in the route requires changes in the physical path [19].

Autonomous Mobile Robots (AMRs) are also mobile industrial robots that serve similar puroposes as AGVs. But unlike AGVs they don't rely on physical paths [19]. Instead, they use different sensors, cameras as well as advanced algorithms to perceive, localize, and navigate their environment autonomously. They are more flexible and can react more dynamically to their environment [19]. Therefore, they can be seen as a more intelligent version of AGVs. However, they are more prone to disturbance if the environment is too complex and dynamic [16].

AGVs and AMRs usually serve the same functions and are used in similar applications [20]. Furthermore, the main difference between them lies in the technology used for navigation and decision making [16]. However, since this study does not delve into the technical distinction between these two types of autonomous robots and does not involve actual implementation, the term 'AGV' is used here as an umbrella term to refer to both AGVs and AMRs for the sake of simplicity.

2.2.3 Internal Logistics System Design for Automation

The implementation of automation in internal logistics, particularly through AGVs, holds significant potential for improving operational efficiency. However, many companies fail to achieve the desired outcomes. This is often due to insufficient planning, misaligned objectives, and a lack of comprehensive strategies that address both technical and organizational factors [14].

For AGV systems to deliver their full potential, the design process must go beyond the vehicles themselves. It requires a design strategy that integrates facility layout, system interoperability, human interaction, and adaptability [14]. The following sections explore these critical aspects and highlight the common challenges and risks that must be managed to ensure a successful and sustainable AGV deployment.

2.2.3.1 Automation suitability based on Layout & Activities

The effectiveness of AGV-based automation depends to a large extent on the tasks that must be carried out, and the physical environment in which the task is performed. AGVs are mostly optimal for repetitive, predictable tasks that involve the transport of goods between fixed points. Ideally, these tasks have low variability and a minimal need for making decisions [21], [22]. It's also important to keep in mind the weight and dimensions of the objects to be transported by an AGV [14].

The environment found at production facilities is not always the best suited for AGVs. Narrow aisles, sharp corners, and high or mixed traffic areas can hinder AGV movement, reduce speed and create accidents [23]. In addition to spatial constraints, environmental factors such as poor lighting conditions and random shadows can negatively affect AGV sensors, resulting in navigation errors or unnecessary stops. That's why it's ideal to try and optimize the transport paths for AGVs, by separating them and creating re-routing capabilities [23]. This usually requires layout reconfigurations, which can be expensive [24]. When AGVs operate closely to other moving objects or must take sharp corners, their speed is reduced drastically. Thus, it's important to rely on solutions such as straight routes, dedicated lanes, guide paths, and traffic separation to improve AGV system performance. The problem is that these solutions might be constrained by existing spatial limitations [23].

Facility tidiness and standardized environments also play a significant role in supporting AGV navigation and performance. In constantly changing settings, AGV systems are prone to errors and inefficiencies [21].

2.2.3.2 System Flexibility and Technical Integration

AGV systems must be implemented with flexibility and scalability in mind. This includes factors such as universal load-handling capabilities, which enable the transport of different types of products or carts [23]. It's not optimal to have AGVs that can only transport one type of product, since this may result in multiple fragmented material flows and the need for a larger AGV fleet [23]. If the fleet size grows, it becomes increasingly important to ensure technical interoperability between different types of AGVs. These differences may relate to navigation technology or simply be due to different AGV model years [23]. Considering these aspects is important to reduce the risk of declining delivery reliability [23].

Another key issue with larger AGV fleets is the increasing variability in delivery times, caused by blockades and other disturbances. To help manage this, companies can adopt unidirectional lanes and traffic rules that prioritize AGVs [23].

Important to note is that all of these changes come at a high cost. Companies must invest in AGVs, make layout modifications, and integrate new systems with existing infrastructure. AGVs require high capital investments, and when there's limited internal knowledge of AGV systems, it becomes difficult for the companies to adapt or reconfigure them in response to changing production demands. It's also difficult for companies to justify financial investments into automation since advantages such as ergonomics or space efficiency are difficult to quantify [14].

In addition to cost, it's also difficult to estimate the reliability and technical availability of implemented solutions. Companies often underestimate the maintenance needs during early deployment stages, which can lead to uncertainty and a perception of unreliability around AGVs. It's also common for companies to lack managemental responsibility for the AGVs after the initial implementation phase is complete [14].

Software integration presents another challenge. Connecting AGV systems with existing platforms, such as ERP, can cause delays and increase costs, particularly when documentation is poor or internal expertise is lacking [14]. In many cases, successful integration requires specialized external support, increasing a company's reliance on consultants [24].

2.2.3.3 Organizational Readiness and Human Factors

Many companies lack the internal infrastructure and skills necessary to support automation initiatives, relying heavily on external consultants [24]. This dependence can increase costs and introduce long term lack of knowledge, especially when documentation of external work is incomplete or unclear [24].

Employee training is frequently underemphasized. Effective AGV implementation requires that operators, technicians, and managers understand AGVs and their behavior. This understanding is crucial for fostering organizational acceptance and ensuring smooth interaction between humans and machines [23]. Organizational resistance from leadership and employees can undermine automation initiatives. Without support from top management and active engagement at all levels, projects risk being forgotten or end up failing altogether [14].

Succesful AGV implementation also requires organizational changes. New routines and responsibilites must be assigned to maintenance teams, operators, and managers in order to ensure system uptime and responsiveness to issues that occur during operation [21]. This is even more important if the fleet size of AGVs is growing [21]

Strategic and managerial challenges further complicate implementation. High up-front costs, uncertainty around return on investment, and a lack of top-management commitment can stall or derail automation efforts [21]. Many organizations also struggle with formulating clear requirements, evaluating potential technologies, and conducting proper feasibility assessments. These gaps frequently lead to misaligned expectations and poorly integrated systems [14].

It's also common for companies to struggle with evaluating automation alternatives, formulating technical requirements, and making sound investment decisions. This leaves many automation initiatives vulnerable to poor alignment and eventual failure [14].

2.3 The concept of Lean

Lean manufacturing is a Japanese philosophy that originates in the Toyota Production System, with a primary focus on eliminating waste in production systems [25]. Although it has its origin in the manufacturing and automotive industry, lean has been applied to a wide range of industries and sectors, such as lean service in the service sector, lean management in organizations, and lean logistics. Lean relies on a variety of concepts and ideas that contribute to waste elimination and help achieve an efficient flow of operations. One of those is the concept of pull production, which involves delivering material or a service to a customer or the next process only when requested [25]. It is mainly driven by customer demand and therefore helps reduce buffers, inventory, and waste. Lean also has a set of practical tools and methods used to achieve the core goals of lean. Kanban is such a tool that is used for material replenishment triggered by demand. It therefore helps minimize inventory and achieve the Just-in-Time concept [25].

2.3.1 Waste

In lean philosophy, waste is defined as any activity that does not lead to value creation for the customer [26]. Waste is classified into three categories. These are Muda (waste), Mura (unevenness), and Muri (overburden) [25]. All three types of waste are connected, as one type of waste could lead to another. Having a holistic perspective when analyzing waste is therefore crucial to avoid suboptimization [26].

Muda

Muda refers to waste generated from unnecessary activities. These activities utilize resources in terms of money, material, time and manpower without adding value to the final product and therefore to the end customer [26]. The different types of waste in muda are classified into the following seven categories [27]:

- **Over-production**
  Producing more and faster than current demand, resulting in increased and costly inventory of finished goods.
- **Waiting**
  When people or equipment are idling unnecessarily because of materials or other resources being inaccessible, waiting time waste occurs.
- **Transport**
  Transport of parts and products that does not add value to the process. This occurs mainly when transportation takes more time than necessary or when transporting wrong parts.
- **Over-processing**
  Unnecessary or incorrect processing that doesn't add value. This waste can occur due to unclear work instructions or poor design of the product and tool.
- **Inventory**
  Unnecessary holding of excess materials in storage and buffers, due to either purchasing and overproduction.
- **Motion**

Motion waste occurs when there is unnecessary body movements by operators during a task, such as searching, reaching, and bending.

- **Defect**
  This waste occurs when the produced parts or process does not achieve the correct quality level, due to unskilled personnel, faulty supplies or incapable processes.

These wastes can be identified and analyzed by conducting Gemba walks, which involves going to the place where the work occurs. In a production environment, this would be the shop floor, where factors such as the types of transportation and the extent of manual handling can be observed [25].

Mura
Mura refers to fluctuations in demand and production, leading to an irregular production schedule. Reducing variability in cycle time is crucial, as sudden increases or decreases in demand can result in inefficiencies, such as overloading or underutilizing equipment and operators, which is known as "Muri" [25].

Muri
Muri refers to the overloading of equipment, operators, and other resources beyond their natural capacity. Overburden leads to downtime, defects, decreased performance, and the creation of other forms of Muda [25]. The underutilization of equipment and operators is also defined as Muri [26].

2.3.2 Karakuri

Karakuri is a form of low-cost automation that uses simple mechanical elements and gravity to improve production processes [28]. This type of automation does not require electricity as a source of energy, making it both environmentally friendly, cost-efficient, and constantly available. The primary goal of Karakuri is to enhance productivity by reducing non-value-adding activities. These activities often relate to processes such as material flow [28]. Karakuri solutions are often built and customized in-house to meet the specific needs of a company. This approach encourages high employee involvement and fosters creativity. As a result, Karakuri solutions are typically cost-effective, easy to maintain, and well adapted to the workplace [28]. Karakuri helps eliminate unnecessary motion and waiting times and prevents the overburdening of workers [28]. Karakuri is generally best suited for handling smaller and lightweight components, as its mechanical nature makes it difficult to effectively manage larger or very heavy items [28].

Although Karakuri traditionally relies on purely mechanical solutions such as levers, pulleys, springs, and gravity, technological advancements have increased its potential. Simple sensors and control systems are now being integrated into Karakuri mechanisms in order to increase adaptability to other complex systems [28]. Figure 2.1 illustrates the mechanism through which material and empty boxes are transferred between two Karakuri carts with the transfer process triggered by a locking mechanism.

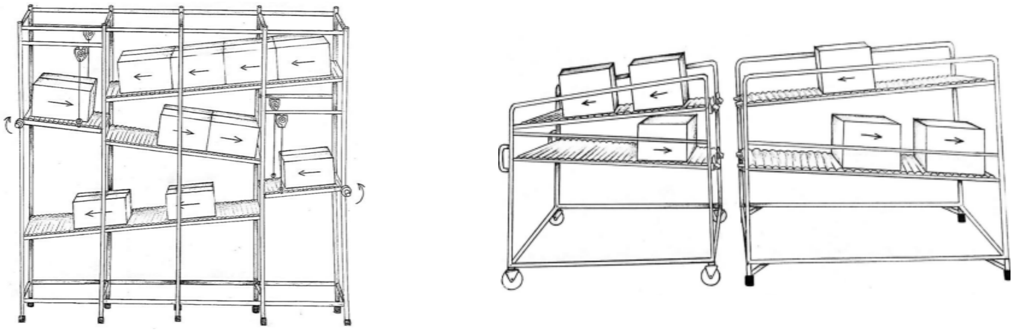

Figure 2.1: Sketches of common Karakuri solutions [Volvo's internal documents]

3

Methodology

This chapter outlines the methodology used to meet the objectives presented in Section 1.4. A combination of qualitative and quantitative data collection methods were used to gain a comprehensive understanding of the internal transport system at Volvo Trucks Tuve. The collected data was then analyzed to assess current operations and explore potential for automation.

3.1 Data collection

The data collection phase was critical for understanding the current operations and identifying inefficiencies, challenges, and automation opportunities. Different kinds of methods were applied to gather relevant information.

3.1.1 Observations

Observing processes is essential for understanding shop floor operations in a production environment. Gemba walks, which is an observation method, is an effective approach, emphasizing regular plant tours to assess process flow, layout, and workstations [29]. These walks help identify inefficiencies and waste while providing opportunities to ask questions to operators and gain deeper insights into the process [30].

3.1.2 Interviews

Interviews are used to gather data by asking interviewees a series of questions and recording their answers. The answers are based on the experiences, knowledge and opinions of the interviewees [31].

There are different types of interviews, namely structured, semi-structured, and unstructured interviews [31]. Structured interviews involve a set list of questions that are asked in a specific order, providing consistency across interviews. Semi-structured interviews allow for a mix of predetermined questions and flexibility to explore topics that arise during the conversation. Unstructured interviews are the most flexible, where the interviewer has a general topic but no fixed questions, allowing the conversation to flow naturally [31].

Semi-structured and unstructured interviews are beneficial because they allow experienced interviewees to easily share valuable information and explain important ideas in detail. It also allows the interviewee to speak freely and does not force the interview in any direction [31].

3.1.3 Internal documents

Volvo Trucks Tuve has a central database that gathers information and data from Volvo Trucks plants worldwide. This includes records of various projects carried out at different sites, as well as past automation initiatives. In addition to this, Volvo Trucks has documents that provide general guidelines for all plants. One such example is the **Volvo Operations Concepts document**, which outlines best practices and preferred methods of working across the organization.

3.1.4 Spaghetti diagram

Spaghetti diagrams are used to visualize the movement of materials in a production process, by mapping their routes on a map of the area being studied. By going on "Gemba walks", and tracking route length and travel time, these diagrams help identify inefficiencies such as excessive travel distances [29]. The biggest advantage with spaghetti diagrams is that no prior knowledge is required, enabling fast evaluation and identification of wastes. One disadvantage is the difficulty of evaluating larger processes where there are many routes [29].

3.1.5 Process activity mapping

Process Activity Mapping is a methodology used for making a detailed analysis of the activities within a process. It helps identify the time taken for each activity and the distance traveled during execution. The process typically begins with Gemba walks to observe and capture key activities of the process [30].

Each activity is classified as either value-adding (VA), necessary non-value-adding (NNVA), or non-value-adding (NVA), based on whether it directly contributes to material delivery, is required for the process to function, or represents waste. To better understand how time is spent in the process, the results can be visualized using pie charts, showing the share of time each type of activity takes.

3.1.6 Stopwatch time & method study

Time study is a procedure used to measure the time required for a process or activity to be carried out [32]. Time study goes hand in hand with method study and is often combined together to analyze the way a certain activity is done, what elements the activity is made of, and in what sequence the activity elements are done. This gives insight into why an activity takes a certain time and allows for method improvement and elimination of steps that are non-value adding [32]. Before conducting a time study on an activity, the activity must be observed to be able to divide it into simpler elements, which can then be measured in a stopwatch time study [32]. A minimum number of observations are needed to get reliable results. One simple method to determine the adequate number of observations is to plot the result values in a histogram. The number of observations is adequate if the histogram follows the shape of a normal distribution curve [32].

3.2 Data analysis

Following data collection, the gathered information was analyzed to evaluate layout efficiency, activity structure, and automation potential.

3.2.1 Layout evaluation

The layout evaluation aimed to identify spatial and logistical challenges that affect the performance of internal transport and that may hinder future automation. Representative routes for both transport categories were selected within the Cab Line area. For a deeper understanding of the selected routes, Gemba walks and unstructured interviews with operators were used to understand material flow, congestion points, and maneuverability issues along each route.

The spaghetti diagrams were annotated with challenges observed during deliveries, such as narrow aisles, sharp turns, frequent traffic congestion, and limited overtaking possibilities. The diagrams helped visualize problem areas where autonomous navigation would likely be impaired and provided a foundation for proposing layout adaptations or evaluating the feasibility of automation along these routes.

3.2.2 Activity evaluation

The purpose of the activity evaluation was to break down each transport category into its constituent activities, determine their time consumption, and classify them based on their value contribution. Two complementary tools were used in this analysis: Process Activity Mapping, which was used to identify and categorize all tasks along a given route, and a Time and Method study, used specifically for the pallet switch activity in the PoW category.

The time and method study was conducted with the aim of identifying inefficiencies and other elements that make the pallet switching process take such a long time. First, the switching process at the delivery points was observed a sufficient number of times to identify all the included steps, which were then noted chronologically in a list. This list of operations was then used when conducting time measurment to determine the duration of each step. An observation size of 10 was adequate in this case, as the observation values followed a normal distribution when visualized in a histogram; See figure A.1

Each identified activity was classified into one of the following categories:

- **Value-Adding (VA)**: tasks that directly contribute to material delivery.
- **Necessary Non-Value-Adding (NNVA)**: tasks essential for the process to function, but not directly value-adding.
- **Non-Value-Adding (NVA)**: tasks that represent pure waste and should ideally be eliminated.

These classifications enabled an assessment of how time was distributed during internal deliveries. For example, in the Pallet on Wheels (PoW) category, it was found that only 35% of the time was dedicated to value-adding tasks, while a significant portion was spent on PoW cart handling, which was classified as Non-Value-Adding.

3.3 Concept generation & Evaluation

Following the identification of inefficiencies in the internal transport system, a set of potential automation concepts were gathered from both internal and external sources. The goal was to explore a range of solutions offering different levels of automation, suitable for further evaluation.

The sources of these concepts consisted of:

- **External suppliers**, who provide commercially available automation solutions.
- **Internal documentation**, which includes previous automation initiatives and internal best practices at Volvo Trucks Tuve.

Generated Concepts for Automating PoW Deliveries

The concepts presented for PoW deliveries were sourced from the company STILL, which specializes in internal logistics solutions such as automated forklifts and tugger trains. Four different concepts were presented. Concepts 1–3 are directly based on solutions presented by STILL, while Concept 4 uses ideas from Volvo's internal documents.

The following list contains the different automation concepts STILL has to offer:

- **Concept 1** – Automated Pallet Switch Tugger Train [33]
- **Concept 2** – Unit-Load AGVs [33]
- **Concept 3** – AGV Tugger Train with Frame-Based Cart Exchange [34]

Concepts 1–3 focus on automating the current PoW process, while Concept 4 explores a more fundamental change.

Concept 4 - Replace PoW with Synchronous deliveries

Concept 4 takes a different approach by proposing a preliminary reconfiguration. The suggestion was to replace PoW with Synchronous deliveries that have higher potential for automation.

Generated Concepts for Automating Synchronous Deliveries

For Synchronous deliveries, the focus was on finding solutions that enable automatic cart switching and material handover. One supplier, Creform, offers a range of AGVs for material handling. The most common solution involved AGVs delivering single kitting carts, which formed the basis for Concept A. Additional concepts that include Karakuri mechanisms were sourced from Volvo's internal documentation.

The following concepts were selected for evaluating Synchronous deliveries:

- **Concept A** – Single-Cart AGV Deliveries [35]
- **Concept B** – AGVs Combined with Karakuri [Volvo internal documents]
- **Concept C** – Tugger Train Featuring AGV and Karakuri [Volvo internal documents]

Concept evaluation

The identified automation concepts were evaluated to determine their suitability for implementation at Volvo Trucks' Tuve plant. The evaluation was guided by a set of predefined criteria, which are presented in 2.1.2. For each concept, its expected impact on the presented criteria was assessed.

The most promising concepts in each transport category were selected based on how well they aligned with Volvo's strategic goals of increasing automation while maintaining flexibility and simplicity in their production.

4

Current Setup and Analysis of Internal Logistics

This chapter outlines the current logistics setup and existing automation solutions for material delivery at the plant. It also analyzes key transport categories, highlighting their advantages, inefficiencies, and automation challenges. The analysis draws on methods such as stopwatch time studies and process activity mapping.

4.1 Factory layout

Volvo Trucks Tuve plant operates according to the fishbone principle which means that subassemblies, sequencing and kitting stations are positioned along the assembly lines to supply it with parts and components.

The main assembly line is divided into three areas. The Base Module (BM), which marks the beginning of the main assembly line, where the truck's complete subframe is assembled. Once finished, the subframe is sent to Final Assembly 1 (FA1), where it is fitted with the required number of axles and additional components such as springs. After that, the subframe moves to Final Assembly 2 (FA2), where it is combined with the cab, wheels, and other large components. The cab is transported from the Cab Line area, which is a separate assembly line located on the other side of the facility.

Cab Line

An overview of the Cab Line area is shown in Figure 4.1. The Cab Line is where the trucks' cabins are assembled. This process takes place across two separate but parallel assembly lines, and each cabin must pass through both. Currently, the cabins are transported between the two lines using forklifts.

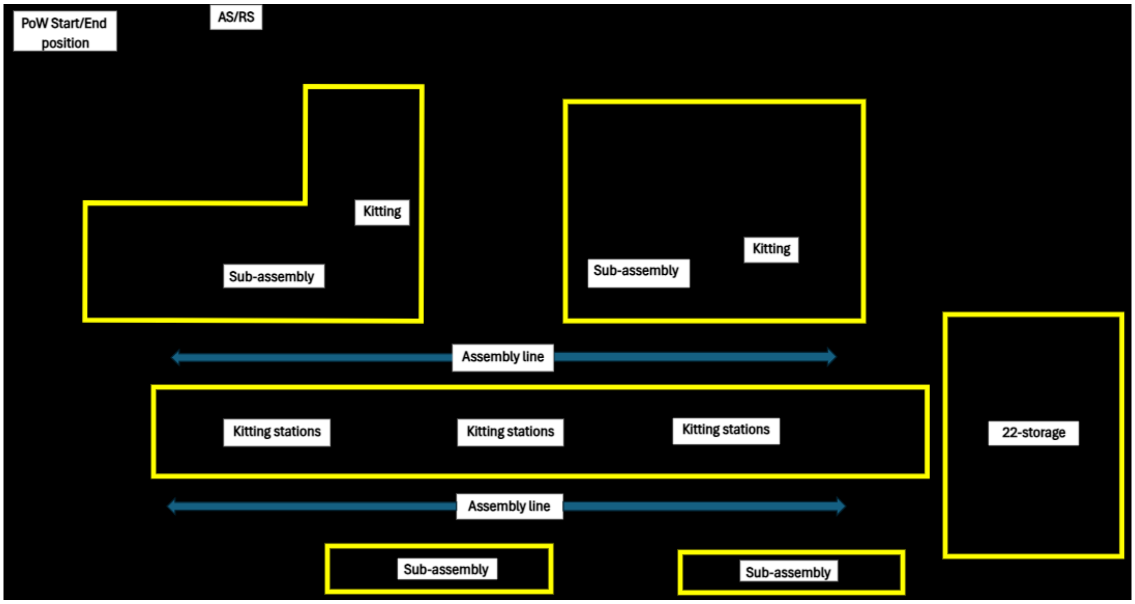

Figure 4.1: Layout for the Cab Line Area

There are many stationary PoW carts located at the kitting stations. A quick estimation during Gemba walks showed that there are roughly 400 different carts placed around the Cab Line area. The majority of the carts are placed between the two assembly lines, forming kitting stations that supply complete kit sets and some sequenced carts manually to the lines. In addition to the kitting stations, there are several pre-assembly stations that deliver assembled components manually directly to the assembly lines. Some of these pre-assembly stations are also supplied by their own kitting stations, that get PoW carts delivered to them. The pallets are supplied from the AS/RS and placed on the PoW carts at the "PoW Start/End position". They are then delivered to kitting stations throughout the Cab Line area. The different locations are shown in Figure 4.1.

The 22-storage area mainly holds oversized materials and pallets. It supplies various parts of the Cab Line area by delivering sequenced bulky items directly to the kitting stations and assembly lines. The 22-storage also serves as the start and end point for Synchronous deliveries in the Cab Line area.

4.2 Pallet on Wheels (PoW)

To enable forklift-free zones along assembly lines, Volvo Trucks Tuve uses tugger trains to transport carts carrying pallets, hence the name Pallet on Wheels (PoW). Each cart is loaded with one pallet, with a maximum of five carts delivered by a tugger at every round. An example of a PoW tugger train is shown in Figure 4.2. A new order is triggered when the kitting operator scans a barcode indicating the need for replenishment of a specific part number. The deliveries have a fixed frequency, which means that the time interval between every delivery is fixed. This concept is mainly used in the Cab Line area, where pallets are delivered from AS/RS to kitting and subassembly stations. There are approximately 300 pallets delivered daily using PoW.

Figure 4.2: Pallet on wheels train [36]

4.2.1 Advantages with the PoW concept

During observations in the plant, several advantages related to PoW were identified.

- The loading/unloading process of carts can be done on either side of the train. This is useful as delivery points can be located on both sides of the train.
- The PoW concept allows for the transport of large quantities of parts at once, as each pallet can carry a high volume if the components are not too large. This makes it more suitable for high-volume part transport compared to kitting or sequencing carts, which are designed for specific chassis variants and therefore carry fewer items.
- Enables a high utilization rate, by allowing up to five pallets to be transported per route, although many times fewer pallets than five are transported.
- Forklifts are removed from the delivery process along the assembly lines, enhancing safety.
- The PoW concept enables kitting stations to be positioned near the assembly lines, as it eliminates the need for forklifts, which are restricted close to the assembly lines for safety reasons. One benefit is that the kitting operators deliver kitting/sequencing carts manually by pushing the carts a short distance. The short distance between the kitting stations and the delivery points along the assembly line is especially useful when the delivery frequency is high, as is the case with follow-lead kit carts.

4.2.2 Inefficiencies with the PoW concept

With the usage of observations, process activity mapping and time studies, it was shown that the PoW concept involves multiple activities beyond just transportation, such as preparing pallets and switching carts when delivering at PoU. Many of these activities introduce inefficiencies and waste into the system. The time spent on each activity in the PoW process is presented in Table A.1.

The results of the process activity mapping are presented as pie charts in Figure 4.3 and 4.4 to visualize the portion of time dedicated to each activity. Only the driving activity, which constitutes 35% of the process, is immediately value-adding (VA), as it involves delivering material to the desired position.

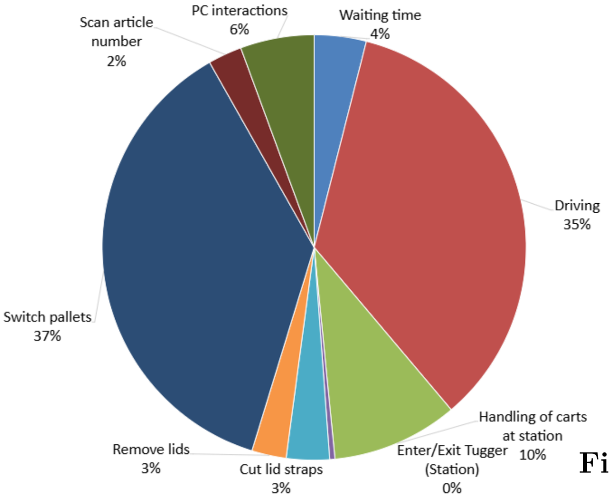

Figure 4.3: Percentage of time spent on various activities during a PoW route

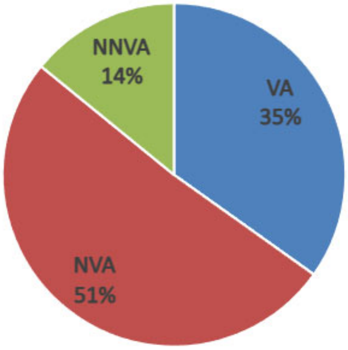

Figure 4.4: Classification of the activities into VA, NNVA, and NVA

37% of the total time is spent on pallet switching. To gain a better insight into what activities are included in that, a time study was conducted, See 3.1.6. The result of the time study for PoW pallet switches with values and activities can be seen in Table A.3. One inherent inefficiency with pallet switches is related to attaching/detaching the PoW carts to the tugger train. The reason for this is that the carts must be disconnected from the train, and most times the carts can be the middle ones, which means disconnecting the whole train in order to reach the wanted cart. In addition, when delivering new pallets, the old ones have some parts left in them that need to be transferred to the new one.

The results of the time study also show that there is a large variation in the time it takes to complete a pallet switch at PoU. The fastest pallet switch in the time study took 64 seconds, while the slowest took 145 seconds. This variation stems mainly from two activity elements in the pallet-switch process. Those are the transfer of the remaining material from the old to the new pallet, as well as the handling of the lids. One common characteristic for those two activity elements is that they do not always occur. Only some pallets have a lid. Furthermore, the time for material transfer varied in the time study between 0 seconds, where no material was left in the old pallet to be removed, to 57 seconds, where the material could be of high quantity or bulky and heavy.

The relatively long time it takes to switch a PoW cart often results in blocking the way for other tuggers and forklifts in areas where overtaking is not possible. This is not a minor issue, as the PoW delivery points are located near the Cab Line, where many other materials are also delivered. This impact is reflected in the additional waiting time allocated to Synchronous tugger trains to account for these delays.

It can also be seen in the pie chart in Figure 4.3 for the process activity mapping that 10% of the time is spent in the PoW area dismantling the train with empty pallets, attaching new carts with loaded pallets. During this step, the carts must be detached one by one so that the empty pallets can be removed and the new pallets can be loaded by a forklift. Afterward, new PoW carts with new loaded pallets are reassembled for next delivery. Although this makes it easier for forklifts to load/unload pallets, it also constitutes a major source of inefficiency.

Another inefficiency in the PoW concept relates to poor space utilization. All PoW carts at the kitting stations are positioned horizontally, with no option to store materials above the pallets, resulting in minimal use of vertical space. This limitation increases the demand for floor space. Moreover, the placement of the kitting stations between the two assembly lines prevents vertical storage solutions, as implementing them would require reach trucks, which is an unsafe option given the proximity to the assembly lines.

Sometimes there's underutilization of tugger trains, as they can be loaded with up to five carts, but sometimes carry fewer. Whether this was the result of operator behavior or inherent problem was not further investigated. The mapping and analysis does not consider this phenomenon. However, one possible explanation is that the tugger trains do not have time to wait for all five orders as there is a risk of delayed orders.

4.2.3 Layout challenges for PoW

Valuable insights into the layout of the Cab Line area were obtained through Gemba walks and interviews with operators and logistics personnel. PoW deliveries in the Cab Line area follow three routes: red, green, and pink. The red route is the longest, spanning 740 meters, and has the highest number of pallet deliveries. Due to its length and delivery volume, it serves as a representative case for identifying transportation challenges associated with PoW in the Cab Line area.

Figure 4.5 illustrates the chosen red route, and some of the challenges of the current layout for implementing robots in the internal transport system. During Gemba walks, it was noted that space utilization is a major issue, with a lack of floor space in the plant and an overflow of material near the assembly lines, making it difficult for current and future robots to navigate efficiently. This aligns well with the theory presented in Section 2.2.3.1.

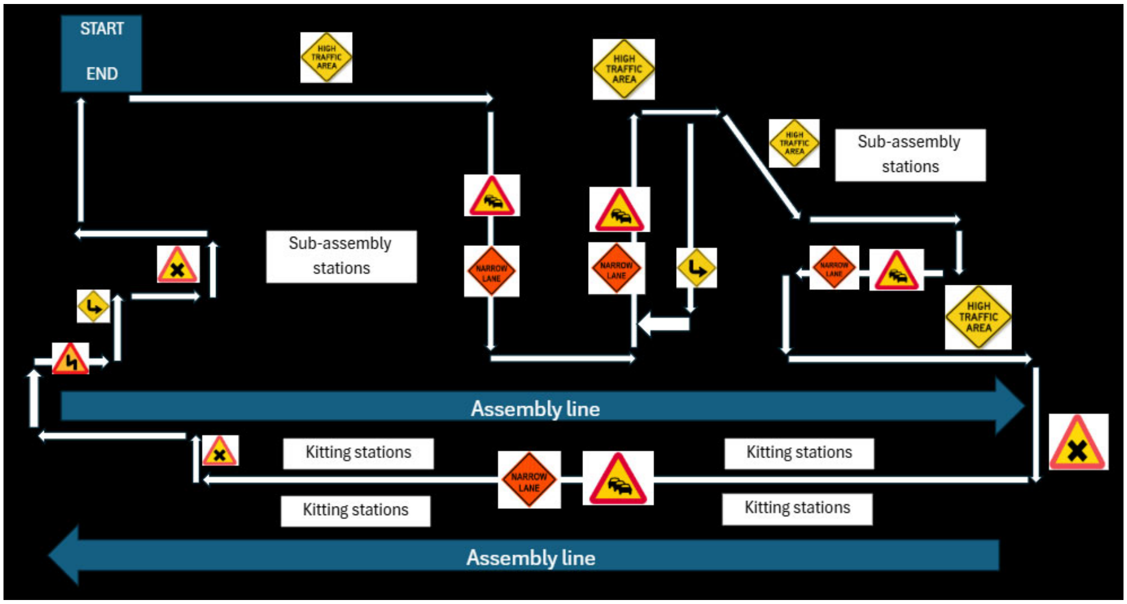

Figure 4.5: Challenges with the route taken by the red PoW tugger train

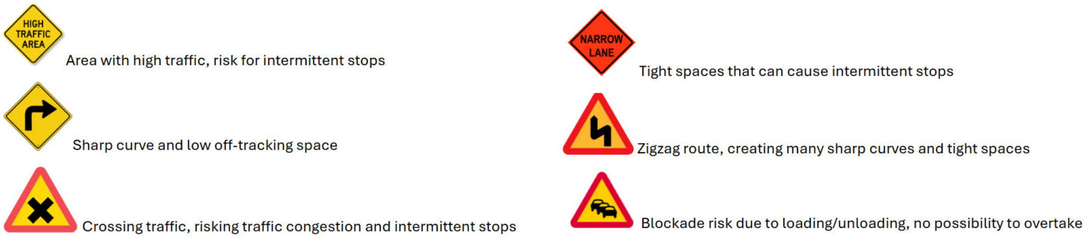

Figure 4.6: Definition of the illustrated signs

In general, the PoW routes have long transport distances, which consist of many narrow paths. These constraints not only make maneuvering difficult for tugger trains, but also severely limit future robot mobility. For example, overtaking is limited due to these narrow spaces, which further complicates AGV operations by restricting their ability to navigate around obstacles, or overtake other AGVs. These routes also have numerous bends and curves, making maneuvering difficult for tugger trains, and in the case of implementing robots, sharp curves limit their speed. Similar layout-related limitations on AGV efficiency are also discussed in the theoretical framework presented in Section 2.2.3.1.

The Spaghetti diagram was filled with symbols that highlight problem areas for automation. One of the most common issues observed during Gemba walks was constant traffic congestion due to previously mentioned narrow spaces, leading to frequent deadlocks that disrupt both human-operated and robotic systems. Some routes in the Cab Line area have heavy traffic, making it difficult to collaborate with AGVs since they stop if they detect an obstacle in their path. A potential solution to minimize these occurrences, if AGVs are implemented, is to introduce traffic rules or separate human and AGV traffic flows, as suggested by the theory presented in Section 2.2.3.1.

The current layout frequently experiences traffic congestion due to ongoing loading and unloading of carts and forklift operations. With long transport routes and limited possibilities for rerouting, operators often have to wait until these activities are completed, leading to delays. This lack of flexibility also poses a challenge for future AGV implementation. Additionally, PoW trains must follow the full transport route even when deliveries are only required at the end, as there are no available shortcuts. This further reduces operational efficiency. The presented theory in Section 2.2.3.1 suggests that rerouting strategies and optimizing crossover points could help minimize unnecessary travel distances and improve flow, especially important if AGVs are to be integrated into the system in the future.

4.2.4 Challenges with automating PoW

The PoW process is challenging to fully automate due to the complex cart switches at delivery stations and preparatory process required before starting the delivery route. Even if only the transport process is automated, operators would still need to switch the carts, meaning that the dominant waste, which is pallet handling according to Figure 4.3, would still exist.

The preparatory process involves cutting straps and removing lids from pallets, tasks that require either an operator or future automation. Implementing automation for these steps would only eliminate a small fraction of waste, according to Figure 4.3.

One major challenge in automating pallet deliveries is transferring the remaining parts from an almost empty pallet to a newly delivered one. This issue is particularly relevant in a one-bin system, which is the most common setup, except for some highly frequent parts that use a two-bin system. This challenge is relevant in all types of pallet deliveries and not only in those where PoW carts are used. Currently, it causes delays in the delivery process and presents a significant barrier to future automation implementation.

An additional complexity involves the ability of an AGV to navigate and deliver to the numerous delivery points. There are around 400 different delivery points in the Cab Line area where material is delivered using the PoW concept. In every delivery route, pallets are delivered to different delivery points. Although automating delivery to so many different PoU is not impossible, it is much more complex than delivering material to a few predetermined PoU. This is also discussed in Section 2.2.3.1, which emphasizes that standardization, in this case fixed delivery points, makes automation implementation easier, as it reduces the need for decision making and ensures consistent and repeatable processes that minimize disturbances.

As mentioned in Section 4.2, PoW uses an electronic replenishment system. Thus, automating these deliveries requires deeper integration between the automated transport vehicles and plant software systems such as MES, ERP, and WMS. While this is achievable, it is a complex process that may incur significant costs. This is consistent with the theory presented in Section 2.2.3.2, which highlights that system integration is often costly and complex, particularly when there is limited internal expertise or process knowledge.

4.3 Synchronous deliveries

Synchronous deliveries refer to tugger trains used to deliver kitted, sequenced, and subassembled parts, where several carts can be delivered at once. An example of these tugger trains is presented in Figure 4.7. Each route has a predefined number of specific picking and delivery points. These deliveries follow a detailed schedule to ensure a continuous material flow and maintain synchronization with the assembly line's speed throughout the facility. Unlike PoW, no barcode is scanned to trigger new orders.

Figure 4.7: Tugger train used for Synchronous deliveries

4.3.1 Material Handover Methods from Tugger Train to Point-of-Use

During Synchronous deliveries, when the tugger train arrives at the delivery point, the material must be transferred from the tugger train to the PoU. This transfer is carried out using various methods, depending on the amount, size, weight, and dimensions of the delivered objects. The most common solution is manual cart switch, where an empty cart on the production line is replaced with a new, fully loaded one from the tugger train. One example of a kitting cart that relies on this method is shown in Figure 4.8. This kitting cart is attached to the train with the help of a frame during transport, and then switched manually by the driver during delivery.

Figure 4.8: Kitting cart positioned at PoU

Not all the material is delivered via cart switches, sometimes only the material is transferred. For some components, the tugger train is typically aligned precisely with a storage rack, allowing the material to be manually pushed over from the train to the rack. Two types of these racks are shown in Figure 4.9. In cases where the objects are too heavy to move manually, lifting aids are used to lift and transfer the material from the cart to the PoU.

Figure 4.9: Two different storage racks along the assembly line

Since material handover methods are often selected based on the specific characteristics of the parts being transported, it can be challenging to develop a universal handover method that accommodates all part types.

4.3.2 Advantages with Synchronous deliveries

The following advantages were identified for Synchronous deliveries:

- Synchronous deliveries follow fixed schedules and only deliver what is required to meet production demand. This reduces the storage requirement along the production line and supports lean manufacturing by ensuring components arrive exactly when needed for production.
- These types of deliveries use the tugger train principle and can carry up to five carts, depending on length of each cart.
- Guarantee that all Points of Use (PoU) are consistently serviced, both deliveries and the collection of empty units.

  In terms of automation, Synchronous deliveries has several benefits:

- Synchronous deliveries has less variability in terms of fixed pick up and delivery points. Thus, more predictable deliveries than PoW and higher potential for automation See section 2.2.3.2.
- Synchronous deliveries are generally Karakuri-friendly, particularly for small and lightweight parts. The predetermined delivery stations make it easier to utilize karakuri for material transfer as it is known in advance which side of the tugger train the delivery station is located on. This allows the orientation of karakuri carts to be planned and selected accordingly.

4.3.3 Inefficiencies with Synchronous deliveries

Synchronous deliveries are highly sensitive to disruptions, since any delay or failure can lead to a line-stopping event, halting production. Maintaining a perfect synchronous delivery system is challenging. It requires precise coordination, continuous monitoring, and proactive issue resolution.

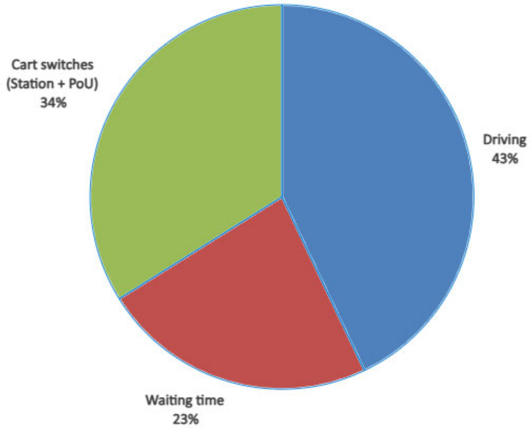

Figure 4.10: Main activities during a synchronous delivery route

As shown in Figure 4.10, the majority of time during synchronous deliveries is spent driving around the facility and conducting deliveries. The remaining time is divided between performing cart switches and waiting. The cart switches include both the exchanges made when loading full carts at the kitting stations and when delivering them at the PoU.

The allowed time for the delivery routes to be completed are calculated by Volvo Trucks Tuve, and the calculation includes extra time, called "waiting time", in order to take into account abruptions during deliveries, such as traffic or other types of disturbances. PoW deliveries have 1 minute of waiting time per delivery route, whilst Synchronous deliveries get 3 minutes. For this route specifically, the driving time is only 5 minutes, and the waiting time is 3 minutes, which increases the total delivery time by 60%. The waiting time is caused by the prolonged loading/unloading processes by forklifts and PoW deliveries. A modified layout or efficiency increase for PoW, or removal of forklift deliveries could minimize this waiting time for Synchronous deliveries.

In these types of deliveries, it's always expected that the existing material at the PoU is fully used shortly before new material arrives. In practice, this is not always achieved due to different reasons. Minor production line stoppages or tugger trains arriving earlier than scheduled, often by driving faster than planned, can cause material to remain unused on the old carts when new deliveries arrive. This gives the tugger train driver additional tasks, such as transferring the remaining material from the old to the new cart, or wait until the material is fully used before switching the carts.

The kitting carts are designed differently depending on the size, shape, and amount of material on them. These factors restrict universal usability of carts for different materials. This means that different types of carts are used at every delivery point where Synchronous delivery is used. That makes the number of unique carts used during material delivery large, and even larger when the part numbers increase.

4.3.4 Layout challenges for Synchronous deliveries

Synchronous deliveries primarily serve the assembly lines, which are currently characterized by tight spaces and high traffic density. This congestion is largely due to the close proximity of the assembly lines to kitting stations, which generate significant transport activity from various forklifts and PoW tugger trains.

One notable example is the blue kitting route at the Cab Line, which is one of four kitting routes in that area. It is approximately 500 meters long and mainly composed of long, straight paths. Despite the favorable geometry, frequent blockages occur due to other transport categories performing loading or unloading, as well as forklifts delivering oversized pallets. These interruptions often take place along the straight sections where overtaking is limited, creating bottlenecks. The route and associated challenges are illustrated in Figure 4.11, using the same symbols introduced in Figure 4.6.

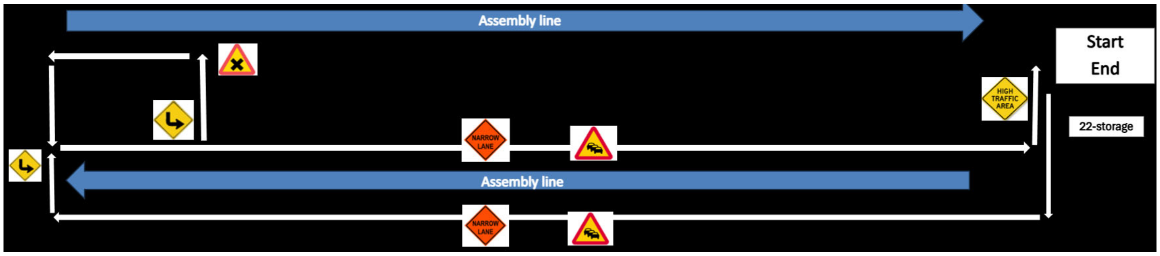

Figure 4.11: Challenges with the blue route used for Synchronous deliveries

The presence of sharp curves and tight bends throughout the facility restricts the allowable train length, as longer trains increase the risk of collisions. According to Section 2.2.3.1, rerouting capability is an essential requirement in automated systems to mitigate such disruptions. Sharp turns require additional consideration, as they contribute to reduced travel speeds and increase the likelihood of disturbances for the daily situation and future automation.

While the long, straight segments of the route are beneficial for automation, improvements are needed to reduce traffic density and enable more efficient flow. As emphasized in Section 2.2.3.1, solutions such as dedicated transport lanes or overtaking possibilities are critical to support smooth, uninterrupted deliveries and enhance the feasibility of automation.

4.3.5 Automation challenges for Synchronous deliveries

As mentioned earlier, one common issue is the lack of timing alignment between the tuggers and actual material consumption at the PoU. In some cases, the tugger arrives before the previously delivered batch has been fully consumed, forcing operators to manually intervene, either by transferring the remaining materials or waiting until they are completely used. For these deliveries to be fully automated, a higher level of synchronization with the assembly line is required to eliminate the need for human intervention to handle material.

Another challenge for these deliveries is the high variation in parts, which requires the carts used during transport to be specifically modified to fit each part. The number of parts is as mentioned earlier, expected to increase drastically. This results in a large number of customized carts, especially as the variety and volume of parts increase. This variation also poses challenges on material handover at PoU when automating those deliveries. For example, different Karakuri mechanisms have to be developed to suit different materials and components with different shape, size and weight.

4.4 Train sets

Train sets consist of a tugger pulling trailers, mainly designed to transport materials in pallets from the goods reception station to warehouses within the assembly plant and to handle the transportation of empty pallets to an empty pallet station. Those train sets drive both inside and outisde the plant. While train sets will not be analyzed further in terms of efficiency and automation potential, they are mentioned here due to their relevance in the upcoming analysis.

4.5 Automation solutions existing today

Observations show that automation solutions have only been implemented in a few isolated cases within the internal transport system at the Tuve plant. These solutions are located in different parts of the plant, and cover only short distances. They also have different navigation technologies, operate on predetermined routes, and each solution only delivers one specific part to one specific station on the assembly line.

Camera-Guided AGVs for Muffler Delivery

Volvo Trucks Tuve recently automated the delivery of mufflers to the main assembly line from a pre-assembly station using a newly developed system called GPSS (Generic Photo-based Sensor System). This system relies on AGVs that navigate with the help of cameras mounted on the ceiling, which use computer vision and machine learning technology to create a map of the environment.

The GPSS system was recently implemented at the facility and is currently being tested in a live production environment. Volvo Trucks Tuve sees it as a promising solution for future automation, as it is considered both cost-effective and scalable once the system is developed properly. The system features a user-friendly interface for manual handling when needed and is reportedly easy to adapt when making operational changes within the facility.

Figure 4.12: GPSS AGVs carrying mufflers, awaiting dispatch

LiDAR-SLAM AGVs for Chair Transport

The chairs required for assembly in the Cab Line are delivered by an AGV that navigates using SLAM (Simultaneous Localization and Mapping) technology, which allows it to build a map of its environment and track its position within that map in real time. A key part of this system is contour-based navigation, where the robot recognizes the shapes and outlines of fixed structures such as walls and equipment to orient itself. This is made possible by LiDAR (Light Detection and Ranging) sensors, which scan the surroundings and provide accurate distance measurements. This particular AGV is show in Figure 4.13.

Figure 4.13: AGV used for delivering chairs, docked at the charging station

Wire-Guided AGVs for Battery Handling

The automated delivery of batteries for electric trucks is managed by AGVs that navigate by following wires embedded in the ground, which is shown in Figure 4.14. At decision points, the AGVs detect different emitted frequencies and use these to follow the predetermined path based on information stored in its memory. This method is not easily expandable since it requires extensive installation and is also a costly solution. This solution helps both logistics and production, since it's an automatic transport and has a collaborative battery assembly function.

Figure 4.14: AGV used for delivering batteries for electric vehicles to the assembly line

5

Concept Presentation & Evaluation

In this chapter, general criteria for automation, identified as needs for Volvo are selected based on the performance indicators presented in Section 2.1.2, followed by a section in which automation concepts, either provided by different suppliers or already used at Volvo, are presented and described. The concepts are then briefly evaluated in terms of the identified criteria to determine their suitability.

5.1 Formulation of Criteria

Based on interviews and discussions with Volvo, several criteria that can be served as requirements were identified. Those were selected from the performance indicators presented in Section 2.1.2. Those indicators do not constitute a strict requirement specification that must be followed precisely as in product development projects. Instead, they are used as guidelines to determine the suitability of a certain concept for Volvo's needs. In every evaluation, some points might conflict with each other. Therefore, a trade-off and holistic approach is necessary when evaluating different concepts.

Space

As described in Chapter 1.1, lack of space is a huge challenge and a constraining factor in the plant. With the substantial increase in part number volumes in the coming year, space will become an even more relevant factor. Considering the impact on space is therefore important in every concept or change evaluation in the plant.

Complexity

When it comes to automation solutions, Volvo looks for simple solutions that are easy to implement and with low complexity. Simplicity here is also related to low costs and the ability to develop and implement solutions in-house.

Flexibility

The plant is undergoing constant changes, both in terms of product variety, production volumes, changes in part number volumes, and layout changes. Hence, offering solutions that are flexible, easy and less expensive to change is important.

Cost

Cost is an important criterion for Volvo. Implementation of automation projects or other changes that result in a short return on investments are prioritized. However, no investments cost analysis will be conducted. Running costs is another dimension of cost that is important to consider. Furthermore, each of the aforementioned criteria can more or less be quantified in terms of cost.

5.2 Presentation of possible automation concepts

This section presents and evaluates several automation concepts for Pallet on Wheels (PoW) and Synchronous deliveries. Each concept is briefly described and evaluated based on the criteria mentioned in Section 5.1.

5.2.1 Pallet on Wheels deliveries

In this section, automation concepts for PoW are presented and evaluated.

5.2.1.1 Concept 1 - Automated Pallet Switch Tugger Train

In this concept, an AGV is combined with the concept of tugger train to deliver several pallets simultaneously. To make the cart-switching process feasible, carts with electric roller conveyors are used. Each cart has a roller conveyor with an electric motor that allows for horizontal pallet transfer between the train cart and the delivery station. The delivery station must also have a roller conveyor to receive the pallet. The number of carts possible in this type of tugger train is unknown. However, one empty cart is needed to load the empty pallet from the delivery station. An illustration of the concept can be seen in Figure 5.1. This solution is provided by several companies, such as STILL [33] and ABB [37].

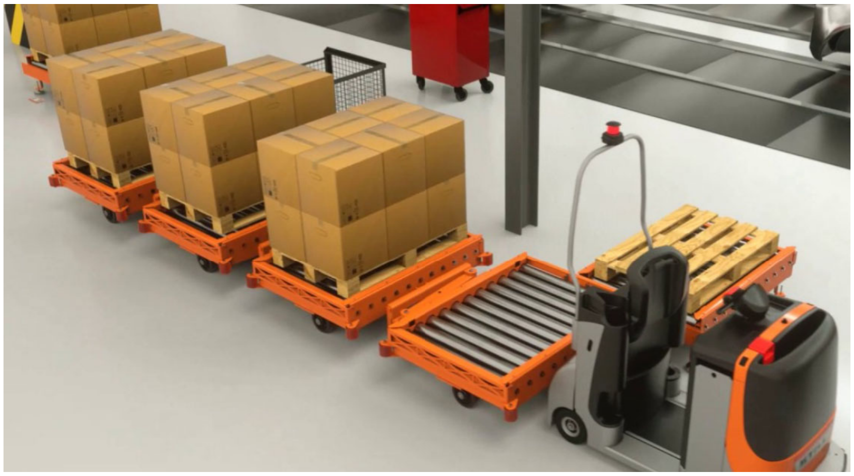

Figure 5.1: Illustration of automated pallet switch and navigation [33]. Reprinted with permission.

Evaluation
This concept makes automating the transport and pallet switching process theoretically possible. However, there are many challenges with it as well. One challenge is the transfer of material from the old pallet to the new pallet. The use of space at delivery locations is unchanged, as every PoU would have a roller conveyor cart that can receive a pallet. The number of tugger trains needed would more likely be higher than the current number of trains, as it is unlikely that the train can have six carts, which is necessary for the train to have the same capacity as the current PoW train, as one cart has to be empty for receiving an empty pallet. There are approximately 400 PoW carts stationed in the Cab-trim area, meaning each would need to be replaced with a delivery station equipped with

an electric roller conveyor. This entails high investment cost in terms of required infrastructure. This solution is not flexible, as future layout changes will be highly restricted and costly, and relocating the delivery stations would be a challenge. This concept is not ideal, as it conflicts with Volvo's preference for simplicity and flexibility.

This solution aims to eliminate the waste that occurs during the transport and delivery of PoW. The waste generated during cart preparation, such as cutting straps and removing lids, would still persist. These tasks could be transferred to an operator, but in that case, the waste would remain within the system.

5.2.1.2 Concept 2 - Unit-load AGVs

Another alternative is to discard the concept of PoW and tugger train and instead deliver pallets individually with underride AGVs. This solution is the most common one when it comes to AGVs and the way they transport material. It is provided by many suppliers [33], [37].

Figure 5.2: Underride AGV lifting a unit load. Support structure allows AGV to lift the unit load [33]. Reprinted with permission.

Evaluation
Currently, an estimated 380 pallets are delivered daily to the Cab-trim area, delivered by four tugger trains. Delivering pallets individually with AGVs would result in 380 individual deliveries daily, posing several significant challenges. The relative long distance between the pick-up point at AS/RS and the delivery stations, as well as the high number of deliveries per day would result in a large AGV fleet size. The large fleet size of AGVs directly impacts the investment cost negatively. Using underride AGVs would also require the use of a support structure at every delivery point that allows the AGVs to drive under and lift pallets as can be seen in Figure 5.2, which further increases the investment cost in terms of infrastructure. Another significant challenge would be the complexity of traffic and the risk of congestions when so many AGVs would have to interact with each other

and other dynamic objects, as described in 2.2.3.2. Even with optimized routes, a higher number of simultaneously operating AGVs could lead to more inefficiencies. In addition to the impact on cost, the need for a support structure at every delivery points makes this concept less flexible to changes as well.

5.2.1.3 Concept 3 - AGV Tugger Train with Frame-Based Cart Exchange

As mentioned in Section 4.2.2, around 37% of the time in PoW activities is spent on switching pallets, which constitutes a large part. Reducing that time will not only make the PoW concept more effective, it will also reduce the waiting time for other tuggers and forklifts waiting behind, contributing to overall efficiency. One possible way to achieve this is to use frames, also called mother/daughter systems. In this system, the daughter cart with a pallet is rolled on and off the mother cart. Figure 5.3 shows the difference in the mechanism for connecting / disconnecting carts between the tongue and hitch system as in the current PoW carts used by Volvo and the mother/daughter frame system.

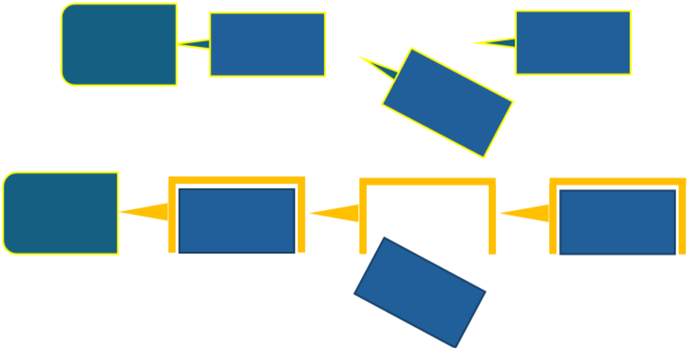

Figure 5.3: Illustration of tongue and hitch system (upper train) vs mother/daughter system or frames (lower train)

Figure 5.4 shows two frames available on the market. Both meet the requirement of accessing pallets on both sides of the frame, which is necessary since the delivery points can be located on both sides of the train.

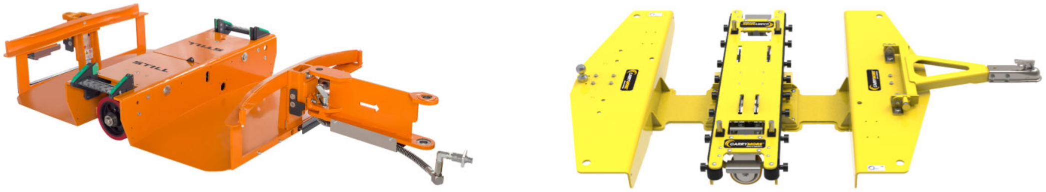

Figure 5.4: B-frame from STILL [34] (left), H-frame from Jtec Industries (right) [38]. Reprinted with permission.

Evaluation
In this solution, the train can be operated by AGVs, but the process of switching carts

is still manual, which means that an operator will have to devote time for the pallet switch. This would with all likelihood not be possible as it would disturb the workflow of the kitting operators. By using frames, the switching process is expected to be faster. However, due to the configuration and location of the casters on the current PoW carts, no frames compatible with the carts were found. For carts to be compatible with existing frames shown above, the casters must be located at the corners of the cart. According to the supplier of the PoW carts currently used in the plant, it is possible to reconfigure the carts by relocating the casters' position and replacing the two fix casters with two swivle ones, to make them compatible with B-frames provided by Still. Another alternative would be to buy new carts for every pallet delivered this way to make them compatible with the frames above. That is associated with very high cost due to the large amount of carts needed.

Since real word testing of the frame is not possible, a theoretical and rough estimate of the saving in time is given. This is based on the results of the time study for the PoW pallet switching process, as seen in Table A.3. The study of operation elements for switching pallets, both for Pow carts and the concept of frames, which was analyzed by [39], was also used. Figures 5.5 and 5.6 show the difference in operations in each mechanism. To roughly estimate the time for switching pallets when frames are used, the time for those operation elements that do not exist in the frame concept when doing pallet switches, are simply removed from the total time. The theoretical time savings was estimated to be around 10% of the total time in PoW operations; see Appendix B. It is important to note that this number is based on rough assumptions, and real-word testing of this mechanism with frames must be conducted to determine the possible gain in efficiency.

The space impact of this solution is similar to the current setup of PoW concept. It is worth mentioning that this solution is not intended to automate the whole process. It is only intended to automate the transport, and make the pallet switching more efficient.

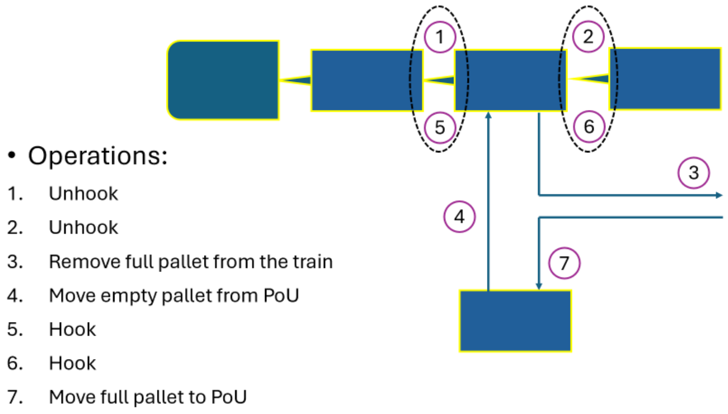

Figure 5.5: Illustration of steps in tongue and hitch type of system

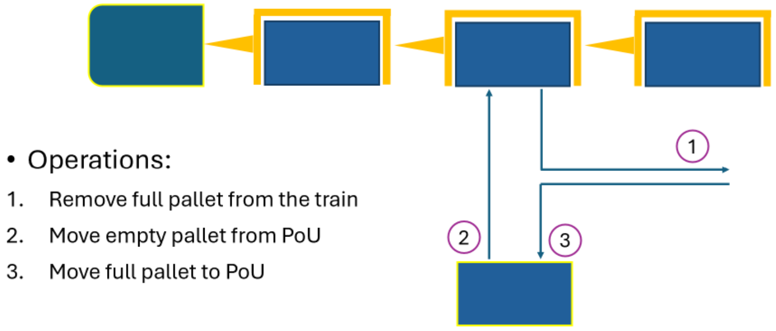

Figure 5.6: Illustration of steps in tugger trains when frames are used

5.2.1.4 Concept 4 - Replace PoW with Synchronous deliveries

Each of the above-mentioned concepts for automating pallet delivery has its own challenges and problems. However, a common challenge for all of them is moving parts from old pallets to new pallets at PoU without human intervention. Furthermore, in all the concepts mentioned, there is still a lack of vertical space utilization at the kitting stations between the cab, see Section 4.2.2.

Given all the challenges with the proposed solutions and the inefficiencies with PoW as a concept, a new concept is proposed. In this scenario, the concept of PoW is discarded. Additionally, the kitting stations between the two cab lines where pallets are delivered with the PoW concept are moved closer to AS/RS where the pallets come from. Figure 5.7 shows a schematic illustration of the current and the proposed setup.

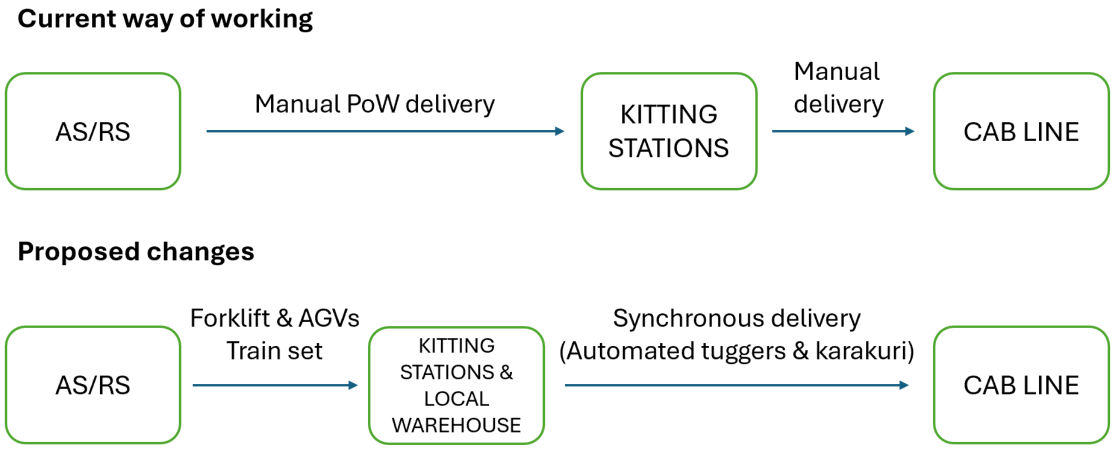

Figure 5.7: Schematic illustration of current setup and the proposed concept. The arrow length represents changes in distances

Kitting carts can be delivered from the new location of kitting stations to delivery points along the cab line by tuggers with Synchronous delivery. The idea is that automating this kind of delivery will be easier for several reasons. The possibility of automating the loading/unloading process is bigger with Synchronous carts than pallets using simple solutions such as Karakuri. In addition, kits and sequenced carts are connected to specific end products, and therefore, deliveries are synchronized with the production rate. This allows for more predictability, better scheduling, and optimization of routes, as well as minimizing congestion. The issue of moving the remaining parts from the old to the new container can be eliminated, since every delivery point would have at least two Synchronous carts, also called a two-bin system. In Synchronous deliveries, every route has specific pick-up and delivery stations which further facilitate automation as AGVs are most suitable for delivery between fixed points, see Section 2.2.3.1. In contrast to automating PoW, where pallets are delivered to five different stations every time. This also allows for automation with less requirement on integrating the AGVs with business software such as ERP, MES, and other systems, as every route has the same pick-up and delivery station and there is less need for electronic replenishment system.

An additional benefit would be the possibility to build a pallet racking system at the new kitting stations and combine local storage with kitting aisles, a concept that is common in the plant. Figure 5.8 illustrates the concept of local warehouse schematically. This has two advantages in terms of vertical utilization of space. It would allow for more vertical storage of pallets at the higher shelf levels, as is the case in other local warehouses around the factory. It would also allow the vertical presentation of more than one pallet with different part numbers to the kitting operator, increasing the use of space compared to the current setup.

At least one of the pallets must have fewer collars to reduce height and make material in the upper pallet accessible to the operator, thus fewer parts in the pallet. This remains beneficial as the number of parts in the plant is expected to increase drastically in the coming years, while the consumption rate of some specific part might decrease since different variants of a specific part will be available. Pallet replenishment in the local warehouse and kitting stations would be the responsibility of reach trucks, as is the case in other locations of the plant with this concept.

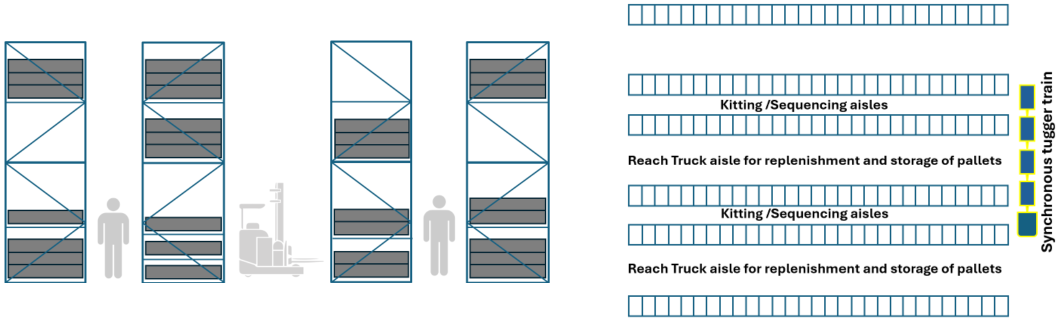

Figure 5.8: A schematic side and top view of the local warehouse & kitting station concept. The side view shows the vertical usage of space and arrangement of pallets with varying heights on the lower levels, available for kitting operations.

Building pallet racking system at the current location of the kitting stations is not possible as the area between the two cab lines is too narrow for that. It also requires forklifts to store pallet vertically and replenish material; this is not desirable from a safety point of view when the racks are close to the cab assembly line.

The transportation of pallets from AS/RS to the new local warehouse can be done with different modes depending on how close the new local warehouse/kitting stations would be to AS/RS. Forklifts could take over the responsibility of transportation if the location is close enough to AS/RS. A train set could also be used here to transport many pallets at once, which is a common transport mode for delivering material to local warehouses. The possibility to automate the transportation from AS/RS to the closer located kitting stations would also be greater.

In general, the possibility of automating pallet transportation from ASRS to the new kitting stations, as well as transportation of kit carts from the kitting stations to the cab line is bigger. This is because many tasks that make automation challenging will be located and handled manually by reach trucks, such as variations in terms of pallet deliveries to many PoU as mentioned in Section 2.2.3.1, and other activities such as moving material from old to new pallets, as well as straps and lid handling.

5.2.2 Synchronous deliveries

This section explores different automation concepts for Synchronous deliveries to assess automation feasibility.

5.2.2.1 Concept A - Single-cart AGV utilizing cart switching

One potential automation concept is single-cart underride AGVs designed to transport single kitting and sequencing carts. This solution, depicted in Figure 5.9, autonomously transports individual carts from the kitting stations to PoU, and is also capable of handling cart switches. This AGV model is designed to move underneath a stationary kitting cart and secure it with a locking pin for transport. The AGV would deliver a fully loaded cart to the designated PoU, drop it off, collect the corresponding empty cart, and return it to the starting point. For this to work efficiently, each PoU must be equipped with two designated cart positions, one for incoming carts and one for outgoing empty carts.

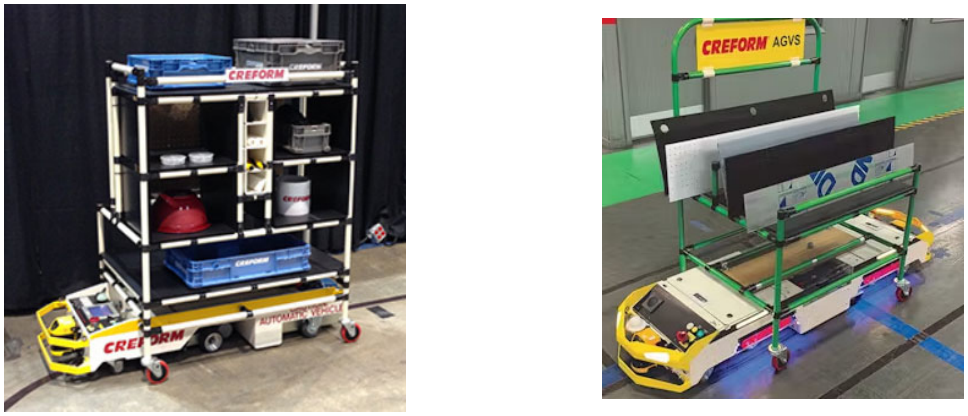

Figure 5.9: Creform NSI AGV 2.0 (BST AGV Model CA-Z50060-K9) with different types of kitting carts [35]. Reprinted with permission.

Evaluation

While this concept removes the need for traditional manual tugger trains, it introduces several significant challenges. Replacing a tugger train with single-cart AGVs is inefficient, significantly increasing the number of transport cycles, which in turn demands a larger AGV fleet. A large AGV fleet correlates to a high investment cost, and increased maintenance requirements. The large AGV fleet also contributes to high traffic level on the shop floor, raising the risk of congestion. These implications are supported by the findings in Sections 2.2.3.2 and 2.2.3.3, which emphasize the operational strain caused by high-frequency, low-capacity transport solutions.

The increased fleet size would also result in a high cost for investing in the AGVs. A key advantage of this concept is its flexibility. The AGVs can handle a wide variety of kitting carts, making the system adaptable to different part types. The AGVs are also capable of transporting heavy and bulky parts as long as they are loaded onto compatible carts.

This solution is attractive due to its simplicity and potential compatibility with standardized kitting carts. The cart switching process is simple and does not require complex solutions. However, it assumes sufficient layout space for dual cart positions at each delivery location.

5.2.2.2 Concept B - Single-cart AGV utilizing Karakuri

This concept involves the use of AGVs in combination with Karakuri mechanisms to enable fully automated transport and material handoff to the PoU. Karakuri leverages gravity and mechanical principles to perform tasks such as unloading carts. Important to note for this concept is that there are no cart switching opportunities. Figure 5.10 shows an example of a material transfer using Karakuri with an AGV.

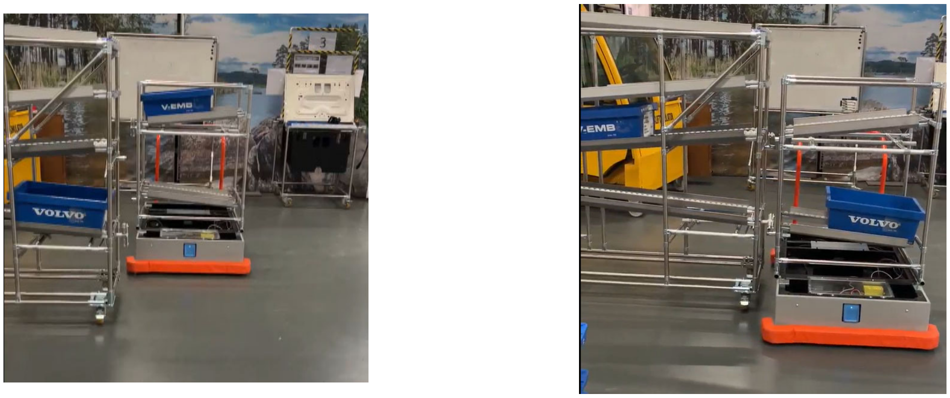

Figure 5.10: Unloading mechanism for a GPSS AGV using Karakuri solutions [Volvo's internal documents]

Evaluation
One of the key strengths of this concept is its cost-effectiveness. Karakuri systems can be developed internally using standard components and trolleys, eliminating the need for expensive outsourced kitting carts or Karakuri solutions. Volvo has already demonstrated the feasibility of such solutions in other facilities, and is something currently being tested

at Volvo Trucks Tuve, with different kinds of carts and Karakuri mechanisms.

This concept is capable of transporting both individual items and entire boxes to the PoU. When individual items are delivered and consumed directly at the PoU, there is no need for a return flow, allowing the AGV to continue with other tasks. However, when full boxes are delivered, the empty boxes must be returned. Figure 5.10 shows an example of an automated box replenishment.

Compared to Concept A, this solution is more space-efficient, as it enables material transfer rather than requiring cart switches for every transport. This reduces the total number of carts in circulation and space usage at PoU, which is especially beneficial in space-constrained environments. A key limitation of this concept is that Karakuri mechanisms, which rely solely on mechanical principles like gravity and levers (see Section 2.3.2), are not suitable for safely handling large or heavy components.

Another drawback is that this setup, similar to Concept A presented in 5.2.2.1, does not utilize the existing tugger train principle, which is efficient in handling multiple deliveries. Without this, a larger fleet of AGVs may be required to maintain the same delivery frequency, especially for routes needing deliveries every five minutes or less. This could lead to increased traffic and coordination complexity.

5.2.2.3 Concept C – Tugger Train Featuring AGV and Karakuri

This concept combines the tugger train principle with AGV navigation and Karakuri-based unloading mechanisms to create a fully automated material delivery system. The AGV serves as the driving unit for the tugger train, pulling multiple carts to the delivery stations. Upon arrival at the PoU, Karakuri mechanisms are used to automatically unload the carts. An example of this concept is presented in Figure 5.11.

Figure 5.11: An AGV using Karakuri solutions to unload a tugger train at PoU [Volvo's internal documents]

Evaluation
This concept combines AGV, with Karakuri and tugger train principle. The main benefit of this solution is that it retains the efficiency of grouped deliveries while adding automation for both transport and material transfer at PoU. This makes it one of the most promising and logistically efficient concepts, especially for high-throughput environ-

ments, if implemented successfully.

This solution is among the most cost-effective. Using the tugger train principle minimizes the number of AGVs required for a given material volume and reduces maintenance needs. Additionally, using Karakuri carts, that can be built in-house provides a cost-effective mechanism for material transfer. This solution provides relatively good flexibility as no fixed infrastructure is needed.

This concept can't switch kitting carts at PoU. Additionally, many of the parts used in production are heavy or bulky and may not be suitable for mechanical unloading without significant redesign of either the product or the cart.

Another challenge is the delivery point layout. At Volvo, delivery points are not clustered, they are distributed along the assembly line. This layout limits the effectiveness of Karakuri unloading unless the tugger train includes a reliable cart identification mechanism to ensure that each cart is delivered and unloaded at the correct delivery point.

Finally, while the concept shows strong long-term potential, its implementation would require changes to cart design and layout planning to ensure reliable unloading and route management. Despite these challenges, the combined AGV and Karakuri tugger train remains one of the most scalable and efficient automation paths if these conditions can be met.

6

Discussion

In this chapter, key findings are summarized and discussed, the proposed automation concepts are evaluated and compared to the current setup at Volvo Trucks Tuve. This chapter also outlines study limitations, future steps, and implications for sustainability and further research.

6.1 Concept recommendation

While each automation concept for PoW had its strengths and weaknesses, automating the full PoW process proved to be challenging. One major challenge was material transfer from old to new pallet. Additionally, inefficiencies particularly in terms of space utilization were associated with PoW. Concept 4 was therefore introduced as a transformative approach, where a transition from PoW to Synchronous deliveries was recommended to achieve higher automation potential while achieving benefits in terms of space efficiency by utilizing vertical storage. The idea behind Concept 4 was to separate transport, pallet handling, and other tasks into distinct processes. This makes the workflow more suitable for automation by relocating the more complex tasks away from the lines. Another key point is that cart switching in Synchronous deliveries is not only faster than pallet switching in manual operations, but also significantly easier and cheaper to automate based on the evaluated concepts.

A key change in Concept 4 is relocating the kitting stations away from their current position in the Cab Line area. While this requires utilizing space elsewhere, it enables vertical pallet storage and reduces overall space consumption. Even though this change may result in higher running costs, it might be necessary given the lack of space and the projected drastic increase in part numbers in plants.

For Synchronous deliveries, Concept C provides the highest efficiency. Several carts can be delivered at once with a simple material transfer mechanism that can be designed in-house. However, applying karakuri mechanisms can be challenging and not always possible, especially for transfer of bulky material. Using concept A might be necessary in that case, where kit and sequenced carts themselves can be switched at delivery point.

6.2 The gap between proposed and current solutions in the plant

One important aspect worth discussing is the gap between the proposed automation concepts mentioned and the current automation solutions in internal transport in the plant. Currently, a few isolated cases of single AGVs are used, all of which transport one specific component or one unit load between two fixed points, a pick up and a delivery point. Additionally, those AGVs operate over short routes, often under 100 meters, where they are exposed to minimal disturbances. Those AGVs are not integrated with any software systems in the plant, so the deliveries are triggered either manually or by some other simple mechanism. Making a transition from this limited setup to more automation solutions would therefore represent a substantial leap. The highly dynamic environment with many moving forklifts and tuggers as well as the limited space are some of the main challenges. Overcoming these challenges might require both changes in the environment and the use of AGVs with sophisticated navigation systems that could interact dynamically and adapt to their environments. For Synchronous deliveries, Karakuri was recommended as an inexpensive automation solution for material transfer. Although simple in design, substantial effort might be needed to develop good Karakuri mechanisms that function as intended for different types of material and components.

6.3 Study limitations

The study provided valuable insights for automating the internal transports at Volvo Trucks Tuve. However, there are some limitations to the findings. Not all the different material handover methods within Synchronous deliveries were evaluated for automation, and not all the delivery routes for the transport categories were assessed for layout-related challenges. Only one route was inspected for each category.

Many of the proposed automation concepts, particularly those involving AGVs and Karakuri mechanisms, were evaluated theoretically. Real testing was not conducted. As a result, all potential integration challenges and practical limitations may not have been fully captured.

Organizational and human factors such as employee readiness, required training, and change management were not explored in depth. These elements are crucial to the successful implementation of automation and may pose significant barriers if not addressed properly in future work.

6.4 Future academic work

In this study, only some aspects of automation were investigated. However, for a successful implementation of an AGV fleet, a system design approach for automation needs to be taken where several dimensions of automation implementation must be analyzed, see 2.2.3. Future academic work should therefore investigate technical and organizational aspects, as well as other transport categories that were not investigated in this study.

Technical Aspects of AGV Implementation

Technical aspects of AGVs implementation can be related to aspects such as selecting the best navigation type for a certain task, software integration, battery capacity and strategies to minimize downtime as well as rerouting capabilities in highly dynamic environments [15].

Organizational Aspects

Organizational readiness is crucial for successful automation implementations [20]. Therefore, considering organizational aspects for an expanded implementation of AGV is important for Volvo. Some aspects that are worth investigating could be change management, operator training, lack of ownership, and how prepared departments such as maintenance are to support a larger AGV fleet.

6.5 Generalizability of Study Findings

To what extent certain plants or organizations can benefit from the study depends on how generizable the findings are. This thesis was conducted at Volvo's assembly plant in Tuve, where two categories of internal transports were analyzed. The results are therefore most directly relevant to Volvo Trucks Tuve, followed by other Volvo plants. Volvo has many plants worldwide, all of which follow the 'Volvo Operations Concept', which outlines best practices and guidelines. Lastly, external companies within the automotive industry could also benefit from certain aspects of this study.

Findings that were directly obtained from literature such as system design for automation, general automation and layout challenges can be applied more generally by many companies. The findings related specifically to the two transport categories, such as challenges with automating these and the presented automation concepts can be utilized by companies that have these transport categories in their internal logistics operations and seek to investigate implementing automation solutions.

The recommended suggestion in concept 4 to discard PoW and move towards more Synchronous deliveries was based on several important factors highly specific to Volvo. Therefore, that suggestion is specifically relevant for Volvo Trucks Tuve.

6.6 Project Ethics & Sustainability

Automation has historically been a concern for many people, mainly driven by the fear of being replaced with robots. While many tasks and occupations have been fully automated, new professions have been created due to automation. This study is expected to have very little impact on that aspect, at least in the short term. This is because this work serves as an initial study and a lot has to be fixed in the plant before massive use of AGVs can be utilized.

The aim of this project was not to completely replace human labor, but to reduce repetitive, physically demanding, and low-value tasks while at the same time achieving cost efficiency in internal transports. By automating these tasks, the study could have a positive impact on safety and ergonomics. In this study a phase out of PoW as a delivery method for pallets was suggested. PoW is associated with ergonomic problems, such as manually moving pallets. By discarding PoW, increased occupational safety and ergonomics could be achieved.

This project has the potential to positively impact the environmental dimension of sustainability by identifying and addressing inefficiencies in internal logistics. One of the core principles guiding the analysis was Lean thinking, which emphasizes the elimination of waste in all forms. Reducing these waste elements leads to more efficient resource use. The study also highlighted the use of low-energy automation solutions such as Karakuri, which operate without external power and offer an environmentally friendly way to improve material flow.

7

Conclusion

This project investigated the possibility for implementing automation solutions within the internal transport system at Volvo Trucks Tuve. The focus was on two transport categories, namely Pallet on Wheels and Synchronous deliveries. These transport categories were first analyzed to identify current inefficiencies in their processes, followed by an assesment of automation potential. Finally, automation concepts were presented and evaluated for each transport category.

One of the key findings was that fully automating the PoW concept is challenging due to complex pallet handling and several preparatory steps required before starting the delivery process. Therefore, a shift towards more Synchronous deliveries was proposed to enable simpler and more cost-effective automation. The automation of Synchronous deliveries was found to be less complicated, utilizing solutions such as AGVs and Karakuri.

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A

Appendix 1

Process activity mapping									
O - Operation T - Transport I - Inspection D - Delay									
Activity		Type of activity	VA	NNVA	NVA	Distance (meters)	Time for activity	Frequency	Time (min)
1	Driving	T	X			740	7.88	19	167
2	Handling of carts at station	O			X		0.49	94	46
3	Enter/Exit Tugger	D			X		0.1	19	1.9
4	Cut lid straps	O		X			0.17	94	15.7
5	Remove lids	O		X			0.33	38	12.6
6	Use PC (Book via)	D		X			0.14	19	2.7
7	Scan article number	I		X			0.13	94	12.4
8	Use PC (Book task)	D		X			0.14	19	2.7
9	Switch carts	O			X		1.88	94	177.6
10	Use PC (Choose article number)	D		X			0.14	94	13.3
11	Use PC (Choose article number and scan checksum)	I		X			0.09	94	8.3
12	Waiting time	D			X		1	19	19
Total						740			479.8

Table A.1: Process activity map for PoW deliveries, specifically for the red route at Cab line

Process activity mapping							
O - Operation T - Transport I - Inspection D - Delay							
Activity		Type of activity	VA	NNVA	NVA	Distance (meters)	Time (min)
1	Driving	T	X			502	144
2	Waiting time	D			X		78
3	Exit tugger	O		X			23
4	Release latch	O			X		8
5	Release cart	O			X		8
6	Change carts in facade	D		X			21
7	Place empty cart in train	O		X			10
8	Lock the latch	D			X		8
9	Enter tugger	O		X			23
10	Erase board	D			X		15
Total						502	338

Table A.2: Process activity map for Synchronous deliveries - Blue synchronous route at Cab line

	Observation number										Calculations				
Activities	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MIN**	**MAX**	**MEAN**	**RANGE**	**ST. DEV.**
Exit tugger & walk towards cart	6	7	7	8	9	10	9	7	8	9	6	10	8	4	1.2
Detach cart from train	6	10	12	12	10	9	7	12	8	12	6	12	10	6	2.1
Move new cart from train	12	6	14	16	15	13	12	16	12	14	6	16	13	10	2.8
Transfer remaining material from old to new cart	42	35	47	0	45	27	0	57	33	42	0	57	33	57	18
Move old cart from PoU	7	8	9	9	10	8	7	10	9	10	7	10	9	3	1.1
Move new cart to PoU	8	6	7	7	9	5	7	8	7	6	5	9	7	4	1.1
Lid handling	0	0	13	15	0	0	0	10	0	0	0	15	3.8	15	6
Move & attach the old cart to the train	9	8	9	8	8	10	11	10	12	17	8	17	10.2	9	2.6
Scan article number	3	5	3	6	6	7	4	7	8	8	3	8	5.7	5	1.8
Enter tugger	4	6	4	10	9	8	7	8	10	7	4	10	7.3	6	2
Total time	97	91	125	91	121	97	64	145	107	125	45	164	106	-	-

Table A.3: Detailed time study of the pallet switches during PoW deliveries

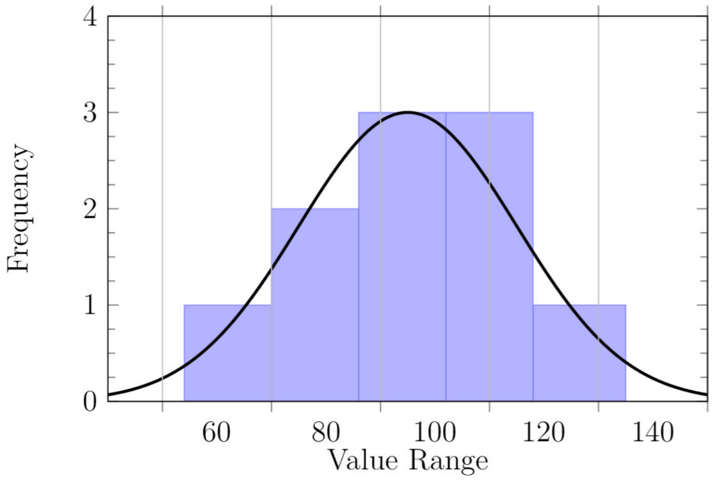

Figure A.1: Histogram of observed values overlaid with a normal distribution curve.

B

Estimated Time Savings when Using Frames

Theoretical time savings can be estimated when using frames instead of traditional pallet handling methods. Specifically, 2 *unhook* operations and 2 *hook* operations are eliminated, See Figure 5.5 and 5.6. These 4 operations correspond to the following two steps in the time study conducted for PoW pallet switches:

- Detach cart from train: 10 seconds
- Move and attach the old cart to the train: 10.2 seconds

Since the second operation includes both moving and attaching the cart, an assumption is made that half of this time is used for the cart attachment.

Time Savings per Pallet Switch at PoU

$$\text{Mean value of saved time per pallet switch} : 10 + \frac{10.2}{2} = 15.1 \text{ seconds}$$

$$\text{Mean value of total time for one pallet switch according to the time study} : 106 \text{ seconds}$$

$$\text{Percentage of saved time for one pallet switch at PoU} : \frac{15.1}{106} = 0.142 \Rightarrow 14.2\%$$

$$\text{Relative to total PoW operations} : 0.142 \times 0.37 = 0.525 \Rightarrow 5.2\%$$

Time Savings per Pallet Switch at PoW Area

$$\text{Saved time per switch (same assumption)} : 10 + \frac{10.2}{2} = 15.1 \text{ seconds}$$

$$\text{Total time per switch at PoW area} : 29.4 \text{ seconds}$$

$$\text{Percentage of saved time for one pallet switch at PoW area} : \frac{15.1}{29.4} = 0.51 \Rightarrow 51\%$$

$$\text{Relative to total PoW operations} : 0.51 \times 0.10 = 0.051 \Rightarrow 5.1\%$$

Total Theoretical Time Saving

$$\text{Total savings} : 5.2\% + 5.1\% = \boxed{10.3\%}$$

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