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Warehouse automation in the construction material and lumber industry

A case study of the Swedish company Derome Bygg & Industri AB

Master's thesis in Supply and Operations Management

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Cover: This thesis presents a framework for selecting suitable automation technologies in construction material logistics. The framework is designed to help decision-makers identify automation opportunities that match operational characteristics and strategic priorities. Key insights and recommendations are presented in Chapter 5

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SUMMARY

Suppliers of construction materials face an increasing demand for efficient logistics operations, while the use of automation in their supply chains remains limited. A key challenge lies in the bulky and heavy nature of construction materials, which complicates handling and automation. This study investigates how Derome Bygg & Industri AB (DBI) can improve their logistics through implementation of automation in picking, packing, and loading operations.

A mixed-methods approach was employed, including interviews with DBI logistic managers and operational staff, on-site observations, analysis of historical company sales data, and a literature review focusing on warehouse design, automation, and Industry 4.0 technologies. Empirical data was also collected from suppliers of automated equipment.

The study examines DBI's current operations and develops a categorisation of product groups suitable for automation. Several technological solutions were found suitable to DBI's context. The analysis indicates that wooden planks and sheet materials offer the greatest potential for efficiency gains through automation. The findings provide practical implications to support DBI's future investment decisions and contribute to a broader understanding of warehouse automation strategies in the construction material sector.

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Keywords: Warehouse design, Construction material warehousing, Industry 4.0, Automated picking, Picking construction materials, Automated loading, Internal logistics

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1 Introduction

This chapter introduces the context and motivation for the study. It begins with a background to the construction material industry and the challenges faced in its logistics operations. The chapter then presents the problem statement, followed by the aim and objectives of the study. Two research questions are defined to guide the investigation. Finally, the scope and limitations are outlined, specifying the boundaries within which the research was conducted.

1.1 Background

Traditionally, businesses have prioritised cost reductions in manufacturing and other business areas. However, logistics has historically not been recognized as a strategic business function on its own (Rushton et al., 2022). In recent decades, the strategic importance of supply chain within businesses has increased. Industry 4.0 and emerging technology such as Internet of Things (IoT) and big data have enabled more comprehensive management of supply chain inputs and outputs (Yavaş & Özkan-Özen, 2020). Additional enablers of modern, efficient warehouses include technology advancements in automation, robotisation and digital communication. The adoption of these innovations enables potential to achieve significantly improved supply chain performance. Nevertheless, Patrucco et al., (2020) identify several challenges associated with implementing such technologies, particularly for the construction materials sector. Despite these challenges, recent technologies have proven essential for improved logistics performance and managing complexity in medium and large-sized enterprises.

One of the companies that could benefit from advancing its supply chain in line with Industry 4.0 principles is Derome Bygg & Industri AB (DBI), a Swedish supplier of building materials and tools, mainly serving professional carpenters (M. Hansson, personal communication, January 20, 2025). DBI is part of the Derome group and is distinguished from its competitors by its vertically integrated supply chain. The company derives its name from its founding village, Derome. It operates its own production facilities, warehouses, vehicles and provides support and services to forest owners. Distribution is a core component of DBI's operations. Customers can either load materials into their own vehicles at DBI's warehouses or have the orders delivered by DBI directly to construction sites. At the current regional warehouse in Mölndal, customers load their vehicles in the same area where DBI prepares orders for delivery. However, the new warehouse (referred to as the logistics centre throughout this study) will be closed to customers and dedicated exclusively to distribution using DBI's own vehicles.

One distinguishing characteristic of the building materials industry is the combination of short lead times, and diverse deliveries in terms of volume and weight (Patrucco et al., 2020). At DBI, deliveries are typically fulfilled the day after an order is placed, as demanded by its customers. This underlines the critical role of logistics in the company's total cost structure and highlights the high potential return from logistics improvements. According to M. Hansson (personal communication, January 20, 2025), DBI recognises that developing a robust and responsive supply chain is essential in today's competitive environment. As key competitors are investing heavily in restructuring their logistics operations, DBI seeks to retain their competitiveness. A revised logistics strategy is therefore seen as a key enabler for enhancing logistic performance, increasing profitability, and supporting long-term growth.

As part of DBI's logistics strategy, the company plans to establish a structure with central warehouses that supply logistics centres (M. Hansson, personal communication, January 20, 2025). The preliminary plan also includes connecting each logistics centre to a small number of hubs. These logistics centres are expected to support a range of activities, including storage, consolidation,

packing, and picking. Furthermore, the logistics centres are assumed to accommodate several types of building materials, such as those for residential construction, kitchen building, wooden decks, hardware store and workwear.

DBI's vision is to reach state-of-the-art level of operations, which includes implementing recent technologies to enable fast and flexible processes (M. Hansson, personal communication, January 20, 2025). Due to the wide range of stock keeping units (SKUs) in terms of shape and size, the operational complexity is considerable. As a result, several systems are expected to be integrated. The large number and variety of SKUs also necessitate careful storage planning, with different types of storage solutions required to meet diverse material requirements. Furthermore, since various types of vehicles enter the logistics centres, the loading operations must be adaptable to ensure efficiency.

The logistics department of DBI is tasked with presenting a new warehousing and logistics strategy, which must be approved by the top management, including the CEO and logistics manager (M. Hansson, personal communication, January 24, 2025). The company has outlined strategic targets. By 2029, DBI aims to increase the sales volume distributed through its delivery service by 50 % compared to 2024 and improve its profit margin by reducing costs through more effective logistics operations. A key component in achieving these goals is the design and implementation of a new, efficient logistics centre. It is assumed that operational costs can be reduced by implementing a purposefully designed logistics centre. A key enabler in this effort is the use of automated technologies, which also can enhance productivity, revenue, and overall output (Hardy and Brougham, 2022). Additional benefits include fewer errors, improved ergonomics, and resilience. These benefits align strongly with DBI's strategic requirements.

1.2 Problem Statement

Efficient logistics is crucial to become competitive for construction material suppliers; however, the warehouse management remains low in adaptation of recent technology (Demirkesen & Tezel, 2022). This is also clearly noticed from DBI in practice (M. Hansson, personal communication, 20 January 2025). For companies, such as DBI, with operations characterised by short lead times and high customer requirements, in combination with a varied assortment, inefficient warehouse picking and loading are considerable cost drivers. Currently, DBI's picking and packing operations are handled manually, which indicates that the staff must handle heavy and bulky products, such as plaster- and wooden boards. This results in a low picking frequency to avoid injuries. Lack of performance in this area risks driving costs and decreased service level to customers. In an interview with M. Hansson (personal communication, January 24, 2025), it was stated that the current picking operations at DBI have reach its full potential within the existing working method, indicating that new methods are required.

Furthermore, based on real world observations of loading and unloading operations at DBI's main warehouse in Mölndal, and from the interview with M. Hansson, the logistics responsible of DBI (personal communication, January 20, 2025), it becomes apparent that loading construction materials is time consuming. This is likely caused by the high complexity and varied goods characteristics. DBI has developed their manual processes to support efficient operations and high customer satisfaction, however, there are generally drawbacks of manual handling compared to automated handling. For example, manual handling can result in high personnel and operations costs, and decreased customer satisfaction, if the delivery precision is affected negatively. In addition, delays can occur because of inefficient operations. In this context and based on the literature and empirical data collected (more details in Results & Analysis chapter 4), picking and loading appears to have the largest impact on the overall logistics performance. Thus, the main focus in this study is on the picking and loading operations at DBI logistics centre. At DBI, the packing is performed by the

picker between the picking and loading process. Therefore, packing is also studied to ensure a complete process solution from picking to loading and avoiding bottlenecks related to packing.

As previously stated, automation offers many benefits with a strong match to DBIs strategic requirements (Hardy and Brougham, 2022). The challenge is that there are also many barriers that must be overcome to gain these benefits, otherwise there is a risk of costly errors. The technical aspects are one of these barriers (Rathore et al., 2022). The challenge is that automated solutions are often designed to handle a specific job and lack flexibility in handling a diverse range of products. DBIs assortment vary widely in shape and weight and many different unit loads are used. Therefore, to enable automation the assortment was separated in different product categories, and these categories were then matched with suitable technology. Since not a single automated solution can be used for the whole assortment, an analysis of relative sales quantity corresponding to each product category was conducted to ensure automation is applied where it has the highest total performance impact.

Automation within warehousing is addressed in previous research, with extensive literature covering areas such as picking technologies, storage systems, and overall system integration (Roodbergen & Vis, 2009; Boysen et al., 2019; Faccio et al., 2020). However, there is a notable gap in research within automation of large and irregular sized construction materials, such as wooden planks and sheet materials. Thus, there is a lack of knowledge about automated technology and its effect on performance and efficiency within DBI's future logistics centre. To remain competitive, many businesses must face changes in their supply chain, which require decisions regarding investments and thorough planning before implementation. Even though there is much research about warehouse layout design in the literature, there is limited research within the area of construction materials.

In the article from Demirkesen & Tezel (2022), it is explained that in practice, automation processes within construction materials face a distinct set of challenges compared to other industries. Therefore, little is known regarding how automation processes and designs could fit into the requirements of different material categories in warehousing of the construction industry. Existing research within automation in warehouse design focuses on standardised and smaller products. Seidlova & Sourek (2010) addresses the challenge of designing warehouses for materials that are difficult to handle, like building materials, however it does not address automation. The issue of designing warehouses utilizing the technology of Industry 4.0 has also been addressed in previous studies (Yavaş & Özkan-Özen, 2020), however only a few studies have focused on the construction material industry. One study indicated that automation in the construction materials industry in Nigeria is underutilized, which implies increased cost and delays in delivery (Alumbugu et al., 2022). The underutilization could be caused by a lack of understanding in how to apply technology in this area. It can therefore be concluded that there is an apparent lack of knowledge in how to implement the automation in the construction material logistics, and to a varied assortment in general.

1.3 Aim & Objectives

The aim of this study is to develop a better understanding of how automation can be utilised and implemented in warehouses in the construction material industry. According to Baker & Canessa (2009) and Yavaş & Özkan-Özen (2020), technology is crucial when designing a new warehouse. This study aims to contribute new insights in an area where knowledge is currently limited. To narrow down the scope, the study focuses on processes where the highest potential performance impact from automation could be expected. Previous literature indicates that picking drives most of the warehousing cost, and therefore this will be a focus of the study (De Koster et al., 2007).

The study addressed the categorisation of DBI's assortment to identify the physical characteristics and logistical requirements of the products. An investigation and evaluation of feasible automation solutions was also conducted for picking, packing, and loading processes corresponding to the distinct product categories. Successful implementation of automation may be crucial for DBI, as the company are targeting a 50% increase in sales volume through its delivery services, combined with a reduction in logistics cost relative to revenue by 2029. By a clearly identifying which product categories are suitable for automation, this study aims to provide a decision basis for DBI's future investments. In summary the objectives of this study are to:

- Identify and categorise the SKUs within a construction material warehouse that are most feasible for automation.
- Identify, evaluate, and match suitable automated solutions for picking, packing, and loading processes based on the selected SKU categories.

1.4 Research Questions

As a logical consequence of the problem statement and aim of the following research questions was defined.

RQ1: What SKU categories in construction material warehouses are most suitable for automation, and for which of these categories do automation offer the greatest potential improvement in overall warehouse performance (productivity, cost-efficiency, and quality)?

From the literature it appears that automation may bring benefits that strongly match the strategic goals of DBI (Hardy and Brougham, 2022). However, automated solutions are often highly limited in their ability to handle a varied assortment; therefore, the problem becomes deciding what product categories are suitable for automation.

RQ2: In what ways can automation be implemented within the picking, packing, and loading processes of a construction material warehouse, specifically targeting the SKU categories identified as most suitable?

After identifying the product categories most suitable for automation, the subsequent challenge is to determine suitable technical solutions that align effectively with these specific categories.

1.5 Scope & Limitations

The study focuses on the aspects of warehouse design that have the greatest impact on overall logistics performance. The authors initially intended to examine all processes and SKU categories at DBI, the scope was later narrowed down to enable a more in-depth analysis of selected, relevant aspects of warehouse design. Given the time constraints of the study, the analysis is limited to the automation of picking, packing, and loading processes within the logistics centre. Although order receiving and returns handling are essential, they are not within the scope of this study.

The geographical scope of this study was limited to the Gothenburg area; however, the logistics centre may potentially be replicated into other regions, if DBI decides to. The preliminary service area for the logistics centre is between Strömstad and Halmstad. The optimal placement of the logistics centre, transport solutions, financial considerations, and data handling were not within the scope of this study, as these aspects would require extensive geographical analyses which is beyond the core subject of internal logistics. Furthermore, the influence of the central warehouse and the hubs on the logistics centre was not addressed.

The authors aimed to prioritise the investigation of the processes and product groups where improvements would lead to the greatest total performance impact. Detailed economic analyses, such as return of investments and budgeting, were outside the scope of this study. However, the sales quantity analysis and the focus on the most resource-intensive processes aimed to investigate automation where it has the highest potential for cost savings and performance improvements, ensuring a cost-effective design from the bottom up. Another limitation is that a detailed analysis and comparison of specific automation technologies was not conducted due to time constraints and limited data availability. While such an investigation would have added value, the study still contributes new knowledge to the literature, as the topic has not previously been explored in this context.

Considering the logistics centre and the proposed automated solutions, the focus has been on the overall concept and the material flows rather than on detailed technical specifications. Due to insufficient reliability of the available sources for certain automatic technologies, these have deliberately been excluded from the analysis. This decision was made to maintain a high validity and reliability of the study's conclusion and recommendation. Regarding the technologies used for picking, loading, and packing, the emphasis was placed on exploring general concepts rather than conducting a detailed evaluation or comparison.

The limitations imply that the results and conclusions of the study are specifically tailored for DBI's requirements and assortment and may not be generalisable to companies with different product mixes or operational conditions.

2 Literature Review

The purpose of this literature review is to present a theoretical background to warehouse design by explaining how Industry 4.0 can be implemented in a warehouse that is providing construction materials, and to identify research gaps connected to picking, packing, and loading of various construction materials. Furthermore, literature on the implementation of automation is presented. And finally, a summary of the literature review is made together with findings of research gaps.

2.1 Industry 4.0 in Logistics

The Fourth Industrial Revolution, Industry 4.0, was introduced in Germany in 2011 to enhance the country's industrial competitiveness through increased digitisation of manufacturing processes (Kagermann et al., 2013). While Kagermann et al. (2013) introduces the concept of Industry 4.0, Lu (2017) focuses more on the technical integration of physical and digital systems. Industry 4.0 includes merging physical and digital environments via advanced information technologies, such as Internet of Things (IoT), big data, and artificial intelligence (Lu, 2017). This makes it possible to connect machinery, people, and systems in real time, and thereby creating more flexible, efficient, and data-driven value chains. Further on, Kagermann et al. (2013) explain a key component of Industry 4.0, which is cyber-physical systems (CPS), where computer systems interact with physical devices in the supply chain, such as warehouses, factories, and vehicles. Physical objects can be equipped with sensors and communicate with other devices in a network to provide real-time data. Yavaş & Özkan-Özen (2018) in contrast, focus specifically on the role of Industry 4.0 in logistics. It is emphasized that the use of CPS and 4.0 technologies in logistics can streamline information and resources in the supply chain to enhance efficiency and lower the costs of producing customized products. A crucial enabler for industry 4.0 is the real-time data availability. Zhong et al. (2017) describe how IoT-based technologies facilitate real-time monitoring and information sharing across supply chains, providing greater transparency and operational efficiency. Radio-Frequency Identification (RFID) is a core IoT application, enabling accurate tracking and tracing of materials throughout the supply chain. Zhong et al. (2017) stress the role of real-time transparency across the supply chain, whereas Lee et al. (2017) discuss the design and application of an IoT-based warehouse management system for smart logistics and argue that it can increase accuracy and efficiency in picking.

Robotics is a key part of modern material management, and through Industry 4.0, Automated Guided Vehicles (AGV) has been introduced for internal material handling and is described in Wang (2016). AGVs can move material between inbound, storage locations and outbound, without human interaction. This can increase both the efficiency and the flexibility in warehouses. Further on, Wang et al., (2016) describes industry is heading towards smart material flows, where the products can communicate with and guide machines. This indicates that a palletised product with a sensor can give a signal to a robot that it is ready to be moved to the next station, decreasing the requirement for manual instructions. According to Wang et al. (2016) the result of IoT and robotics in materials management include increased efficiency, reduced errors, increased productivity and savings. While Wang et al. (2016) examine fully automated systems such as AGVs, Chemweno and Torn (2022) highlight the utility of collaboration between humans and robots. Moreover, Chemweno and Torn (2022) claims that heavy lifts or monotonous tasks can be reduced through modern collaborative robots, or also known as “cobots”, that work together with humans, side-by-side, and thereby flexibility can be increased. As a conclusion, robotics enhance efficiency within material handling where real-time data and automation cooperate.

In conclusion, Industry 4.0 technologies, including IoT, CPS, robotics, and real-time data integration, offer significant potential to transform logistics operations. By adopting these technologies,

warehouses can achieve higher efficiency, better accuracy, and greater operational flexibility, which is critical for industries with complex supply chains, such as the construction material sector. These technologies are highly relevant to the development of DBI's logistics operations.

2.2 Warehouse Design

In parallel to the evolution of Industry 4.0, warehouse design principles have also developed to address the growing complexity of modern supply chains. In Jones et al. (1997) Lean Logistics is described as identifying and eliminating non-value-added activities, while newer paradigms like Smart Logistics, explained by Lee et al. (2018), utilize real-time data to optimize inventories, and according to Zhong et al. (2017), anticipate demand fluctuations. A foundational approach is provided by Baker & Canessa (2009), who propose a structured step-by-step methodology for designing warehouses, from determining business requirements to finalizing equipment selections and workflows. By integrating lean thinking and advanced digital tools, warehouse design can more effectively respond to volatile demand, improve material handling efficiency, and maintain cost-effective operations in an Industry 4.0 landscape.

In warehouse design, research generally define the central processes as receipt, put away, storage, picking, packing, and shipping (Tompkins et al., 2010; De Koster et al., 2007), illustrated in Figure 2.1. Construction materials can be more complex in material handling, since they often do not conform to typical unit-load configurations like palletised goods (De Koster et al., 2007; Kasim et al., 2013). Furthermore, Kasim et al. (2013) observe that many traditional or paper-based methods persist, leading to inefficiencies and difficulties in tracking items. De Koster et al. (2007) highlight that order picking implies high costs and labour intensive for warehouse operations. In the construction materials context the processes can vary, because of the complexity of large-scale and bulky items (e.g., lumber, or heavy building materials). When comparing De Koster et al. (2007) and Kasim et al. (2013), both identify inefficiencies in warehousing but Kasim et al (2013) focus on the drawbacks of paper-based systems while De Koster et al. (2007) stress the resource intensity of picking operations.

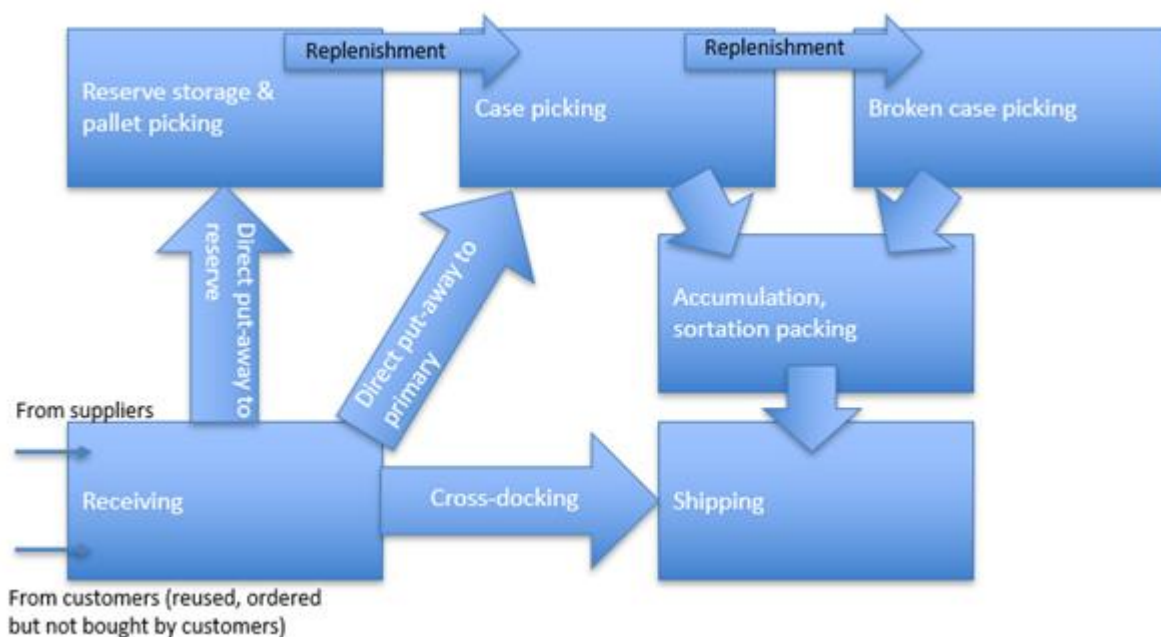


Figure 2.1: Illustrating the general process flow in warehouse design.

Note. Retrieved and adapted from Baker & Canessa (2009)

The framework and tools for the various steps in warehouse design, as described by Baker & Canessa (2009), has been foundational for the analysis in this thesis. It was not followed exactly, instead it has been adjusted to suit this study and is illustrated in Figure 2.2.

The first step of warehouse design is to define the system requirements (Baker & Canessa ,2009). This includes understanding the strategic role of the warehouse. The suggested tools to use for this includes using literature on supply chain strategy and scenario planning. Functions like cross-docking and storage are also considered.

The second step is to define and obtain data and the tools used include gathering relevant spreadsheet data from the company database and using checklists to document the current processes (Baker & Canessa, 2009). The data to be gathered include product details, order profiles, goods arrival, dispatch, and cost. It is suggested to extract database data, consult with different stakeholders in the company and then summarize the data in a useful way. The third step includes analysing the data. The tools include spreadsheet models and visualizing the flows and processes of the warehouse. Specifically, SKU popularity distribution and demand, customer order profiles and inventory profiling can be analysed.

The fourth step includes establishing the unit loads to be used and for this simulation or mathematical models are commonly used (Baker & Canessa, 2009). It is also suggested to consider the full supply chain and unit load constraints from suppliers. After this, the fifth step involves determining the operating procedures and methods.

Moving on, the sixth step includes listing equipment types and their characteristics (Baker & Canessa, 2009). For this it is common to use spreadsheet models, simulation, or decision trees. Equipment can also be evaluated according to the scale of the operation and flexibility requirements. The equipment attributes are evaluated to ensure suitability for the application. Full cost analysis is also described. Further on, equipment capacity and quantities are calculated in spreadsheets. The expected impact on KPIs from implementing distinct types of equipment is analysed. This aims to provide a base for equipment selection.

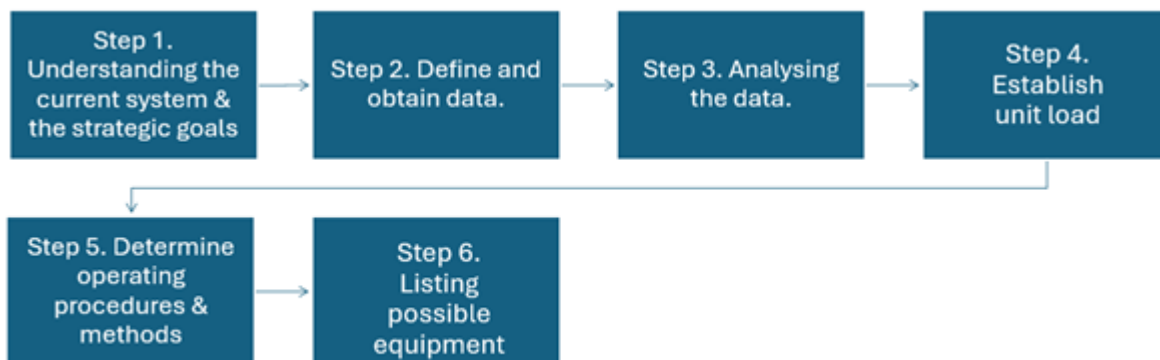


Figure 2.2: Step 1-6 of the warehouse design framework.

Note. by Baker & Canessa (2009).

2.3 Picking

Picking is typically one of the most labour-intensive and costly activities in warehouse operations, typically accounting for up to 55% of total operating expenses (De Koster et al., 2017). While Industry 4.0 technologies offer significant opportunities for improving warehouse operations it has still not been widely adopted in the construction material sector. Alumbugu et al. (2019) studied

manufacturing warehouses for construction materials in Nigeria and found a reliance on manual picking processes, limited barcoding, and minimal real-time data captured, which decreased service-level reliability. The results suggest that mechanized or partially automated solutions could improve the efficiency and reduce long lead times and high labour costs. Further on, automation may enable decreased prices on construction material and delivery delays. The lack of automation in construction material warehouses emphasized by Alumbugu et al. (2019) might be explained by the complexity of this industry as identified by Tompkins et al. (2010) who found that the relative complexity is high because of the large, heavy, and non-standardised items such as wooden planks and steel profiles. The challenging context identified by Tompkins et al. (2010) may also be a contributing reason why previous studies such as Fernandes et al. (2019) have focused on automation of smaller goods in a more standardised format. Previous studies have focused on handling small and medium sized boxes, however there are no studies found about planks or heavy lumber. Automated systems handling heavier and larger items with real-time data integration is not widely documented. This gap is particularly relevant for DBI's operations, where a sizeable portion of the assortment consist of large and heavy construction materials. The requirement for improving picking efficiency, combined with the specific challenges of non-standardised building materials, highlight the importance of exploring new picking solutions.

2.4 Loading

Carlan et al. (2023) researched if automated cargo loading and unloading brings benefits when both purchase cost and operational cost is considered. The findings indicate that increasing cargo volumes, increased labour costs and improved truck fill rate lead to a better Return on Investment (RoI) for automated solutions. Using forklifts in loading was compared to using automated loading technologies such as loading plate and transport belt. When comparing these technologies, the transport belt produced the best economic results when combining project cost and operational cost over a 10-year period. This is mainly because it reduces the costs associated with employees and energy usage. The other automated technologies however incurred a higher cost after 10 years compared to using forklifts.

Carlan et al. (2023) researched the long-term cost implications of different automated loading system while Thylén et al. (2025) stress the importance of collaboration within the supply chain for successful implementation of automated loading. Thylén et al. (2025) researched the requirements for automated loading and unloading specifically for autonomous transport. It is stated that automated loading and unloading require close collaboration with the companies operating the loading bay and the trucks. Kembro and Norrman (2020) suggest that when implementing automated solutions new competencies are required from the employees. Technical skills for handling the automated loading and unloading systems become more relevant than manual loading and unloading.

When contrasting Thylén et al. (2025) with Agrawal et al. (2023) both studies acknowledge the challenges in automated loading, however, Agrawal et al. (2023) provide a more detailed breakdown of the barriers to address for successful implementation. Agrawal et al. (2023) focused specifically on automation of loading and unloading for autonomous transport. It was indicated that the challenges and requirements which must be addressed for a successful implementation of automated solutions can be divided into five main categories. These include the physical characteristics of the load, the interaction with the information system, the transportation off and onto the trailer, securing and arranging the load to the trailer and the legal aspects. When considering the physical characteristics of the load the non-uniformity of goods must be managed to prevent damaging the goods and ensuring safety. The goods also must be arranged on the trailer in a way that ensures safe and legal weight distribution. Additionally, the non-uniformity creates challenges in automatic

detection of the goods weight, type, and size, which is required for correct loading. The interaction with the information system, automatic registering of goods, requires that the identifier tag is placed in the right location. Additionally, efficient communication between different information systems is required. Another issue is establishing clear boundaries on who is responsible for various stages of the loading and unloading. The information system should also be able to plan the optimal loading sequence of the goods. Another main area is moving the goods off and onto the trailer (Agrawal et al., 2023). An issue with this process is that the environment is constantly changing regarding people and goods in the loading area. This must be managed to avoid damage to equipment or people. The mix and interaction between automated and manual work also must be managed to ensure safety and efficiency. The height difference between the trailer and loading bay also must be addressed. The decision-making abilities of the automated system to be able to handle different situations is also described. Another area to address is securing and arranging the goods on the trailer. Optimum fill rate and goods safety can be challenging with automated solutions like AGVs. Correctly aligning the goods must also be addressed. The load must be secured and unsecured through automation. Finally, the legal aspects must be considered. One of the aspects is the traceability in various stages which is required to detect if the load is correctly secured and to detect when damages to the goods have occurred. There are also legal aspects regarding safety for employees in the loading area. Defining accountability in various parts of the process is also suggested.

2.5 Packing

Efficient packaging and palletising are critical components of effective logistics operations, especially when handling large materials such as wooden planks or sheet materials. According to Szymonik (2016), well-designed unit loads improve transport, storage, and automation, while reducing damages and labour strain. For DBI, applying these principles to their packaging operations, could enhance flow efficiency, minimize manual workload, and lower operational costs. Szymonik (2016) emphasises that the formation of palletized unit loads should follow predefined procedures, considering factors such as the type and arrangement of packaging, pallet structure, transportation condition, and logistics labelling.

2.6 Automation

Rathore et al. (2022) investigated barriers for implementing disruptive technologies in logistics. One of the technologies which was investigated was AI-based robots. The study claims that a diverse product range creates challenges for implementing automated AI robots. The varying product characteristics creates a technical challenge because the robots are not very versatile. The study claims that the Austrian logistics firm KNAPP AG found that the robots can only handle 15 % of the product range successfully. It is therefore not feasible to use one automated system to handle all the product range. Instead, multiple types of automated solutions adapted for the corresponding product types are required. Aside from the technical barrier, the study also found barriers for implementing disruptive technologies which include legal and regulatory framework, lack of top management support, resistance to change and infrastructure.

While Rathore et al. (2022) focused on barriers for implementing disruptive technologies, Hardy and Brougham (2022) address the negative and positive effects of implementing automation. More specifically, Hardy and Brougham (2022) researched the impact, barriers, and enablers of automation in firms in telecommunications, energy, manufacturing, and media sectors. One of the identified benefits of automation includes increased productivity which enables higher revenue and work output. The second impact is cost savings. Thirdly, automation enables resiliency and continuity, robots can operate 24/7. Finally, another main benefit is improved data accuracy and reduced number of errors. One of the possible negative impacts from automation includes automation dependency of employees. While depending on the automatic system the employees' manual skills

can erode which is problematic for operational adaptability. Secondly, automating bad processes creates escalated issues, rework, and inefficiencies. Thus, the findings indicate that there is a risk of magnifying underlying flaws through automation. Thirdly, automation can require regular maintenance and updates which can be costly if not managed properly

The findings of Hardy and Brougham (2022) indicate that a key enabler of successful automation implementation is executive endorsement and approval, which is necessary to ensure prioritization, set direction and secure resources for the project. Secondly, IT infrastructure and involvement is required. It is foundational for automation projects as automated technology is commonly integrated with the IT system. The features of the automated system are limited to the features enabled by the IT infrastructure. Thirdly, process knowledge and mastery are emphasized. Knowing what process to prioritize and applying the automation correctly is emphasised to avoid costly errors and inefficiencies. Finally, resistance is identified as a barrier. This can be addressed by involving and engaging employees and front-line users in the project it is possible to build trust, leverage operational knowledge and support from the employees which is essential for a successful implementation.

2.7 Summary & Knowledge Gap

The findings of the literature review suggests that Industry 4.0 is an enabler for a more efficient warehouse management and design. However, it is concluded that within warehousing of construction materials there are research gaps. For example, He & Turner (2021) suggest that little attention has been made within academia of recent technologies applied to warehousing of forestry products. Therefore, this study aims to contribute to academia by addressing the issue of how recent technologies within construction materials, particularly for forestry products, can be applied to warehousing.

Further on, this theoretical review presents recent technologies. Within recent technologies of picking and packing within warehousing, little is found about handling construction material. Finally, the theoretical review highlights key considerations to be addressed for successful implementation of automation. These considerations are crucial when researching a field that is poorly studied previously.

3 Methodology

The methodology is a mixed methods single-case study. Literature on the topic was systematically reviewed to build a theoretical foundation. The empirical data sources include semi-structured interviews, company presentations, and historical data analysis (e.g. spreadsheets of historical sales and assortment). To improve the reliability of the data, it was validated through reviews by stakeholders at DBI.

3.1 Research Design

To address the research questions, a mixed-method, case-based approach was applied. This was chosen because of the practical, complex, and context-specific nature of the research, focused on the logistics operations of Derome Bygg & Industri AB (DBI). Creswell & Clark (2017) suggest using mixed methods when a single data type is not sufficient for answering the research questions. This justifies the choice of a mixed method for this study as analysing quantitative data is central for answering the research questions however qualitative data is required to guide the interpretation of this data and to understand the broader context and operations of DBI. This is also in line with Creswell & Clark (2017) who argue that mixed methods are recommended when the complexity of a real-world problem requires a nuanced understanding.

Yin (2017) provides a framework for case study research. The framework justifies case study research when the focus is on a contemporary issue in a bounded system. Our study of DBI focuses on the contemporary issue of warehouse automation and conducts an in-depth exploration of DBI as a bounded system which justifies the case-based approach of this study.

Cote (2021) distinguishes between descriptive, diagnostic, predictive and prescriptive data analysis. Descriptive analysis creates the foundation other analysis is built on by visualising and summarising what is already known. Diagnostic analysis aims to establish cause and effect by studying what has happened. Predictive analytics are used to make predictions about the future based on analysing historical data and trends. Prescriptive analysis considers multiple factors to choose between different options using a data-driven approach.

For *RQ1: What SKU categories in construction material warehouses are most suitable for automation, and for which of these categories do automation offer the greatest potential improvement in overall warehouse performance (productivity, cost-efficiency, and quality)?*

First, a descriptive phase documented the current system using:

- Quantitative data (historical sales data)
- Qualitative data (semi-structured interviews and direct observations).

This aligns with common practice in logistics research where quantitative data is used to analyse flows and capacities, while qualitative insights reveal context and operational complexity. Baker &

Canessa (2009) also suggest analysing SKU popularity distribution as a step-in warehouse design, this was conducted by quantitatively analysing the relative sales quantity for every SKU.

Further on, the analysis followed a prescriptive approach for assortment selection using historical data. Subsequently, a predictive approach was applied to forecast 2029 material flows. Finally, the categorised flows were evaluated for automation suitability using a prescriptive framework.

For RQ2: In what ways can automation be implemented within the picking, packing, and loading processes of a construction material warehouse, specifically targeting the SKU categories identified as most suitable?

Building on RQ1, the relevant categories were studied using a descriptive approach to evaluate product characteristics and applicable technologies. Mixed data about the possible technology was then analysed using a descriptive approach. The product categories and their characteristics were also analysed using a descriptive approach interpreting mixed data. A prescriptive approach was then used to compare the findings about the technology and match this to the product characteristics to find the answer for RQ2.

The research is structured according to the warehouse design framework by Baker & Canessa (2009), widely cited in logistics and warehouse planning literature, and illustrated in Figure 2.2. This framework supports a structured, step-by-step process for warehouse design, and was chosen because of its alignment with both academic standards and industry practice. Figure 2.2 summarises the research process for the different issues which have been investigated.

Not all steps of Baker & Canessa (2009) were followed; instead, the study focused on steps 1–6, as illustrated in Figure 3.1, which emphasise strategic role definition, data collection, analysis, studying the product characteristics to establish unit loads, determining operating procedures, and technology evaluation. The reason for following these steps is that they encompass the scope of the research questions. By following these steps, it was possible to first establish the context needed for addressing the research questions. Further on, the method allowed finding the most suitable SKUs and processes for automation and pairing these with suitable technology and thus answer the research questions. Steps 6-12 of the framework focus on layout design, which is outside the scope of this study.

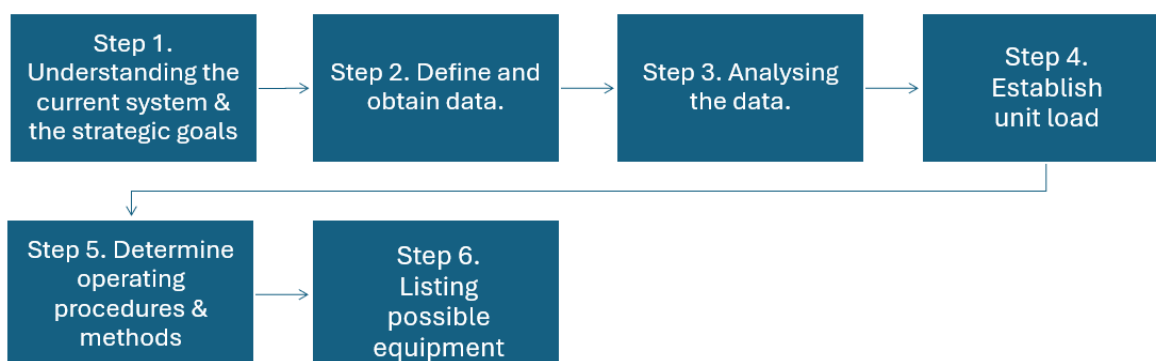


Figure 3.1: Illustrating the framework used for warehouse design.

Note. Adapted from Baker & Canessa (2009), adjusted to suit the context of this study.

3.2 Literature Review

The literature review was conducted systematically to provide a comprehensive understanding of Industry 4.0 technologies, warehouse design principles, and automation challenges in the sector of construction materials. Knowledge of Industry 4.0 was further deepened through targeted research in

logistics. Insights into warehouse design were gathered through continuous information collection focused on the construction sector. The literature search strategy combined keyword-based searches and snowballing, following the approach recommended by Webster & Watson (2002).

The keywords were used for searching in academic databases such as Google Scholar and Chalmers Library. The keywords contained combinations such as:

- “Warehouse design”
- “Logistic centre design”
- “Industry 4.0 in logistics”
- “Construction material logistics”
- “Warehouse automation”
- “Picking automation”
- “Loading automation”
- “Challenges in construction supply chain”
- “Construction material warehousing”

To ensure a balanced searching and finding relevant studies, boolean operators (AND, OR) were used for refinements. Studies made after 2010 were prioritised, however a few older yet significant and foundational works (e.g. Baker & Canessa, 2009; De Koster et al., 2007) were included.

To find the current research trends within logistic centre design and warehouse automation, focused on heavy and large building materials, an iterative searching approach was utilised. After a relevant article was found, backward and forward snowballing were used. Backward snowballing, by using the reference list to find additional relevant articles. Forward snowballing, by searching for studies that have cited that article, to find more recent findings. The literature was collected and evaluated and thereafter categorised and prioritised based on its key areas and relevance for this study. In addition, relevant academic books were selected to provide a solid theoretical foundation for the empirical investigation.

3.3 Empirical data collection

To develop a comprehensive understanding of DBI’s current operations, empirical data was gathered through a combination of interviews, observations, internal company data analysis, and websites of automation technology providers. From this, it was possible to identify feasible opportunities of improvements for the new logistics centre. Interviews were conducted with logistics managers and operational personnel at DBI to collect information on current challenges and future requirements. The interviews have followed a semi-structured approach, which allows flexibility and simultaneously covers the main subjects, such as picking routines, loading processes, warehouse capacity planning, and automation experiences. The list of interviews and meetings are provided in Table 3.1.

Additionally, observations were made during a site visit at DBI’s production facility in Derome and regional warehouses in Mölndal, Derome and Landskrona, as well as the central warehouse in Landskrona. During these visits picking, packing, and loading operations were primarily observed, however bottlenecks, ergonomic challenges, and potential areas of automation were also addressed. Company data, such as historical sales volumes, stock levels, and assortment categorisation were collected and analysed through spreadsheets and pivot tables. This enabled quantitative analysis of sales quantity and frequency categorisation.

When collecting data for answering RQ2, the prioritised sources were academic articles, which provided insights about automated packing and loading. However, it was found that little research had been conducted about automation of picking in this field. Thus, other sources were needed to be able to answer RQ2. Google was used to scan the market for automated technologies in this field. The keywords which were used were: *'warehouse automation for construction materials,' 'automated picking for heavy items,' 'automated loading,' 'automated picking of sheet materials'* and *'automated packaging,' 'automated picking of lumber/timber.'* While scientific articles on the topic would have been preferred as sources, alternative sources were also used. The authors acknowledge the limitations of these sources, however the use of them is justified for illustrating concepts and start exploring this under-researched field. Case studies and market examples within warehouse automation of construction materials were collected. To develop a better understanding of technological options, solutions from Systraplan, Barbaric and Tentoma were investigated to identify existing technologies that were suitable for handling bulky and heavy materials. The combination of interviews, observations, internal data analysis, and benchmarking provided a triangulation of findings, to achieve validity of the results.

Table 3.1: List of interviews and meetings for the master's thesis project

#	Title / Description	Date	Participants	Purpose / Key Topics
1	Meeting with logistic responsible - supervisor	2025-01-20	Mathias Hansson	Introduction of background, purpose and aim.
2	Meeting with logistic responsible - supervisor	2025-01-24	Mathias Hansson	Collecting data, limitations
3	Meeting with logistic responsible - supervisor	2025-01-31	Mathias Hansson	Strategic goals, overview of DBI's operations
4	Meeting with Controller	2025-01-31	Johan Lindblom – Controller	Logistics cost structure, KPIs, budgeting, flow metrics
5	Meeting with Transport Planners and Coordinators	2025-02-03	Erik Strand and other internal logistics operators	Transport planning, ERP, consolidation, real-time issues
6	Meeting with logistic responsible - supervisor	2025-02-06	Mathias Hansson	Technological solutions, logistic operations, DBI's organisation
7	Meeting with Regional Warehouse Manager – Mölndal	2025-02-06	Daniel Jakobsson	Capacity planning, warehouse design, staffing, strategy
8	Meeting with Supply Chain / Procurement	2025-02-11	Daniel Ahrling	Inbound flows, supplier deliveries, order handling, procurement strategy
9	Meeting with operation manager at the regional warehouse of Mölndal	2025-02-11	Jens Baitson	Packing routines, capacity challenges, planning process

#	Title / Description	Date	Participants	Purpose / Key Topics
10	Study visit - Central- and regional warehouse of Landskrona	2025-02-13	Mathias Hansson	Studies of operations in central warehouse, bottlenecks, future plans
11	Meeting with logistic responsible - supervisor	2025-02-13	Mathias Hansson	Bottlenecks in DBI's logistics, logistical costs, problem statements, sustainable goals, economical perspectives, available resources, storage capacity
12	Meeting with supervisor from Chalmers University of Technology and logistic responsible - supervisor	2025-02-19	Altahir Hassan Irshien Ali, Mathias Hansson	Requirements of the new logistics center, research questions
13	Meeting with logistic responsible - supervisor	2025-03-05	Mathias Hansson	Assortment analysis and selection
14	Meeting with Regional Warehouse Manager (Derome)	2025-03-12	Roger Sandersson	Warehouse operations, staffing, picking/loading processes
15	Interview – Automation Expert	2025-04-07	Per Andersson - automation expert	Experiences with automation and its effect on KPIs and logistics

3.4 Data Analysis

The data analysis process in this study followed the structured warehouse design framework by Baker & Canessa (2009), focusing on steps 1–6. These include defining system requirements, gathering relevant data, analysing product characteristics, establishing unit loads, and evaluating operating methods and technology. A more detailed illustration of the method used for the data analysis is made in Figure 3.2. The aim was to generate actionable insights for the design of a new logistics centre for DBI, with a focus on automation potential in picking, packing, and loading. The tools used for analysis was:

- **Defining System Requirements:** The first step was to define system requirements as suggested by Baker & Canessa (2009). Interviews were held to understand the strategic role of the warehouse and were interpreted with strategy literature in mind. Hardy & Brougham

(2022) emphasize the importance of detailed process knowledge before implementation of automation. For this reason, process knowledge was gathered and interpreted using the general process flow described in Figure 2.1 (Baker & Canessa, 2022).

- **Spreadsheet Analysis (Excel):** Baker & Canessa (2009) suggest gathering spreadsheet data on product details, order profiles, SKU demand distribution, etc. It is suggested to use spreadsheet calculation models for analysing the data quantitatively. Excel was the primary tool for quantitative analysis. Historical sales and stock data from DBI were imported into spreadsheets. Pivot tables were used to categorize SKUs by assortment type and frequency class. Calculation models were then applied in Excel. This enabled the identification of high-impact product categories suitable for automation. Figure 3.3 presents an excerpt of the raw excel data. For integrity reasons the complete Excel file is not available and most of the screenshot is blurred.
- **Assortment Selection:** Baker & Canessa (2009) suggest establishing unit loads using mathematical models. In this study this involves assortment selection. SKUs were classified by order frequency and assortment category, with cutoffs defined through historical data (e.g., fast movers: ≥ 52 orders/year). By using pivot tables and calculation models it was possible to find the relative sales quantity and number of order lines for each SKU. Category-frequency pairs below 1% of total order lines or sales quantity were excluded to streamline the logistics design. Using the combination of pivot analysis and stakeholder discussions, the number of SKUs in the future logistics centre was reduced while maintaining 99.3% order coverage and significantly reducing complexity.
- **Sales quantity calculations:** Baker & Canessa (2009) suggest profiling and SKU popularity demand using spreadsheet models and calculating total sales quantity. In this thesis, SKU popularity distribution was analysed by studying historical demand distribution and calculating relative number of order lines for various levels of assortment categorization. Quantitative metrics such as sales quantity and number of order lines were calculated for each SKU class. Adjustments (e.g., 45% reduction of Derome data for specific categories) ensured accuracy in estimating 2024 baseline data. The baseline data was then used to create a forecast for 2029.
- **Detailed Category Analysis:** By using pivot analysis and spreadsheet calculation models the relative sales quantity and number of order lines could be summarized for different detail levels of assortment categorisation. SKU data and pictures from DBI's website was quantitatively and qualitatively analysed.
- **Qualitative Data Interpretation:** Baker & Canessa (2009) suggest using both quantitative data and consulting with different stakeholders at the company. Interview notes were coded and cross-referenced with observational data to identify bottlenecks and manual inefficiencies in current operations. For example, specific challenges in picking and loading heavy items were interpreted through both site visits and staff interviews.
- **Automation Assessment:** As the fourth step, Baker & Canessa (2009) suggest establishing unit loads to be used. As only 5 % of DBI's products are palletised, establishing the unit loads required detailed data analysis as there are almost as many different unit loads as there are SKUs at DBI. Product characteristics at DBI were mapped by studying the spreadsheet data. Individual SKUs were studied in DBI's web shop to determine technical product specifications. Empirical data and literature on automation was studied to analyse impact and

technical specifications of automated equipment. An analysis was then made quantitatively and qualitatively to find a match for the DBI's products with automated solutions. This matches the steps five and six of the warehouse design approach by Baker & Canessa (2009), which include determining operating procedures and listing and evaluating equipment types. Automated solutions can commonly only handle a limited part of the assortment (Rathore et al., 2022) which further justifies this analysis.

- Visualisation: Schematic process flows and figures (e.g., current picking flows, layout zones) were used to map operations and identify critical inefficiencies as described by Baker & Canessa (2009).

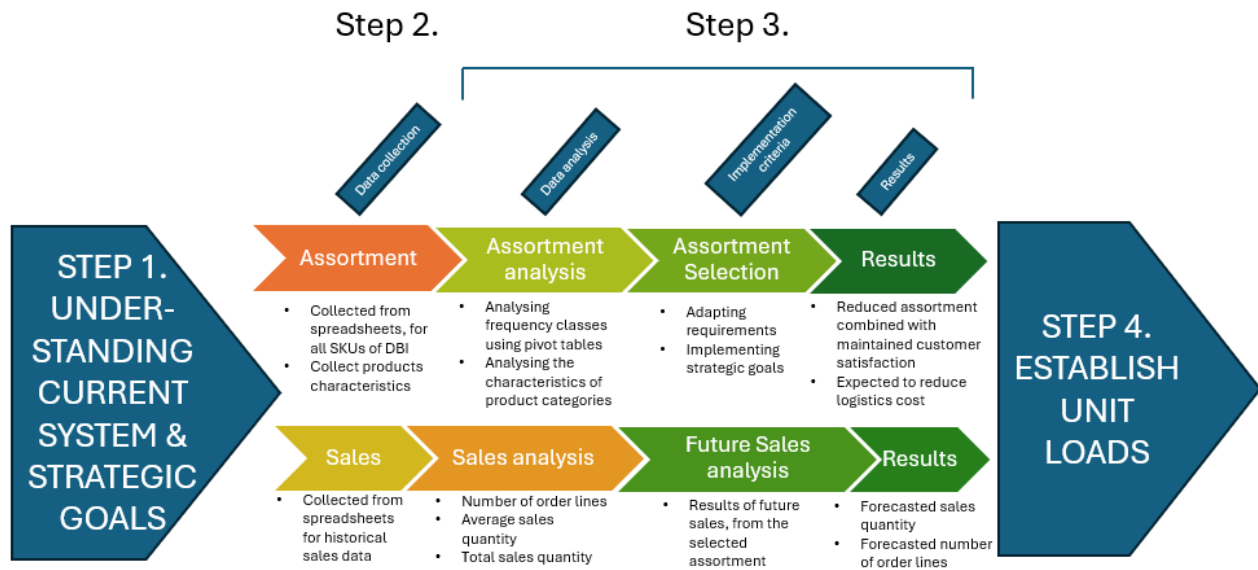


Figure 3.2: Summarization of the analysis process for the issues investigated in the study.

Regional Warehouse	Subcategory	Product category	Storage or not	SKU	SKU number	Frequency class	Assortment date	Storage quantity	Sold quantity	Average sales q. F	Number of sales
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358231 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358232 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358233 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358234 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358235 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358236 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358237 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358238 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358239 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358240 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358241 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358242 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358243 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358244 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358245 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358246 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358247 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358248 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358249 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358250 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358251 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358252 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358253 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358254 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358255 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358256 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
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30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358259 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358260 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358261 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358262 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358263 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358264 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358265 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358266 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358267 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358268 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358269 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358270 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358271 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358272 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358273 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358274 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358275 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358276 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358277 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358278 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358279 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358280 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358281 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358282 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358283 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358284 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
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30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358287 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
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30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358290 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358291 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
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30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358293 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358294 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358295 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
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30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358298 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358299 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11
30511 Regionlager Mohn (010 Bindemedel	010010 Cement	Lagerlagd		32358300 BYGC	3235823	MEDIUM MOVER	JEM	107,00	520,00	8,91	11

Figure 3.3: The figure is a screenshot of the raw spreadsheet data which was used in the quantitative data analysis.

3.5 Research Validity & Reliability

To ensure reliable results, several types of data were used and compared throughout the study. Interviews, internal spreadsheets, company presentations, and literature were all used to cross-check findings throughout triangulation, as explained in Yin (2017), this has strengthened the conclusions. Assumptions were reviewed by DBI's logistics management, providing relevant expert input. In cases where data was missing or uncertain, conservative assumptions were made and clearly explained in the documentation. The entire process was carried out with transparency in mind, with clear records of how decisions were made and what sources were used. Since the study was conducted within the context of a single organisation, the generalisability of the findings may be limited. However, the results are considered robust and well-grounded within the scope of DBI's operations.

4 Results & Analysis

This chapter presents the empirical findings from interviews and the data collection, as well as the analysis based on the literature related to the case and context. This aligns with the framework of Baker & Canessa (2009) that suggest analysing historical data as well as performing interviews with relevant company stakeholders and summarizing them in useful ways for warehouse design. The aim is to explore how automation can be applied in warehouse design for DBI, and to evaluate which product categories and processes are most suitable for improvement.

4.1 DBI's current system and strategic goals

The first step of warehouse design according to Baker & Canessa (2009), as illustrated in Figure 4.1, is to understand the current system and strategic goals. Hardy & Brougham (2022) suggests that knowledge and mastery of the current process is an enabler of successful automation implementation. Otherwise, the risk is to automate an inefficient process and multiply errors. Chapter 4.1 focuses on documenting the strategic role of the warehouse as well as documenting the current processes as this is crucial for answering the research questions.

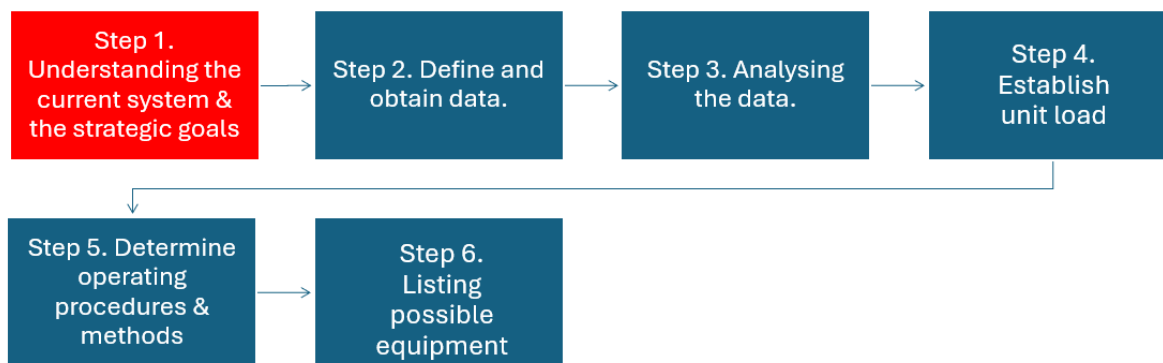


Figure 4.1: Step 1 of the framework, understanding the current system & strategic goals.

Note. Adapted from Baker & Canessa (2009).

DBI supplies customers with construction material in the southwest part of Sweden. From an interview with M. Hansson (personal communication, January 20, 2025), it was stated that they have three warehouses, which are in Derome, Landskrona and Mölndal. In 2024, they decided to close the warehouse in Trollhättan, because of its excessive costs relative to income. Now, the warehouse in Mölndal covers the geographical area Trollhättan previously supported. In 2029, DBI plans to build a new logistics centre to cover Derome's geographical area as well. The logistics centre is planned to be state-of-the-art and suit the context of DBI business by being a node in their new efficient supply chain. The logistics centre is going to function as storage, consolidation area and cross-docking to be able to offer express deliveries (M. Hansson, personal communication, February 6, 2025). Right next to the regional warehouse in Derome (a village with the same name as the company) is where Derome group's main production facility, its sawmill, is located. In the same location as the regional warehouse and the production facility Derome currently has their central warehouse for wooden planks. The production facility and central warehouse will remain after building the logistics centre. However, part of the flow handled by the regional warehouse in Derome is planned to be covered by the logistics centre.

In the warehouse of Mölndal, south of Gothenburg, DBI store a significant part of their construction materials, which are going to be supplied to their customers according to M. Hansson (personal communication, January 20, 2025). Based on a visit to the current warehouse in Mölndal, a blueprint

of the warehouse and an interview with D. Jakobsson (Personal Communication, February 6, 2025), the authors developed an understanding of the current warehouse, illustrated in Figure 4.2. The east building contains planed planks, wooden boards, plaster boards, and insulation materials etc. Outside of the east building there is an open area where the trucks can park to be unloaded or loaded. At the west building there is a drive-in area, where customers can drive their own vehicles into a storage and pick up the construction material that they require. At the drive-in there is also a section for wooden mouldings, which the customer can pick. Next to the drive-in there is a store for hardware and tools.

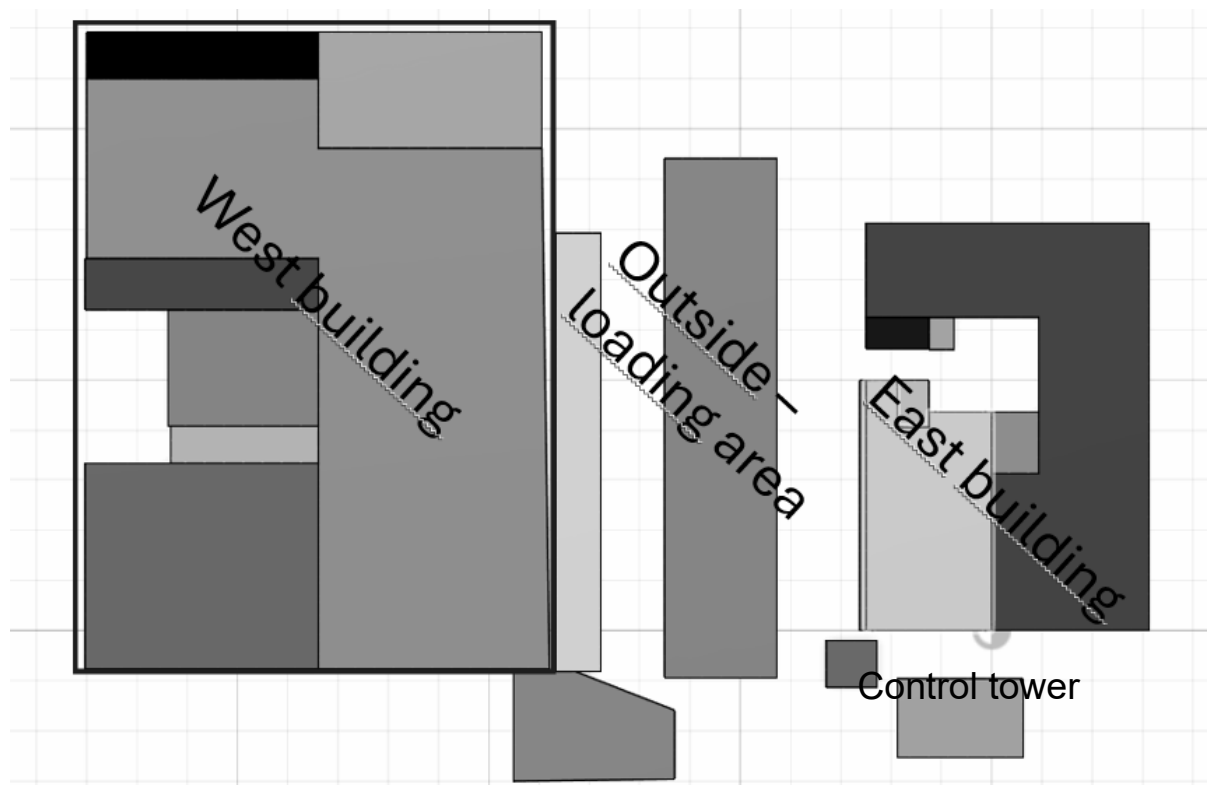


Figure 4.2: An overview of DBI's current logistic center.

Since DBI has one storage space for only internal use and another storage space shared with customers, they are using double the amount of space for many SKUs. This is one of the observed issues, stated in the interview with M. Hansson (personal communication, January 20, 2025), at DBI in the current situation. This also causes an issue within the interaction of customers in the storage area. The customer can accidentally move articles from one storage shelf to another, which results in errors in the inventory. It can also result in issues for the pickers when an order is received. The inventory indicates that there are units left, and the customer that has ordered is promised to get the item delivered when it is not available. This is because other customers may physically pick the units, creating a mismatch in the inventory data and the real-time inventory. Thereby, the shelf can be empty when the picker arrives. The coordinator at DBI will start to search for the missing SKU at another regional warehouse or at a closely located DBI store, which is very time consuming and could have been avoided if customers were not allowed to pick from the same storage inventory.

Next to the east building there is an office area, which is called the control tower and consists of operation manager's offices, and a space for transport leaders and coordinators. The transport leaders plan the routes for the truck drivers, communicate with sellers to fix last minute changes if possible. The coordinators are planning in what order the pickers should prioritise to match the reloading of

the trucks. The coordinators can also plan consolidation of orders. The pickers receive their orders from a computer and print their picking list (transport coordinators at DBI, personal communication, February 3, 2025). Thereafter they walk to the forklift and follow the picking list to drive to the storage location, which is in the picking list for each row, this route is optimised based on the picker's own experience J. Baitson (personal communication, February 11, 2025).

4.1.1 Current picking operations

Since picking is commonly the most resource intensive process in warehousing it was a focus area in this study. The assortment is highly varied at DBI in weight and size, and therefore the picker is required to adapt their methods depending on the SKU to pick, according to J. Baitson (personal communication, 28 March, 2025). Some SKUs are time-consuming to handle, while others are fast and simple. The picking quantity also affects the efficiency because it directly affects the picking time, productivity, and cost.

To further explain the dynamics affecting picking time, a practical example from DBI is provided; planed wooden planks are commonly stored in cantilever racks with four levels. Open packages used for partial picking are typically placed on level one and two, while full, unopened packages are stored on level three and four. In one common figuration, level two holds an open package of one SKU, while level four stores a full package of the same SKU. These full packages measure approximately one meter in both width and height, and the picking process depends on whether a full package or only a limited quantity is required. If the required amount exceeds one full package, the picker can use a forklift to retrieve a complete package from the storage area and move it directly to the loading zone. If the order requires a smaller quantity, the picker will instead move the package to a lower shelf, if no open package is already available, and open it manually. The desired number of planks is then picked by hand and placed on the forklift. After picking, the picker drives to the packaging area, where the wooden planks are manually wrapped using plastic film and secured with straps. The packaged goods are then transported to the consolidation area. All the heavy and/or large sized items, such as wooden boards, gypsum boards and thin steel profiles are made in a comparable way, and the process flow is illustrated in Figure 4.2.

Other types of goods are picked manually from pallets, such as cement bags. Most of the cement bags are made of paper and weigh 20 kg each. While they are most often carried by hand from the storage area to the loading zone, they can also be placed on pallets and transported by forklift. Hardware and tools are picked by a separate team located in the store area. This team works with a dedicated picking list and collects items either from in-store shelves or nearby storage. The picked items are then packed and transferred to a designated zone, where the main warehouse pickers retrieve and consolidate them with the rest of the order at the loading area. Reinforcement mesh is particularly time-consuming to handle because of their size and weight. Upon arrival, it is offloaded from the delivery truck and placed in a designated storage area. From there, it is picked and loaded directly onto the outgoing truck for delivery.

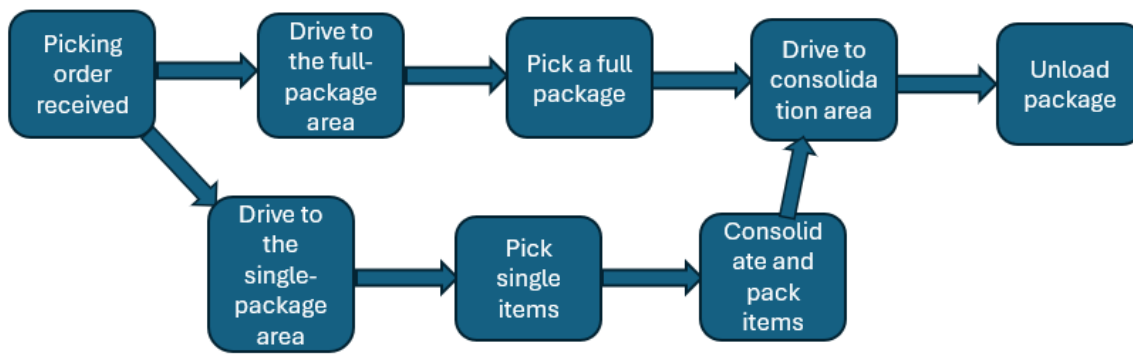


Figure 4.3: Schematic view of the picking process at DBI.

From an interview with DBI’s controller, J. Lindblom (personal communication, January 31, 2025), it was stated that DBI monitors various KPIs, one of them is *number of picked order lines per hour*. However, this metric can be misleading, because of the high variation in item types. Larger and heavier items are more time consuming to handle compared to smaller ones. This KPI can be compared across different warehouses. For example, in 2024, the *number of picked order lines per hour* in Mölndal was 34% lower than in Derome. The main reason is that Mölndal typically handles lower order quantities. This becomes even more clear when studying picked volume per worker, which was 17% higher in Mölndal compared to Derome. Additionally, the average quantity per order line is higher in Derome than in Mölndal.

These differences highlight the requirement for a more nuanced picking performance measurement at DBI. A classification based on material type would improve the accuracy of performance comparisons and better reflect the nature of the work. For instance, picking single wooden planks or flat steel bars should not be evaluated in the same way as picking small screw packages. To measure this, the RFID-technique would be highly supportive. This is also the case within packaging and loading.

4.1.2 DBIs current assortment

Rathore et al. (2022) found that a barrier for implementing automation is that standardised automated solutions cannot handle a varying assortment due to technical constraints. Thus, for being able to implement automation, several automated solutions need to be used, adapted to different parts of the assortment. Baker & Canessa (2009) emphasises analysing the characteristics of products to be handled by the warehouse. For this reason, to further explore the context for answering the research question, DBIs assortment was studied.

The planned logistics center will cover the same area as DBIs current regional warehouses in Mölndal, Derome and Trollhättan while Landskrona is outside the geographical scope. The new logistics center will not have the same assortment as the regional warehouses but mostly it will have the same functions as the current regional warehouses. The Mölndal regional warehouse currently has over 7000 SKUs in its assortment.

Baker & Canessa (2009) suggests analysing historical spreadsheet data about products, dispatch, order profiles etc as illustrated in Figure 4.3. This is analysed in depth in chapter 4.2, but Table 4.1

and Table 4.2 provides an overview.

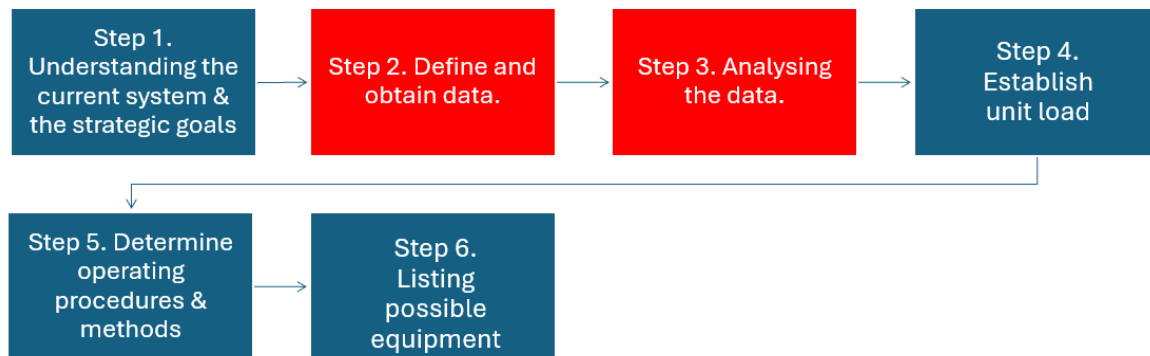


Figure 4.4: Step 2 from the framework; define, obtain and analyse the data.
Note. Adapted from Baker & Canessa (2009).

DBI has organized each SKU in an assortment category. Every assortment category is further categorised in subcategories. These are further categorised in product categories and finally individual SKUs which is the most detailed level. The analysis follows the framework presented in Figure 4.5. Table 4.1 provides an example overview of DBI's assortment categorization, and Table 4.2 presents examples from DBI's popular SKUs.

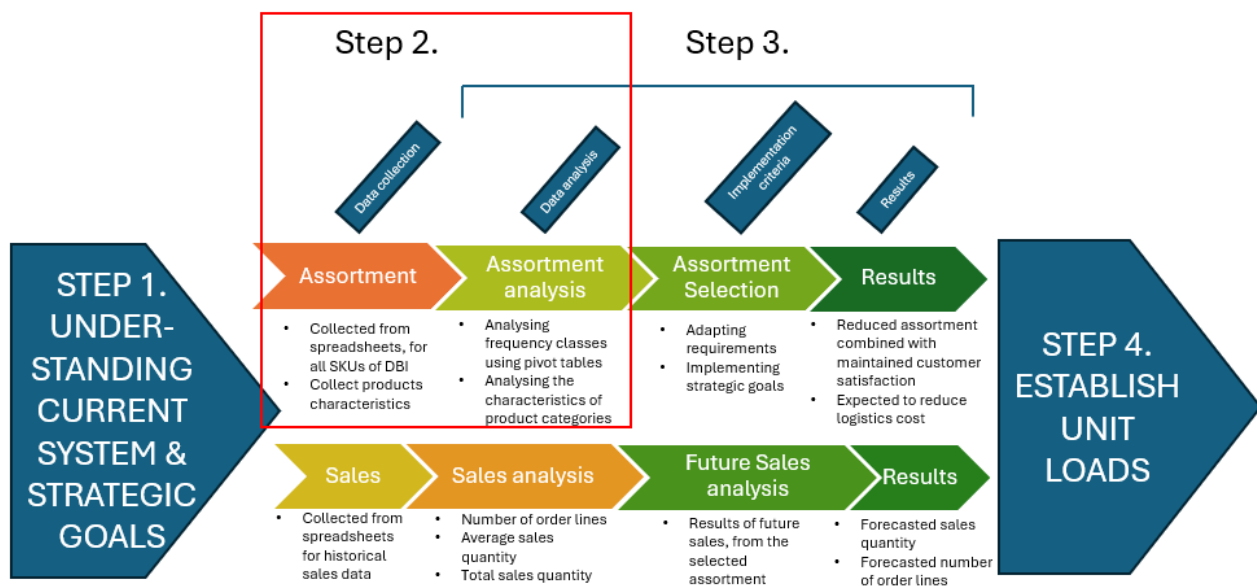
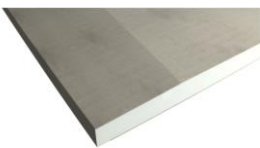


Figure 4.5: Obtaining and analysing the data from the assortment.

Table 4.1: DBIs assortment categories with respective most sold sub categories. IND (industry products) is excluded because the sales quantity of IND products is negligible.

Assortment category	Most sold sub categories
BM (Building materials)	-Sheet materials -Roofing and wall material -Mortar -Rebar and steel -Insulation
JV (Hardware and tools)	-Screws -Chemicals -Cleaning products
SN (Carpentry materials)	-Kitchen interior -Tree interior -Doors
TR (Wooden planks)	-Planed spruce planks -Planed pine planks -Wooden goods

Table 4.2: The table shows examples of DBIs categorization of popular SKUs

Category/Sub category	Product group	Figure
BM - Sheet material	Plasterboards	
BM - Roofing and wall materials	Concrete roof tiles	
BM - Mortar	Dry mortar	

Category/Sub category	Product group	Figure
BM - Rebar and steel	Thin steel profiles	
BM - Insulation	Mineral wool	
JV - Screws	Screws	
JV - Chemicals	Sealant	
SN - Kitchen interior	Kitchen carpentry	
SN - Wooden interior	Wooden moulding	

Category/Sub category	Product group	Figure
SN - Doors	Miscellaneous doors	
TR - Plane spruce	Plane spruce (Construction timber, lath, exterior cladding)	

4.2 Sales Quantity

Continuing with the approach for obtaining and analysing the data in the warehouse design by Baker and Canessa (2009) the next step, shown in Figure 4.5, was to define future sales quantity requirements, by analysing historical sales quantities.

4.2.1 Assortment selection

Before calculating the future sales requirements, it was necessary to select the assortment to include in the logistics centre. This step is not defined by Baker & Canessa (2009); however, it was necessary in this case and is illustrated in Figure 4.7

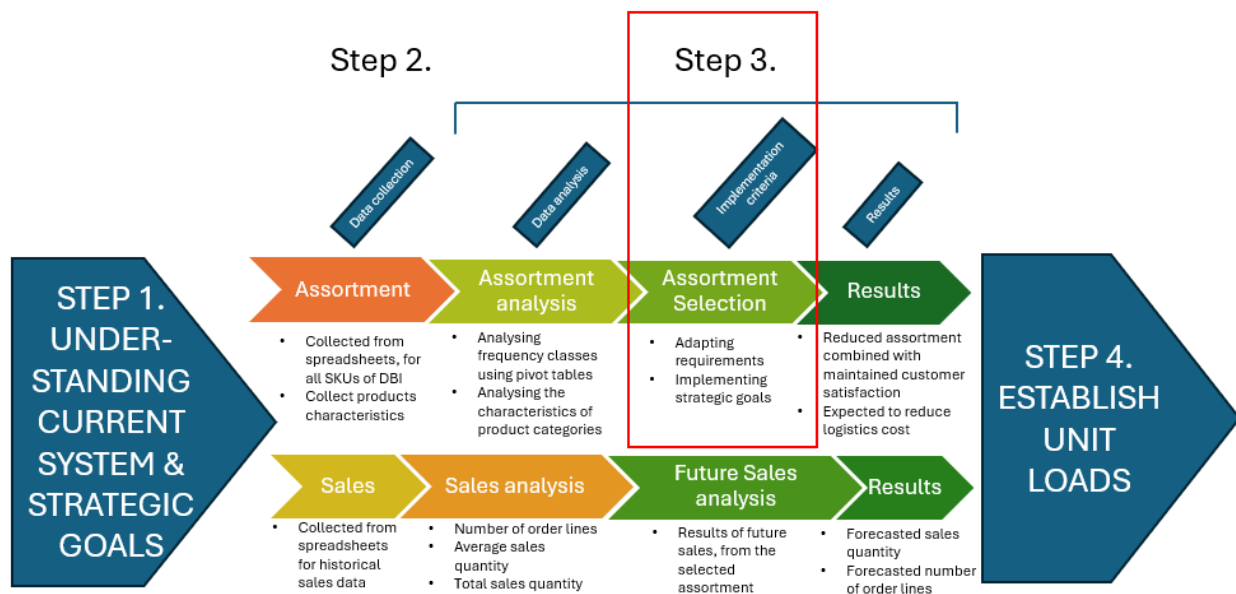


Figure 4.6: Understanding the criteria to select the assortment.

If the whole assortment would be included in the logistics centre, the size of the logistics centre would increase, and it would negatively the operational efficiency. Therefore, not all the SKUs will be included in the planned logistic centre.

Deciding the number of SKUs to include was conducted by analysing historical sales data from the Mölndal regional warehouse for February 2024 to February 2025. In the analysed spreadsheet each SKU was assigned to a frequency class, fast mover, medium mover, slow mover, and very slow mover according to DBIs definition as defined in Table 4.3. Each SKU was also assigned to an assortment category explained in Chapter 4.1.3.

A simplified approach for assortment selection would have been to for cut-off all very slow movers. While this would have been simpler, it fails to manage the complexity of DBIs assortment. For example, JV SKUs can efficiently be transported from DBIs central warehouse to the logistics centre, while other assortment categories are larger and bulkier which justifies including them in the logistics centre assortment. The more detailed analysis in this study ensures an assortment selection which considers DBIs operational dynamics and allow for better performance compared to choosing SKUs purely based on DBIs frequency class.

By using a pivot table, it was possible to extract how many SKUs belong to each assortment category and frequency class. The data also included the number of order lines and the total sales quantity for each SKU. Frequency-category pairs were assigned which is presented in Table 4.3.

Table 4.3: DBIs frequency classes.

Frequency class	Order lines per year
Very slow movers	0-2
Slow movers	3-11
Medium movers	12-51
Fast movers	52+

When selecting the assortment, each assortment category and frequency class pair was evaluated. The main criteria for selecting the assortment were that if the category-frequency pair was historically included in less than 1 % of order lines or total sold quantity, it was removed from the assortment, as it was negligible.

There is also an exception to the assortment selection when choosing the JV (Hardware and tools) assortment. The plan is to supply the JV SKUs from DBIs central warehouse for JV SKUs in Landskrona according to M. Hansson (personal communication, January 31, 2025). Truck deliveries will arrive from Landskrona to the logistics centre every night which indicates that DBI can fulfil their customer promise of delivering the next day without storing the JV articles in the logistics centre. The only purpose of including JV SKUs in the logistics centre is for being able to fulfil express orders, which is defined as delivering the same day as the customer places and order. For this purpose, JV Fast Mover SKUs were included in the assortment. JV medium, slow, and very slow movers were all excluded even if these category-frequency pairs were all above 1 % of total order lines and sold quantity. The reason for this is that DBI can effectively distribute these from their central warehouse which partly eliminates the requirement for including them in the logistics centre assortment. JV SKUs are much smaller in size than other parts of SKU's assortment, and for this reason a centralised distribution strategy is used by DBI for these products since it is more effective. This is in contrast with the rest of DBIs assortment, which is characterised by large and heavy products with short lead times. A highly centralised approach is ineffective for these product characteristics caused by higher cost per distance for each shipped SKU. A centralised approach can decrease total warehousing cost however also increase the distance the SKUs must be shipped. For smaller SKUs which have a lower cost per distance for each shipped SKU, centralisation leads to lower total cost, while for larger SKUs where shipping prices per unit is higher, a more decentralized approach is preferred.

This way of choosing the assortment was decided based on data analysis and discussions with M. Hansson (personal communication, March 5, 2025). The fast mover IND (Industry materials) and fast mover - (unassigned) products are also included in the assortment even though these category-frequency pairs represent very low sales volumes. The reason for including them is that they are expected by customers and required for a complete product offering. This makes these strategically important assortment categories for DBI, and they are thus included.

The result of this assortment selection is that the number of SKUs are reduced from 7573 to 2181 while still covering 99.3 % order lines when analysing the historical data from the Mölndal regional warehouse.

The included category-frequency pairs and assortment selection is presented in Table 4.4.

Table 4.4: The table shows what categories and frequency classes of DBIs existing assortment which will be included in the planned logistics center. X means that it is included and - means that it is excluded.

Assortment Category and Frequency Class	Fast Mover	Medium Mover	Slow Mover	Very Slow Mover
BM (Building materials)	X	X	X	-
JV (Hardware and tools)	X	-	-	-
TR (Wooden planks)	X	X	X	-
SN (Carpentry Materials)	X	X	X	-
IND (Industry Materials)	X	-	-	-
- (Unassigned)	X	-	-	-

The chosen assortment, defined in Table 4.4 as the result from the data analysis of the assortment, together with JV SKUs shipped from the Landskrona central warehouse can cover 99.3 % of DBIs order lines and 99.7 % delivered quantity fulfilling the customer promise of delivering the next day. This number could be even higher assuming SKUs which are not stored in the logistics centre can be delivered the next day through a different method of distribution.

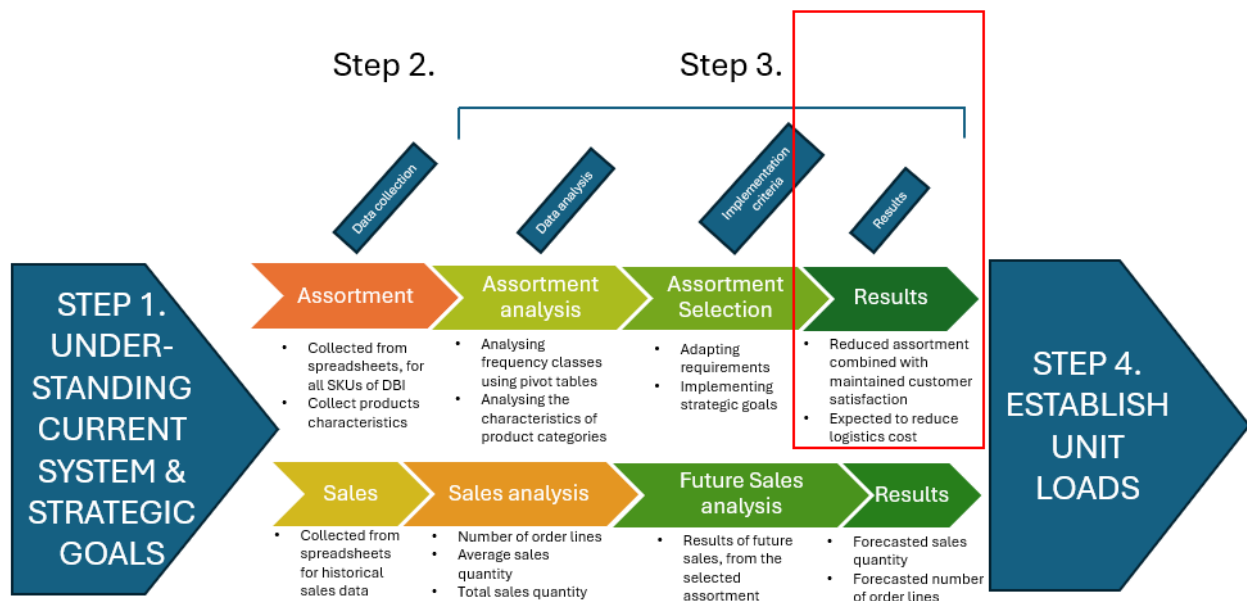


Figure 4.7: The result of the assortment analysis.

This choice of assortment can also cover 74 % of express orders measured in complete order lines and 96.6 % express orders measured in covered order quantity, as defined in Table 4.5. Express orders are defined as delivering the same day as customers place an order which is only possible if the SKU is included in the logistics centre assortment. This is not a calculation of the expected service level but only how many customer orders are covered by the proposed assortment selection logistics. This is also based only on historical data without forecasting; therefore, the number might also be lower when considering that the customer demand for different SKUs changes over time.

Table 4.5: The table shows how the assortment selection in table 4.4 affects how many orders can be covered based on historical data.

Parameter	Before	After (% covered by new assortment + % available through different means of distribution)
Number of SKUs	7573	2181
Covered order lines	100 %	99.3 % + 0.7 %
Covered order quantity	100 %	99.7 % + 0.3 %
Covered express order lines	100 %	74 % + 36 %
Covered express order quantity	100 %	99.6 % + 0.4%
Customer satisfaction	Baseline	Maintained
Cost-efficiency	Baseline	Improved
Productivity	Baseline	Improved

While the proposed assortment for the planned logistics centre cannot cover all orders compared to the current assortment, it is expected to improve productivity and cost efficiency by reducing complexity through decreasing the number of SKUs. The SKUs which are missing in the planned logistics centre can still be delivered through a different means of distribution, for example through shipping from the central warehouse and being consolidated at the logistics centre, to fulfil the customer promise. It can also be shipped directly from supplier to customer, or from central warehouse to customer. For these reasons, the proposed assortment selection is not expected to maintain customer satisfaction and reduce the logistics cost through prioritizing efficient handling of the high-runner SKUs. The productivity and cost-efficiency for handling the SKUs not included in the assortment might be reduced, however since these only make up a minor part of the throughput, the total productivity and cost efficiency is expected to increase, while reducing cost expected through a more intelligent use of resources.

The findings indicate that the same assortment is available in the area covered by DBIs regional warehouses in Derome, Mölndal and Trollhättan. The findings also indicate that the Landskrona regional warehouse has a partly different assortment, however this is not part of DBIs product range for the geographical area the new logistics centre is planned to cover.

When the assortment category and frequency class pairs had been established the next step was to calculate how many SKUs are included in these pairs in the geographical area to be covered by the planned logistics centre. This was analysed by studying historical data for the Derome and Mölndal

regional warehouses. Trollhättan warehouse was not included in this analysis because it was closed in 2024 which indicates that the frequency class data is misleading

Table 4.6 presents the final assortment selection based on how many SKUs belong to the category-frequency pairs defined in Table 4.4 when studying historical sales data from Mölndal and Derome. It can be concluded that SKUs belonging to the IND and - assortment categories represent a negligible part of the assortment in terms of number of SKUs and for this reason these are not included in future analysis

Table 4.6: The table shows the number of SKUs which are planned to be included in the logistics centre.

Assortment category	Number of SKUs	Percentage of Assortment
BM (Building materials)	865	36.3 %
JV (Hardware and tools)	152	6.4 %
TR (Wooden planks)	507	26.8%
SN (Carpentry materials)	854	21.2 %
IND (Industry materials)	1	0 %
- (Unassigned)	2	0 %
Total	2381	100 %

4.2.2 Baseline Sales Quantity and Number of Order Lines 2024

Continuing with the approach for obtaining and analysing the data in the warehouse design by Baker and Canessa (2009) the next step, presented in Figure 4.8, was to define future sales quantity requirements, by first analysing historical sales quantities.

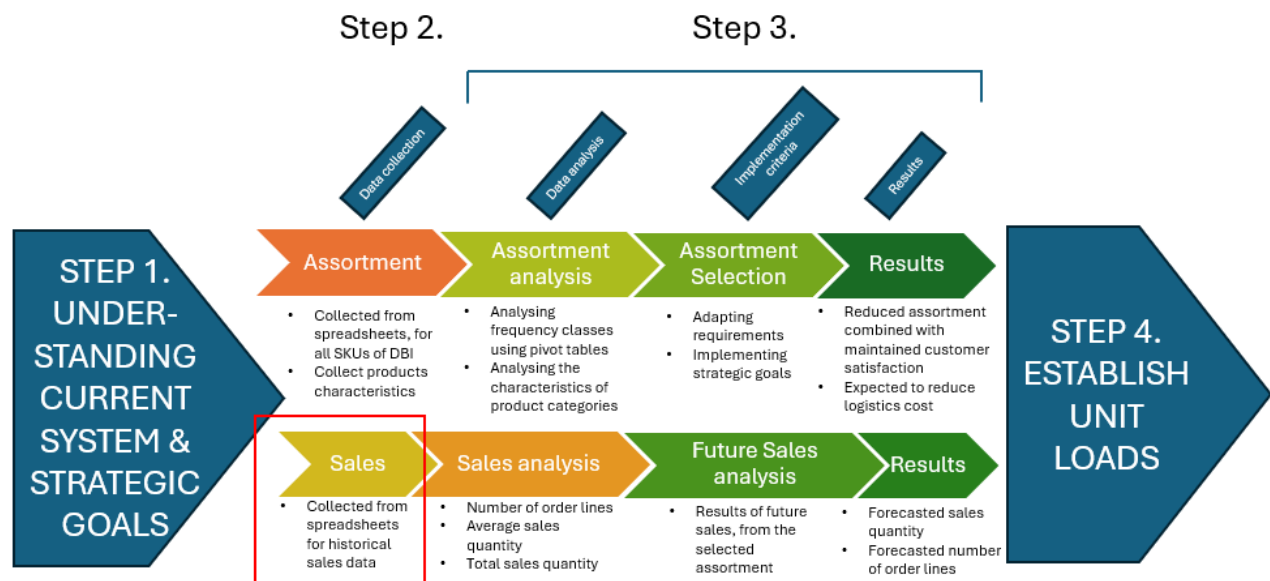


Figure 4.8: Obtain sales data.

After the assortment had been defined, the next step was to calculate the total sales quantity. The historical data was analysed to extract the relevant data based on the selected assortment and geographical scope. The first step, presented in Figure 4.9, of calculating the expected sales quantity expected for 2029, was to calculate the historical total sales quantity during 2024. The sales quantity for 2024 is defined as the total number of sold goods during 2024. For example, this includes the total number of individuals sold planks. This contrasts with the number of order lines, where one order line typically contains multiple sold planks.

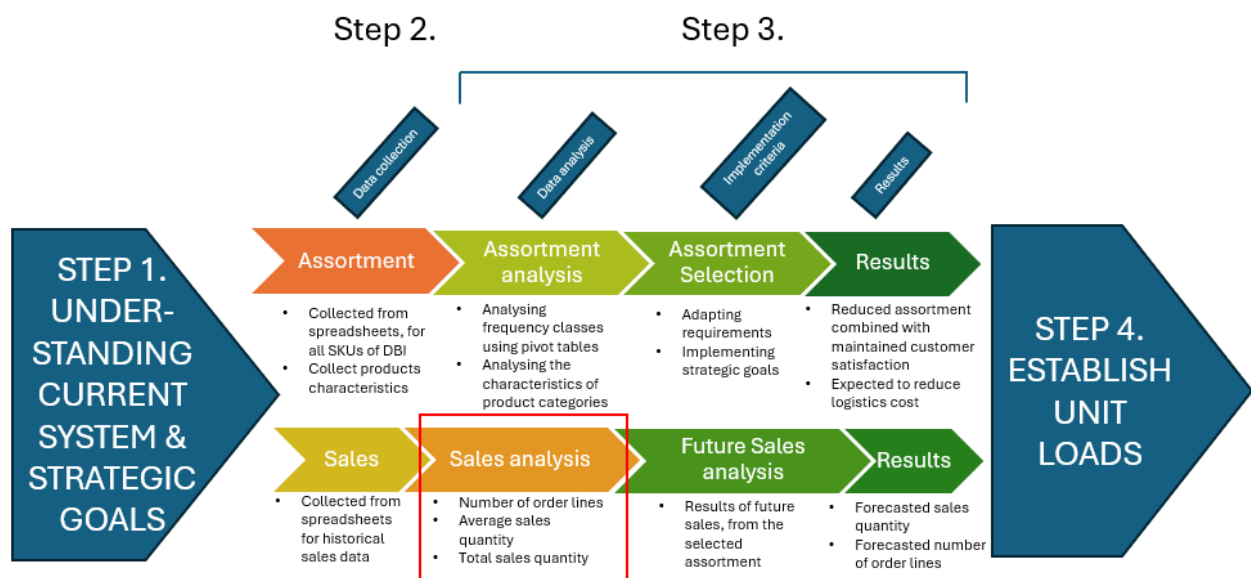


Figure 4.9: The first step of the data analysis of the sales.

In the literature for warehouse design by Baker and Canessa (2009) it is suggested to calculate the number of unit loads the warehouse will handle. In the case of DBI however, palletised goods only make up around 5 % of the total sold goods. Different goods must be handled differently and for this reason the goods flow was separated into distinct categories based on historical sales data and DBI's current categorisation system. Building on the argument that automated technology is limited in its flexibility to handle large assortment (Rathore et al., 2022), it was necessary to study the historical sales quantity for distinct categories to be able to answer the research questions.

When calculating the sales quantity, the first step was to analyse the sales data for 2024 for the warehouses in Derome, Mölndal and Trollhättan and calculate the sum of their sales quantity. This analysis was conducted by analysing the historical sales data using pivot tables to extract the sales quantity data. Using pivot tables the category-frequency pairs defined in Table 4.4 could be separated from the rest of the data. The sales quantity and order lines extracted for all the relevant category-frequency pairs for the three relevant warehouses could then be calculated.

In the raw excel data, however, the material flow from DBI's central warehouse for wooden planks is included in the sales data. Including this data would not represent the flow to be handled by the logistics centre since the central warehouse will remain in Derome. Thus, part of the raw Excel data from the Derome regional warehouse does not represent sales to external customers, but rather internal sales to DBI's regional warehouses in Mölndal, Trollhättan and Landskrona. For this reason, the data was adjusted for it to serve as a baseline for 2024 for the materials to be supplied by the logistics centre. According to R. Sandersson (personal communication, 12 March, 2025) 20 % of the

TR (wooden planks) sales quantity represent internal sales. Thus, 20 % of the wooden planks' sales quantity from the Derome regional warehouse was subtracted when calculating the baseline sales quantity for 2024.

The raw excel data from the Derome regional warehouse also include sales to Derome groups daughter companies A-hus and Varbergshus, with around 25 % of their TR (wooden planks) sales quantity according to R. Sandersson (personal communication, 12 March, 2025). This material flow also does not represent the material flow of the planned logistics centre and was thus subtracted when calculating the baseline sales quantity for 2024. For this reason, 45 % of the Derome regional warehouse raw sales data of TR SKUs is not relevant when calculating the 2024 baseline quantity. The reason is that the planned logistics centre is not planned to supply A-hus, Varbergshus or be a central warehouse for TR products for Derome group. The sales quantity and number of order lines of TR SKUs in the raw excel data supplied by Derome regional warehouse was thus multiplied by 0.55 when calculating the baseline for 2024. The result of the calculations is presented in Table 4.7.

Table 4.7: The table shows the historical sales quantity for 2024 for the warehouses Derome, Trollhättan and Mölndal.

Warehouse	Total Sales Quantity 2024
Derome	6 430 846
Trollhättan	4 076 458
Mölndal	3 966 883
Total	14 474 187

The total sales quantity and number of order lines 2024 for each assortment category was calculated in the same way as described earlier. First a pivot table was used to extract the relevant category-frequency pairs. Then, 45 % of the Derome regional warehouse TR material flow was subtracted. After this, the number of sales and number of order lines from the Trollhättan, Mölndal and Derome regional warehouses were all added together, and the resulting sum is presented in Table 4.8.

Table 4.8: The table shows historical data for the DBIs regional warehouses in Mölndal, Derome and Trollhättan combined. This data only considers the assortment selection described in Table 4.4.

Category	Total Sales Quantity 2024	Number of Order Lines 2024
BM	4 899 054	204 048
JV	192 366	45 837
SN	429 541	54 688
TR	8 953 388	86 401
Total	14 474 187	390 974

4.2.3 Sales Quantity and Number of Order Lines 2029

After the baseline data for 2024 had been established, the next step was to calculate the expected data for 2029, as can be followed from the detailed framework of the data analysis in Figure 4.10. It has been stated by DBI that a 50 % increase in sales volume is expected in the year of 2029

compared to 2024 according to M. Hansson (personal communication, January 31, 2025). Consequently, the Sales Quantity and Number of Order Lines for 2029 is calculated by multiplying the baseline data by 1.5. In addition to this, the relative sales quantity and number of order lines was calculated by dividing the respective data with the total numbers to find the percentages. The result is presented in Table 4.9.

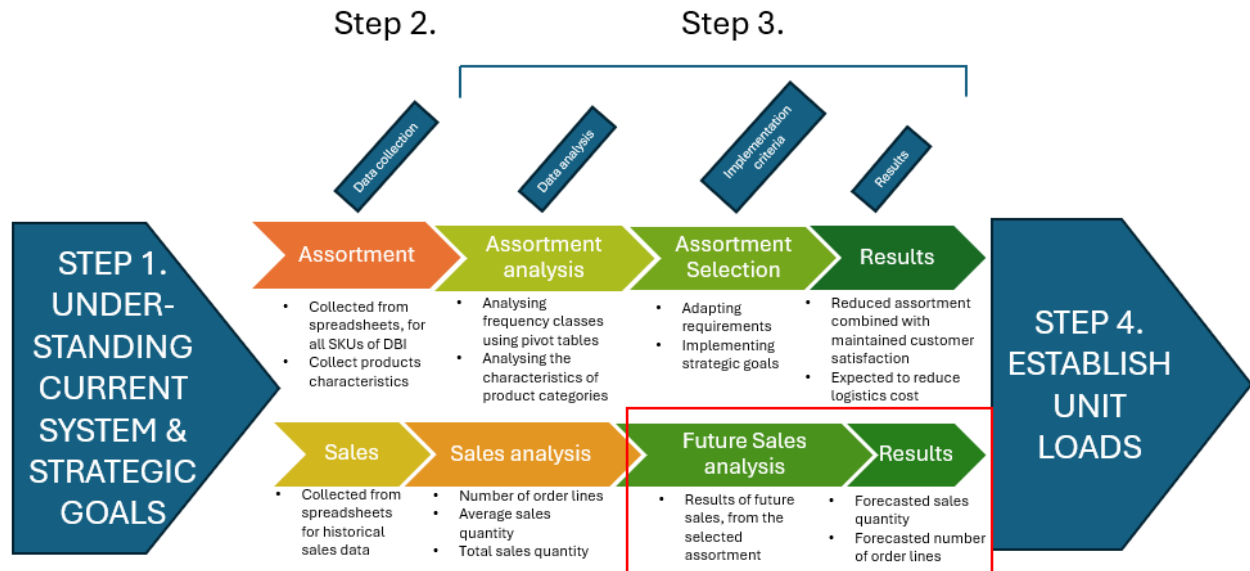


Figure 4.10: The framework shows the steps of future sales analysis.

Table 4.9: shows the forecast for 2029 based on the historical data.

Category	Sales Quantity 2029	% of Total Sales Quantity	Number of Order Lines 2029	% of Number of Order Lines
BM	7 348 581	33.8%	306 072	52.2 %
JV	288 549	1.3%	68 756	11.7 %
SN	644 312	3.0 %	82 032	14.0 %
TR	13 430 082	61.9 %	129 602	22.1 %
Total	21 711 524	100 %	586 462	100 %

4.2.4 Sub-category sales analysis

To facilitate matching with suitable technology, the assortment was divided in categories which have similar technical characteristics. This is presented as the fourth step of the framework adapted from Baker & Canessa (2009) and presented in Figure 4.11. Automation of goods in standardised unit loads, like cardboard boxes or pallets have been previously researched however for the construction material industry there is not much research on warehouse automation. To analyse what part of the SKUs are possible to automate, it was necessary to study the SKUs in such a level of detail that a standardised automation solution could be used to handle it. This was also necessary to assess what technology could be used for automating it. For this reason, the subcategories, product categories, and the SKUs belonging to these categories were analysed. To be able to prioritise what part of the

flow to automate the relative number of order lines and relative sales quantity were included to judge potential impact from automation since it was not feasible to investigate every category of SKUs.

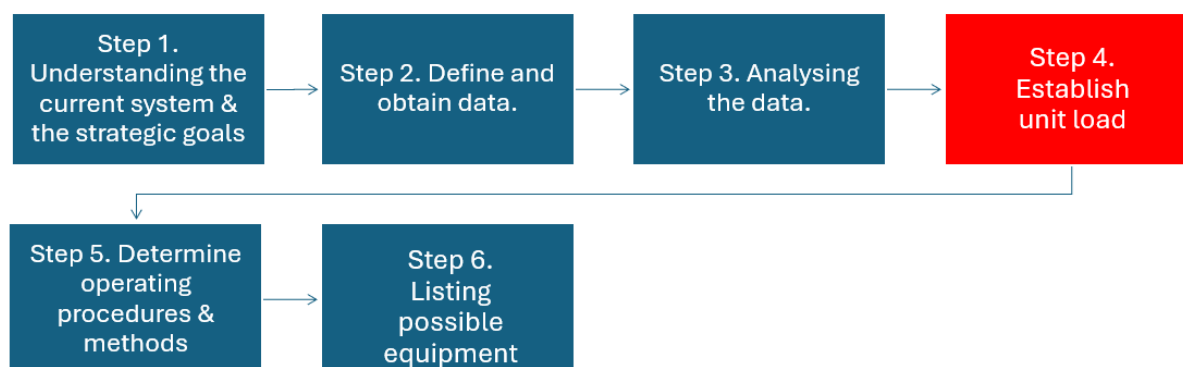


Figure 4.11: The fourth step, to establish unit loads.
Note. Adapted from Baker & Canessa (2009).

Excel analysis using pivot tables and sorting the data based on historical sales quantity in Mölndal was used to understand which subcategories of SKUs most are sold for each assortment category. The analysis is presented in Table 4.10. The percentages are calculated in relation to the sales over all included categories. It should be noted that the analysis is only based on data from the regional warehouse in Mölndal and that if Trollhättan and Derome were included the result might be different. The sales quantity data is based on 1 year of data while the number of order lines data is based on data for 3 months. The result might be different if data for one year would be used for the number of sales because of seasonal demand and other reasons. For confidentiality, the percentages are presented in intervals defined as very low (0-1%), low (1-5%), medium (5-10 %), high (10-30 %) and very high (above 30 %).

By studying Table 4.11 it can be concluded that planed planks make up a high percentage of the total sold quantity and the total number of order lines. This subcategory is also assumed to be homogenous enough to be handled by a standardised automation solution, however this assumption will be further analysed in chapter 4.4.2. The other subcategory which stands out as attractive for automation is sheet materials, for its relatively high sales quantity and number of order lines, as well is its assumed homogeneity which will be further analysed in chapter 4.4.1 Other subcategories which will be investigated for possibility of automation is roofing and wall materials, rebar and steel, screws, kitchen interior and wooden interior, since these are highest on the list if sorting either by sales quantity or number of order lines.

Table 4.10: The table shows the five greatest sub-categories sorted by sales quantity.

Assortment category	Subcategory	% of Total Sales Quantity	% of Total Order Lines
TR	Planed spruce planks	Very High	High
TR	Planed pine planks	High	Low
BM	Sheet materials	Medium	High
BM	Roofing and wall material	Medium	Very Low
BM	Rebar and steel	Low	Medium
	Total	73.9 %	31.7 %

Table 4.11: The table shows the five greatest sub-categories sorted by number of sales.

Assortment category	Subcategory	% of Total Sales Quantity	% of Total Order Lines
TR	Planed spruce planks	Very High	High
BM	Sheet materials	Medium	High
JV	Screws	Very Low	Medium
SN	Kitchen interior	Low	Medium
SN	Wooden interior details	Low	Medium
	Total	63.0 %	45.7 %

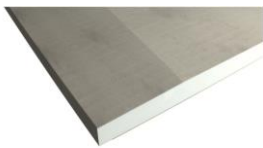
To better understand the product characteristics handled by DBI, a more detailed analysis is shown in Table 4.12. This table shows the relative sales quantity and number of order lines based on historical data from DBI.

For the analysis, it is assumed that the relative sales quantity and number of order lines will stay the same until 2029. Based on the name of the products a first judgement can be made if the product category is standardised enough to be possible to automate. However, judging by the name is not assumed to be very accurate for automation assessment. Therefore, in Table 4.13, pictures are also included for the most sold SKU in each product group.

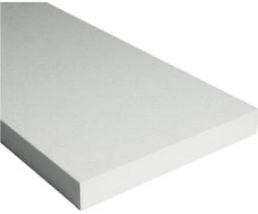
Table 4.12: The table includes the most sold sub-categories for each assortment category, sorted from highest sold quantity. It also includes the most sold product category for each sub-category.

Assortment category	Subcategory	Most sold product categories (% of total sales quantity, % of total order lines)
BM (Building materials)	Sheet materials	- Gypsum boards (Low, Low) - Construction plywood (Low, Low) - OSB boards (Very Low, Very Low) - Particle boards (Very Low, Very Low)
BM (Building materials)	Roofing and wall material	- Concrete roof tiles (Medium, Very Low) - Ceramic roof tiles (Low, Very Low)
BM (Building materials)	Mortar	- Dry mortar (Low, Low) - Self levelling compound (Low, Low)
BM (Building materials)	Rebar and steel	- Thin steel profiles (Low, Low) - Metal formwork (Low, Very Low) - Rebar (Very Low, Very Low) - Reinforcement mesh (Very Low, Very Low)
BM (Building materials)	Insulation	- Mineral wool (Low, Low) - Expanded polystyrene (Very Low, Very Low)
JV (Hardware and tools)	Screws	- Tree screw for exterior use (Very Low, Low) - Plasterboard screw (Very Low, Low)
JV (Hardware and tools)	Chemicals	- Sealant (Very Low, Low) - Adhesive (Very Low, Low)
JV (Hardware and tools)	Cleaning products	- Cleaning tools (Very Low, Low) - Cleaning chemicals (Very Low, Very Low)
SN (Carpentry materials)	Kitchen interior	- Kitchen carpentry (Low, Medium) - Kitchen worktop (Very Low, Very Low)
SN (Carpentry materials)	Wooden interior	- Wooden moulding (Low, Medium) - Planed wood (Very Low, Very Low)
SN (Carpentry materials)	Doors	- Miscellaneous doors (Very Low, Low)
TR (Wooden planks)	Planed spruce	- Construction timber (High, Medium) - Dimension planed (High, Low) - Exterior cladding (Medium, Low) - Lath (Medium, Very Low) - Tongue and Groove (Low, Very Low) - Formwork timber (Very Low, Very Low)
TR (Wooden planks)	Planed pine	- Deck boards (Medium, Very Low) - Construction timber (Low, Very Low) - Dimension planed (Low, Very Low) - Lath (Low, Very Low)

Table 4.13: The table includes the most sold product groups for every sub-category at DBI and the sales quantity and number of sales for these product categories. It also shows what sub-category and assortment category these product groups belong to.

Category/Subcategory	Product category	Figure	% of total sales quantity	% of total order lines
BM - Sheet material	Plasterboards		Medium	Medium
BM - Sheet material	Plywood		Low	Low
BM - Sheet material	OSB-boards		Very Low	Very Low
BM - Sheet material	Particle boards		Very Low	Very Low
BM - Roofing and wall materials	Concrete roof tiles		Medium	Very Low
BM - Roofing and wall materials	Ceramic roof tiles		Low	Very Low

Category/Subcategory	Product category	Figure	% of total sales quantity	% of total order lines
BM - Mortar	Dry mortar		Low	Low
BM - Mortar	Self-levelling compound		Very Low	Very Low
BM - Rebar and steel	Thin steel profiles		Low	Low
BM - Rebar and steel	Metal formwork		Low	Very Low
BM - Rebar and steel	Rebar		Very Low	Very Low
BM - Rebar and steel	Reinforcement mesh		Very Low	Very Low

Category/Subcategory	Product category	Figure	% of total sales quantity	% of total order lines
BM - Insulation	Mineral wool		Low	Low
BM - Insulation	Expanded polystyrene		Very Low	Very Low
JV - Screws	Screws		Very Low	Low
JV - Chemicals	Sealant		Very Low	Low
JV - Chemicals	Adhesive		Very Low	Low
JV - Cleaning products	Cleaning tools		Very Low	Low

Category/Subcategory	Product category	Figure	% of total sales quantity	% of total order lines
JV - Cleaning products	Cleaning chemicals		Very Low	Very Low
SN - Kitchen interior	Kitchen carpentry		Low	Medium
SN - Kitchen interior	Kitchen worktop		Very Low	Very Low
SN - Wooden interior	Wooden moulding		Low	Medium
SN - Wooden interior	Planed wood		Very Low	Very Low

Category/Subcategory	Product category	Figure	% of total sales quantity	% of total order lines
SN - Doors	Miscellaneous doors		Very Low	Low
TR - Plane spruce	Plane spruce (Construction timber, lath, exterior cladding)		Very High	High
TR - Plane pine	Plane pine (Construction timber, lath, deck boards)		High	Low
TR - Plane spruce	Tongue and groove		Low	Very Low

By analysing Table 4.14 it was possible to develop a better understanding of the physical characteristics of the products, relative sales quantity and number of order lines for the product categories in Table 4.13

4.3 Automation Assessment

The findings from the previous chapter provide data for assessing which categories are most suitable for automation, focusing on sales volumes. This chapter builds on the data in the previous chapter by analysing the technical feasibility and potential performance improvement for the various product categories. This is made as step 5, in the method based on the framework adapted from Baker & Canessa (2009) and is presented in Figure 4.12.

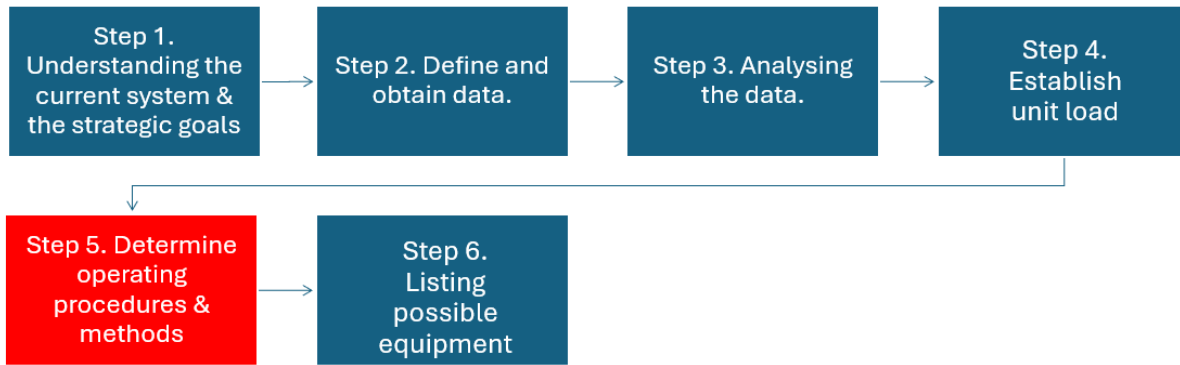


Figure 4.12: The fifth step of the method, determining operating procedures and methods.

Note. Based on the framework adapted from Baker & Canessa (2009).

Based on the data in this stage of the study, wooden planks are by far the category where the greatest performance increase can be expected. The reason for this conclusion is the high sales quantity of wooden planks in comparison to other product categories, in combination with its assumed homogeneity. Automated technologies are often limited in their versatility and works best on products with a standardised format. For this reason, the high homogeneity of wooden planks, judging by the pictures, leads to the conclusion that it is possible to automate. In addition to this, the high relative sales quantity leads to the preliminary conclusion that the category with the highest potential for performance improvements is wooden planks, since an improvement in this area creates high leverage for total performance improvements. Hardy & Brougham (2022) argues that benefits from automation commonly include increased productivity, cost savings, reduced and resilience, assuming the risks and barriers are overcome. Building on this argument, if the barriers for automated handling of wooden planks are overcome, technical constraints included, improved productivity, cost savings, reduced errors and improved resilience is expected.

By using the same reasoning, it was possible to develop the preliminary conclusion that automation of sheet materials, thin steel profiles, roofing and wall materials, wooden interior details and kitchen interior are other good candidates for automation. This is also based on judging by their homogeneity of product group, and their high relative sales quantity, following the same reasoning as for wooden planks. Other product categories could also bring benefits yet are assumed to bring less benefits compared to other categories, following the same reasoning.

As outlined in Chapter 2.1, Industry 4.0 technologies such as robotics and IoT offer significant opportunities for improving logistics operations. Wang et al. (2016) suggests that incorporating robotics and IoT in materials management will likely improve efficiency, reduce errors, increase productivity, and improve financial outcome. Hardy & Brougham (2022) suggest that automation can bring improved productivity, cost savings, reduced errors, and improved resilience, if barriers are overcome. One of these barriers include the technical barrier. The transition from manual to automated solutions at Derome Group's production facility has, according to P. Andersson (personal communication, April 7, 2025), resulted in increased productivity by 30% with a maintained workforce. Building on these findings, the logical consequence is that automation may bring performance improvements to DBI.

When assessing the potential impact of the automation the total sales quantity and number of order lines was for this reason as previously explained a crucial criterion, the other criteria was to analyse the likely performance outcome compared to the current state, considering the dimensions productivity, quality, cycle time and ergonomic.

When assessing the feasibility, the focus was on the technical feasibility through assessing if there are existing solutions on the market that can solve the problem and if the subcategory is homogenous enough to be handled by a standardised automatic solution Secondly, the financial feasibility was analysed. A high sales quantity was assumed to be positive through economies of scale and higher RoI. A high technical feasibility was also assumed to improve the financial feasibility.

The implementation of automation in DBI's future logistics centre may be a viable way to handle increased volumes, improve the working environment and to increase the efficiency in picking, internal transport, and loading. Since picking commonly makes up the majority of warehouse expenses according to De Koster et al. (2007), the evaluation will firstly focus on this. An evaluation of potential impact is made in Table 4.14 and is based on six criteria:

- Subcategory: The specific product group being evaluated.
- % of sales quantity: Estimation of the volume handled and potential impact of automation on throughput.
- % of order lines: Indicates the frequency of handling, helping assess impact on order flows and workload.
- Automation impact: A qualitative judgement on expected gains in productivity, quality, cycle time, and ergonomics.
- Automation Feasibility: Based on existing automation solutions and product homogeneity.
- Picking solutions: suggested technologies or approaches for automation.
- Overall suitability: A summarised evaluation combining volume, feasibility, and expected impact.

In addition, some products are similar in their characteristics and could therefore be used in the same automation method. Picking solutions are also listed.

Table 4.14: An evaluation of potential impact from automation of different sub-categories.

Sub-category	% of Sales Qty	% of Order Lines	Automation Impact	Automation Feasibility	Picking solution(s)	Overall suitability
Planed spruce/pine planks	Very High	High	High	Medium	Suction (multi-cup)	Very High
Sheet materials	Medium	High	High	Medium	Suction (multi-cup)	High
Roof/wall materials (roof tiles)	Medium	Very Low	Medium	Low	No solutions found on market.	Low
Rebar and thin steel profiles	Low	Medium	Medium	Medium	Magnetic/suction.	Medium
Wooden interior details	Low	Medium	Medium	Low	Gripper + AI camera	Low

Kitchen interior	Low	Medium	Low	Medium	Suction	Low
Screws	Low	Medium	Low	High	Shelf-moving AGV's, Autostore	Low
Total	86.1%	54.9 %				

Planed Spruce and Pine Planks accounts for over 60% of total sales volume and over 13% of order lines, making it a high-leverage area. The manual picking process is currently complex, time-consuming, and poses ergonomic risks for workers. Automation may therefore have a substantial positive impact on productivity and safety. However, the feasibility is only medium caused by the physical variation in dimensions, surface irregularities, and the challenge of stacking. Existing automated solutions, such as suction systems used by the Derome group in production, indicate that automation is possible however this may require custom adaptation (e.g., flexible suction systems to handle different plank sizes).

Sheet Materials make up nearly 10% of total sales and order lines. The category has high sales quantity, and manual handling is cumbersome because of size and fragility. Automation would reduce damage to fragile materials and improve ergonomic conditions. Several commercial solutions exist for warehouse automation of sheet materials, including systems from Systraplan and Barbaric that use suction technology. However, the weight and fragility of some items pose technical challenges, requiring careful handling and robust equipment.

Roofing and Wall Materials (mainly roof tiles) has a decent share of sales at almost 10 %, however very low total number of order lines indicates lower picking frequency. Automation could improve ergonomics, but the current picking is not time-consuming, and the complex surface geometry of roof tiles makes automated picking and stacking technically difficult. No suitable automation solutions are currently found on the market, making feasibility low.

Rebar and Steel Profiles (majority Thin Steel Profiles) contribute modestly to sales and order volumes; however, their regular shape and structure make them feasible to automate using magnetic or suction-based systems. Manual picking is time-consuming, and automation could improve efficiency. However, variations in length and handling requirements of steel products present challenges that must be addressed in system design.

Wooden Interior Details has low sales volume but high order line frequency, indicating many small orders. While automation could improve picking accuracy (which is currently a challenge), the high variation in shapes and sizes requires advanced recognition and gripping systems. This increases investment cost and reduces feasibility. Solutions such as robotic claws with AI-based object detection may be required but are complex and expensive. Doors are currently in this category but could be handled like sheet materials.

Kitchen Interior has low sales volume but almost 10 % of order lines. Automation would not significantly improve efficiency because of the low total sales quantity. However, implementation is technically feasible using suction systems. The benefit-to-cost ratio is low, indicating that automation might not be justified unless bundled with other small goods.

Screws, despite having almost 10 % of number of order lines, have very low sales volume. Manual picking is already relatively efficient. However, automation could slightly improve accuracy and

speed. Screws are typically packed in standardised cardboard boxes, which makes them well-suited for automated storage and retrieval systems like Autostore or shelf-moving AGVs. The challenge lies in justifying the high investment given the low number of sales.

When considering automation impact and feasibility sheet materials and planed planks are prioritised. The product category thin steel profiles are also reasonable for automatic implementation, though a lower priority based on its lower sales quantity. Roof tiles are also possible if considering the sales quantity, however because no automated technology was found on the market that unload stacked tiles on a pallet, there are no known possibilities to implement automation for this product group and therefore the feasibility is low. Wooden interior details are not evaluated because of the assumed implementation costs from low technical feasibility compared with medium sales quantity.

The estimated number of single units compared to full packages of lumber is estimated to be 80% of the total quantity and 50% for sheet materials according to Jens Baitson (personal communication, March 31, 2024). The rest of the quantities are shipped as full-packages. The full packaging is not time consuming from today's operations method, using forklifts, and thereby not prioritised for an automated solution as the analysed potential impact from automation is low.

Through the analysis in table 4.15, it is concluded that wooden planks and sheet materials (single units) can be combined with the same type of picking technique. Also, picking solutions may be combined, for example, one automatic solution could be a combination of suction, forklift and magnetic. However, the space utilisation might be too high if combining product groups with such high quantities in one aisle of the warehouse for wooden planks and sheet materials for only one picking robot, and therefore it may be preferable to split those categories into each zone.

In conclusion, DBI's assortment is varied, and the products differ in material, size, weight, and handling complexity. This requires technical solutions that can be adopted to different product categories. For high-volume SKUs it may be justified to invest in automatic systems, while others are more suitable for continuous manual handling. In some cases, manual handling or semi-automatic solutions, or a combination of different subcategories with the same technological solution could be more efficient. There are many products where it is difficult to implement robot picking, such as paper bags, irregular surfaces on roof tiles, in these cases manual handling may be preferred. Some improvements are possible, for example with supportive ergonomic lifting tools and improved layout.

4.3.1 Automated picking of sheet materials

Based on the analysis presented in Table 4.15 sheet materials, lumber, and thin steel profiles seem to be best suited for automation.

To further test the assumption that sheet materials is one of the categories where automation can bring benefits, the subcategory was analysed in more detail to conclude if the product group could be handled by a standardised automation solution by assessing its homogeneity. This is a continuation of step 5 in the method adapted from the framework of Baker & Canessa (2009), illustrated in Figure 4.12.

The purpose of this was also to find the answer for *RQ2: In what ways can automation be implemented within the picking, packing, and loading processes of a construction material warehouse, specifically targeting the SKU categories identified as most suitable?*

To answer this question, it was first necessary to define the technical requirements based on the technical specifications in the product groups. In Table 4.15, only the sales quantity and number of order lines for the most sold product groups is presented.

The subcategory of sheet materials mainly consists of the product categories plasterboards, plywood OSB-boards and particle boards. The maximum and minimum sizes are presented in table 4.15.

Table 4.15: Only shows sales quantity for significant product groups.

Product group	% of sales quantity, % of order lines	-Maximum and minimum dimensions -Dimension of most sold SKU (Width, thickness, length [mm])	Picture	Comment
Board	Very Low, Very Low	1220x12x2740 550x3x1220		Board strips with the width of 45 mm is moved to planed planks
Plywood	Low, Low	1525x21x3050 600x4x1200		One SKU moved to planed planks, due to small sized and low sales quantity
Blockboard & Edge-Glued Panel	Very Low, Very Low	600x18x2500 200x18x1200		
Particle board	Very Low, Very Low	1200x22x2500 600x12x1220		Heat distribution profiles are excluded from the evaluation, due to small sized material
OSB-Boards	Very Low, Very Low	1200x11x2500 900x11x2500		
Panel and cladding boards	Very Low, Very Low	600x11x3020		Low sales quantity and unique surfaces compared to others in the underground of sheet materials. Thereby not included in the automatic evaluation.
Plasterboards	Medium, Medium	1200x13x3000 600x6x1200		

Product group	% of sales quantity, % of order lines	-Maximum and minimum dimensions -Dimension of most sold SKU (Width, thickness, length [mm])	Picture	Comment
Cement based sheets	Very Low, Very Low	1200x12x3050 900x4,5x1200		Several products in these group excluded from the analysis, due to low sales quantity in combination with small size
Shelf board	Very Low, Very Low	900x18x2480 300x16x366		This group could possibly be divided, where products with low width could be handled in the group for planed planks. Shorter SKUs could possibly be handled manually

Based on studying the spreadsheet data and DBIs web shop it was possible to determine the characteristics of sheet materials. They vary from robust cement-based sheets to fragile plasterboards. Plasterboards contribute to over 5 % of the total sales quantity and are therefore the most common product group within sheet materials. Another typical product group is plywood. The sheet materials are from 3 to 30 mm thick and weigh from 2 to 40 kg. The length is from 600 mm to 3050 mm, and the width is from 200 up to 1525 mm. The SKUs with smaller width could be handled with the same automatic solution as planed planks.

The picking order process for single sheet material contains movement to the right picking location, identifying the material to be picked, checking quality for broken edges, cracks etc according to Jens Baitson (personal communication, March 31, 2025). Then fetch the material and place it where it should be consolidated with other boards for the same order before the stack is transported for packing. The weight and the dimensions in this subcategory, as well as the fragile gypsum boards, lead to time consuming picking processes.

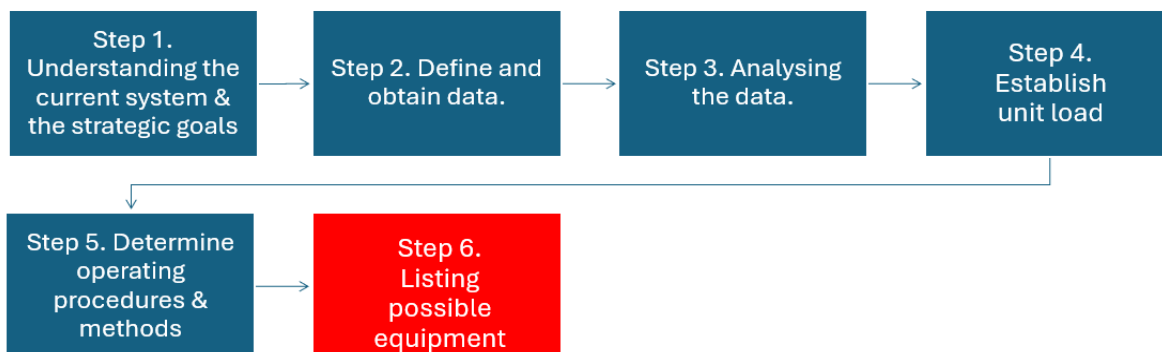


Figure 4.13: Illustrating the sixth step of the method in this study.

Note. Adapted from the framework from Baker & Canessa (2009).

From this stage it is possible to list equipment, as presented in Figure 4.13. While the literature review tried to identify studies on the topic, no studies were found within this field. Thus, it was studied what technology is available on market. The identified solutions include examples from Barbaric and Systraplan, shown in Figure 4.14. The gripper consists of a telescopic arm containing several suction cups that through vacuum holds the material (Systraplan GmbH & Co. KG, 2025). The gripper can place the material in the right stack to the right order and place them in a structure prepared for packing. Systraplan claims that they can deliver tailor-made systems. They offer high bay storage systems, and the carrier can deliver the right quantity sheet material as required. The picking speed, Systraplan claims to be up to 60 consignments per hour. The dimension ranges are 2.8 to 5.8 meters in length and 0.4 to 2.5 meters in width. Further on, a saw can be integrated into the system. In addition, the system can handle kitchen worktops, when the sheet material from the order is completed and stacked, it can be sent to packing on a conveyor system.



Figure 4.14: A high-bay storage and picking solution of sheet materials from Systraplan.

Another conceptual design made by Systraplan demonstrates how the order lines are consolidated on racks, before being sent to the packing machine. This solution provides a more efficient solution in terms of handling several orders simultaneously, by preparing the order lines, and thereafter send them to the packing station when required, illustrated in Figure 4.15.

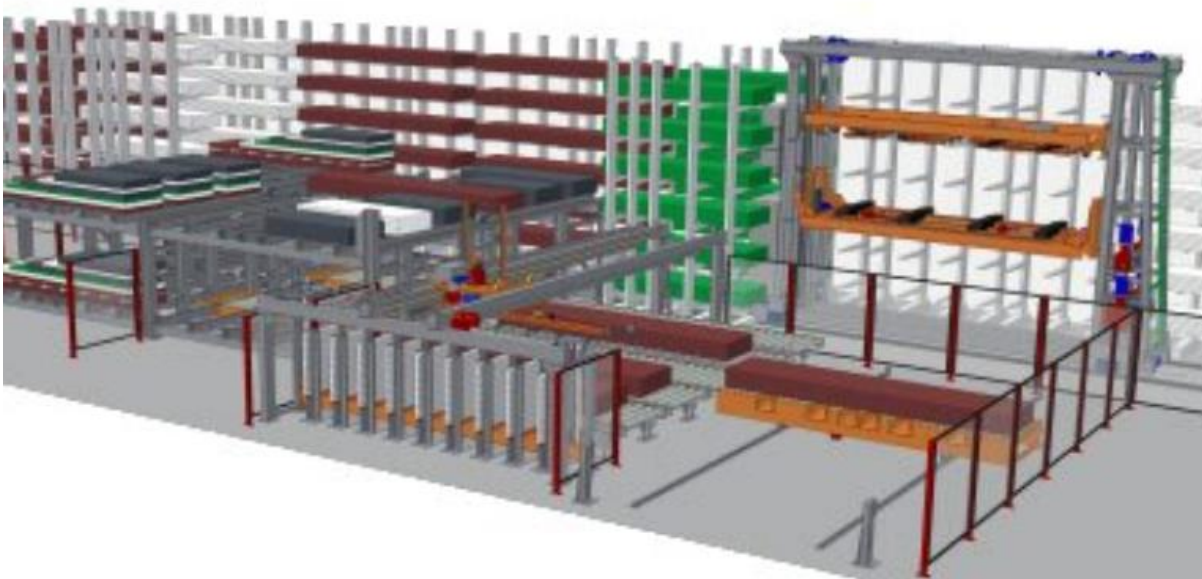


Figure 4.15: A solution from Systraplan, where order lines can be consolidated on racks before being sent for packaging.

Barbaric also presents a solution for sheet material handling, which they call Panel Storage System CSF Industrial (Barbaric GmbH, 2025b), illustrated in Figure 4.16. This system has a cycle time of one minute, which makes it a strong alternative to the solution presented by Systraplan. The maximum storage area is 25 x 75 meters, and handling materials from 2.0 to 5.6 meters length and with 0.6 to 2.1 meters width. The allowed thickness of the sheet materials is from 6 mm, and the maximum stack height is 2.5 meters.

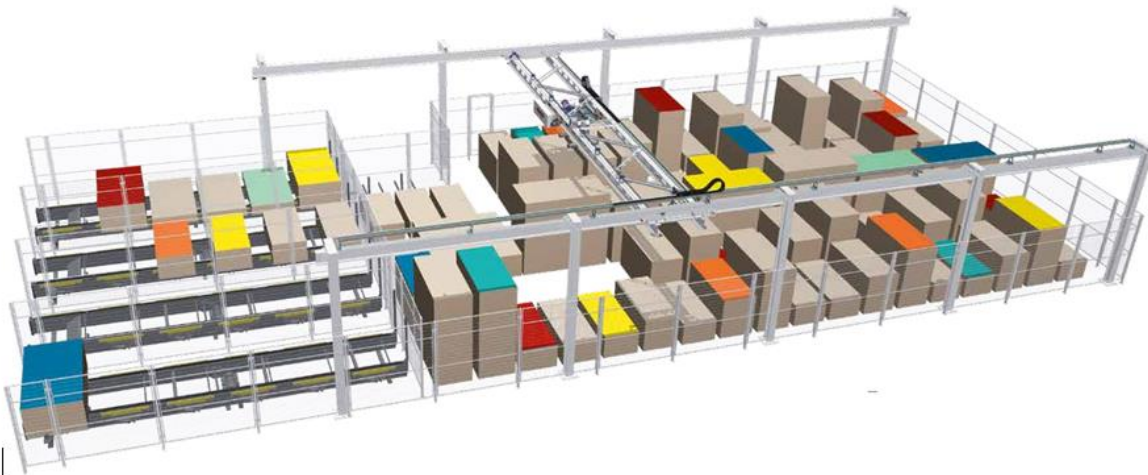


Figure 4.16: A sheet material storage system, shown by Barbaric.

Barbaric also presents multilevel solutions (Barbaric GmbH, 2025b), illustrated in Figure 4.17, to achieve an improved space utilisation. This solution can have two picking cranes working simultaneously and provide faster operations.

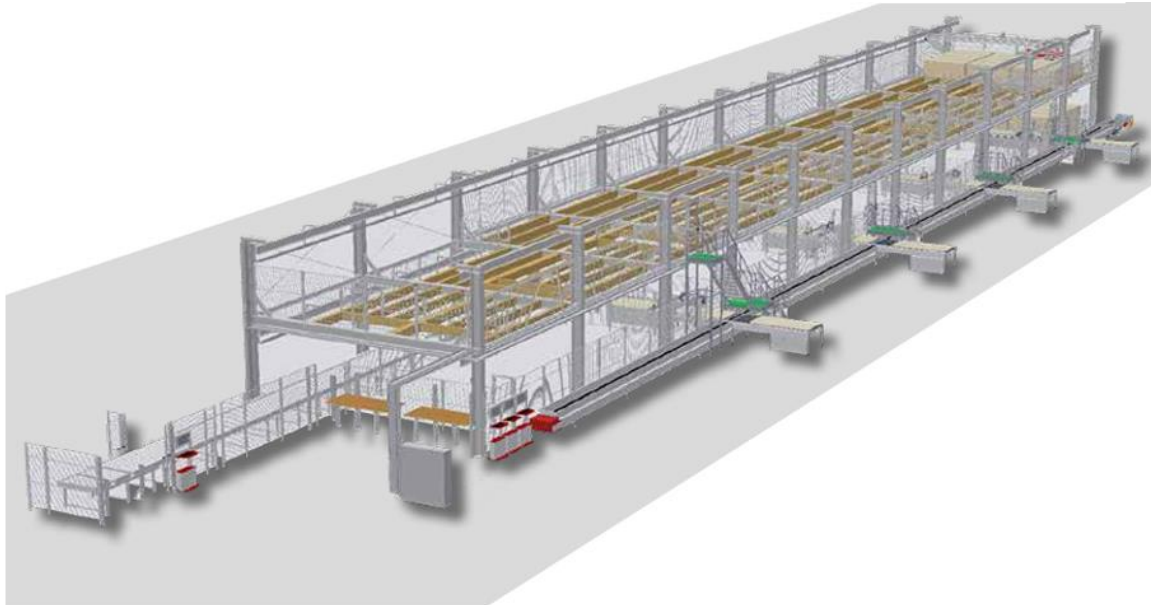


Figure 4.17: A multi-levelled solution for storing and picking sheet materials, shown by Barbaric.

4.3.2 Automated picking of planed planks

To further assess the possibility for automated picking of planed planks, and specifying the technical specifications required for automation, the product groups were studied in Table 4.16. The purpose was to understand the homogeneity of the assortment category as this is crucial for automation feasibility.

The weight was calculated assuming a density of 469 kg/m³ for spruce (International EPD System, 2021). A density of 519 kg/m³ was assumed for pressure treated pine (Derome, 2024). The density was then multiplied with the minimum and maximum volumes for each product group. This was calculated by multiplying the width and height with the length. It should be noted that planed pine is mostly pressure treated which gives it a higher density compared to spruce. The pressure treatment also indicates that the weight will be highest when the wood is newly produced and then lower as the treatment evaporates. Exterior cladding is often painted which indicates that the surface might be different to other product groups.

Table 4.16: Specifying technical specifications of all the product groups in the planed pine and planed pine subcategories.

Sub category	Product group	% of sales quantity, % of Order lines	-Maximum and minimum dimensions -Dimensions of most sold SKU (height, width, length [mm, mm, m]) -Weight [kg]	Picture	Comment
Planed spruce	Construction timber	High, Medium	45-70x45-220x2.5-4.8 45x70x2.5 2.4-34.7		

Sub category	Product group	% of sales quantity, % of Order lines	-Maximum and minimum dimensions -Dimensions of most sold SKU (height, width, length [mm, mm, m]) -Weight [kg]	Picture	Comment
Planed spruce	Dimension planed	High, Low	22-45x45-95x3.0-5.4 28x70x4.8 1.4-10.8		
Planed spruce	Exterior cladding	Medium, Low	17-28x45-195x3.0-5.4 22x95x4.2 1.1-13.8		These are available painted which affects the surface.
Planed spruce	Lath	Medium, Very Low	25-45x38-50x3.6-4.8 25x38x4.8 1.6-5.1		
Planed spruce	Tongue and Groove planks	Low, Very Low	17-23x95-120x2.4-4.2 1.8-5.4		

Sub-category	Product group	% of sales quantity, % of Order lines	-Maximum and minimum dimensions -Dimensions of most sold SKU (height, width, length [mm, mm, m]) -Weight [kg]	Picture	Comment
Planed spruce	Tongue and Groove panel	Low, Very Low	20-23x540x2.4-4.2 23x540x3.6 12.2-24.5		More similar to sheet materials than other planks
Planed spruce	Formwork timber	Very Low, Very Low	22-45x95x4.8 22x95x4.8 4.7-9.6		
Planed pine	Deck boards	Medium, Very Low	22-34x70-145x3.6-5.4 28x120x4.2 2.9-13.8		Pressure treated
Planed pine	Construction timber	Low, Very Low	45x70-220x3.0-5.4 45x145x4.2 4.9-27.7		Pressure treated

Sub-category	Product group	% of sales quantity, % of Order lines	-Maximum and minimum dimensions -Dimensions of most sold SKU (height, width, length [mm, mm, m]) -Weight [kg]	Picture	Comment
Planed pine	Dimension planed	Low, Very Low	22-95x45-95x3.6-5.2 45x45x4.2 1.9-24.4		Pressure treated
Planed pine	Lath	Low, Very Low	28x45x3.6-4.8 28x45x4.2 2.4-3.1		Pressure treated

From this stage it is possible to continue to step 6, in the method adapted from Baker & Canessa (2009). Figure 4.18 demonstrates an automated wood storage machine from the company Barbaric called Solid Wood Storage System SWS (Barbaric GmbH, 2025a). The machine can grip one or multiple planks at once and automate storage and retrieval of materials up to 13 m. It can also be connected to procurement and ERP systems. Multiple picking arms can be used in installations. The company recommends having one storage section where longer planks are stored and another section where shorter planks are stored. The machine can place the picked stacks on a conveyor belt. The conveyor belt could then be used to transport the picked stack to an automated packing station and in this way, it is possible to automate the transport to packing.

When comparing the technical requirements of the wood at DBI to the Barbaric Solid Wood Storage in Table 4.17 it can be concluded that not all planks can be handled by Barbaric standard Solid Wood Storage since DBI has some planks which are at lower than the minimum height and width constraints of the machine. However, many SKUs do match the technical criteria, and Barbaric states on their website that other dimensions are possible after consultation (Barbaric GmbH, 2025a).

It can be concluded that a substantial number (possibly all) SKUs in the wood category can be handled by automated picking using Barbarics Solid Wood Storage System. Building on the results by Hardy & Brougham (2022), the performance impact from implementing automation may include improved productivity, reduced errors, cost savings and improved resiliency if barriers can be overcome. The wooden planks category also has the highest sales quantity by far, creating high

leverage for these performance improvements, leading to the conclusion the wooden planks is the category where the highest performance improvement can be expected.

Table 4.17: The range of technical specifications in the planed pine and planed spruce subcategories. An automated picking solution needs to comply with these requirements to be able to handle all materials in these subcategories.

Parameter	Technical requirements	Barbaric Solid Wood Storage System (other dimensions possible after consultation)
Length	2.4-5.4 m	1.5-16 m
Height	17-95 mm	40 - 260 mm
Width	45-220 mm (excluding tongue and groove board)	80 - 400
Weight	1.1-34.7 kg	500 kg (standard) 1000 kg (max)

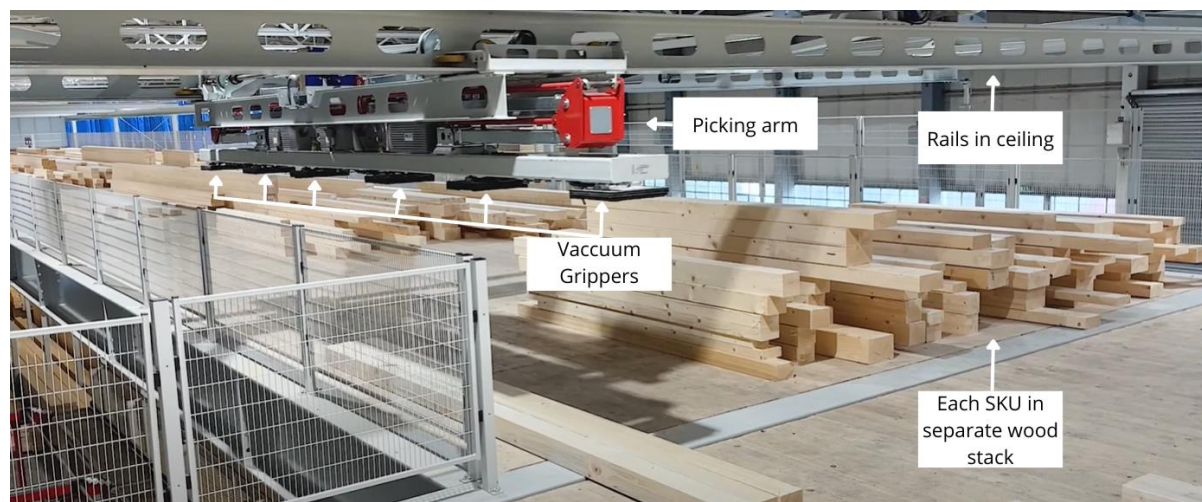


Figure 4.18: The figure is a modified screenshot of a video from the company Barbaric and shows an automated wood handling machine

Note retrieved from Barbaric, (2025a).

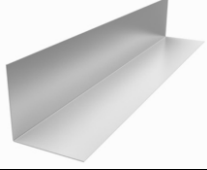
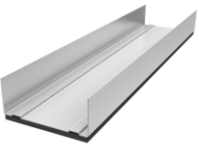
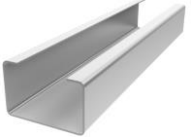
4.3.3 Automated picking of thin steel profiles

Similarly to planed planks and sheet materials, the product group thin steel profiles was explored in more detail for evaluating the feasibility of automation, as step 5 in the method, demonstrated in Figure 4.12. Judging by the pictures, presented in Table 4.18, the conclusion is that thin steel profiles are inhomogeneous in shape, making stacking and automation difficult and technically challenging. Combined with the low sales quantity of thin steel profiles compared to planed planks and sheet materials, the conclusion is that automation of thin steel profiles will not have a significant impact on total performance.

After studying spreadsheets and DBIs web shop the authors concluded that compared to wood-based products and sheet materials, thin steel profiles are usually more lightweight, yet often with a smaller area of flat surface. Therefore, a magnetic picking method could be more suitable. On the other hand, there are several SKUs that are not magnetic, such as stainless steel. After the evaluation, a significant number of SKUs were excluded, because of the lack of a uniform gripping method.

Thereby, the findings indicate than an automated picking solution for thin steel profiles may not be profitable due to low sales quantity.

Table 4.18: Evaluated dimensions from thin steel profiles.

Product group	-Maximum and minimum dimensions -Dimensions of most sold SKU (width, height [mm], length [mm])	Picture
Steel angle	50x50x3	
Multipurpose steel stud	70x40x5 70x40x2.49	
Steel nogging T-joint	2.5 (length)	
Secondary steel stud S	85x25x2.5	
Steel track with polyethylene coating	70x55x3 55x45x3	
Steel stud reinforcement	45x4 [WxL]	
Galvanized steel rail	55x70x3	

4.3.4 Automated packing

The packing is a time-consuming process in DBIs current operations and is conducted frequently according to Jens Baitson (personal communication, March 31, 2025). Through observations and interviews it was concluded that there are often queues at the packing station, and thereby it is a frequent bottleneck. Automated packing in combination with computerised planning is suggested

address this problem. The authors identified several solutions on the market for automated packaging systems. Figure 4.19, 4.20, and 4.21 demonstrates an example from the company Tentoma. Stacked material is entering the packing area on a conveyor and passing the machine which stretches plastic packing material before the goods are entering. The goods pass through the machine, while the plastic material rolls out over the goods, and after the goods have passed the machine seals the plastic cover. This example would be suitable for planed planks, sheet materials and thin steel profiles. It could also be used to pack goods which have been picked manually and placed on a conveyor leading to the machine.

When applying Industry 4.0 insights as described by Wang et al. (2016), to the loading machine by Tentoma, it is reasonable to assume that the machine, or a similar one, can be combined with sensors which automatically detect the shape of the stacks entering the packing machine, and automatically adjust the machine operations to the stacks. This would enable flexibility in handling different size stacks in packing. By combining the existing technology with the latest logistics trends of smart material flows described by Wang et al. (2016), it is reasonable to assume that it is possible to automate packing through smart material flows combined with a machine like the example from Tentoma illustrated in Figure 4.19 - 4.21.

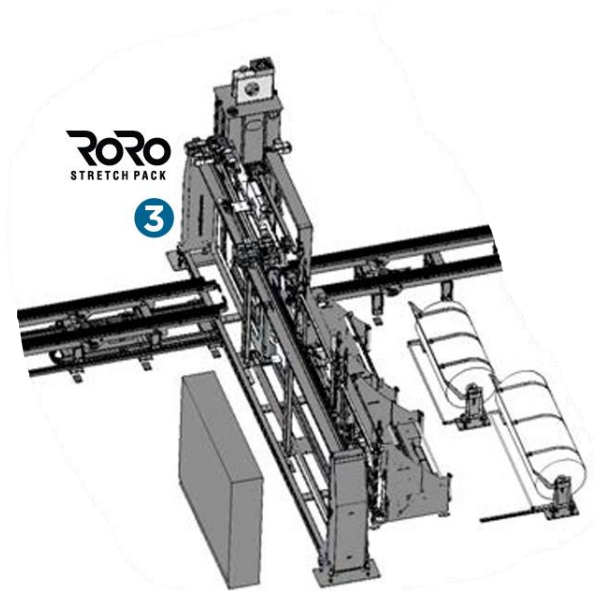


Figure 4.19: Tentoma. RoRo StretchPack® packaging machine.
Note. Retrived from Tentoma (2025)

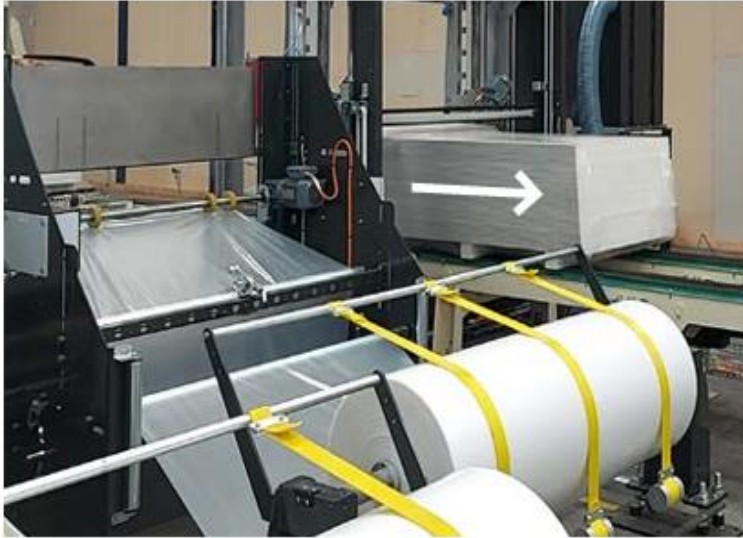


Figure 4.20: Tentoma. RoRo StretchPack® packaging machine.
Note. Retrived from Tentoma (2025)



Figure 4.21: Tentoma. RoRo StretchPack® packaging machine
Note. Retrived from Tentoma (2025)

4.3.5 Automated loading

To further explore what technology can be used to automate a construction materials warehouse and answer RQ2, automated loading was studied.

First DBIs current state was mapped through interviews and observations. Studies on the topic were also found. Carlan et al. (2023) compared automated loading technologies. The study indicated that using a transport belt, presented in Figure 4.22 is the best solution for loading when considering economic indicators over a 10-year period.

Table 4.19: Summarizing the findings of using a conveyor belt for loading (Carlan et al., 2023) compared with current state at DBI.

Parameter	Transport belt	Current state at DBI (forklifts and cranes)
Application	Loading and unloading	Loading and unloading
Loading/unloading speed per trailer	6 minutes per trailer	20-60 minutes (M. Hansson, personal communication, January 31, 2025)
Maximum loading weight	30 ton	
Features	- Conveyor belt on dock and inside the trailer	- Loading by using forklifts - Unloading using cranes
Requirements	- Modifying trailers with conveyor belts - Regular maintenance of moving parts - Trailers and loading dock need to be well aligned	- Labor intensive

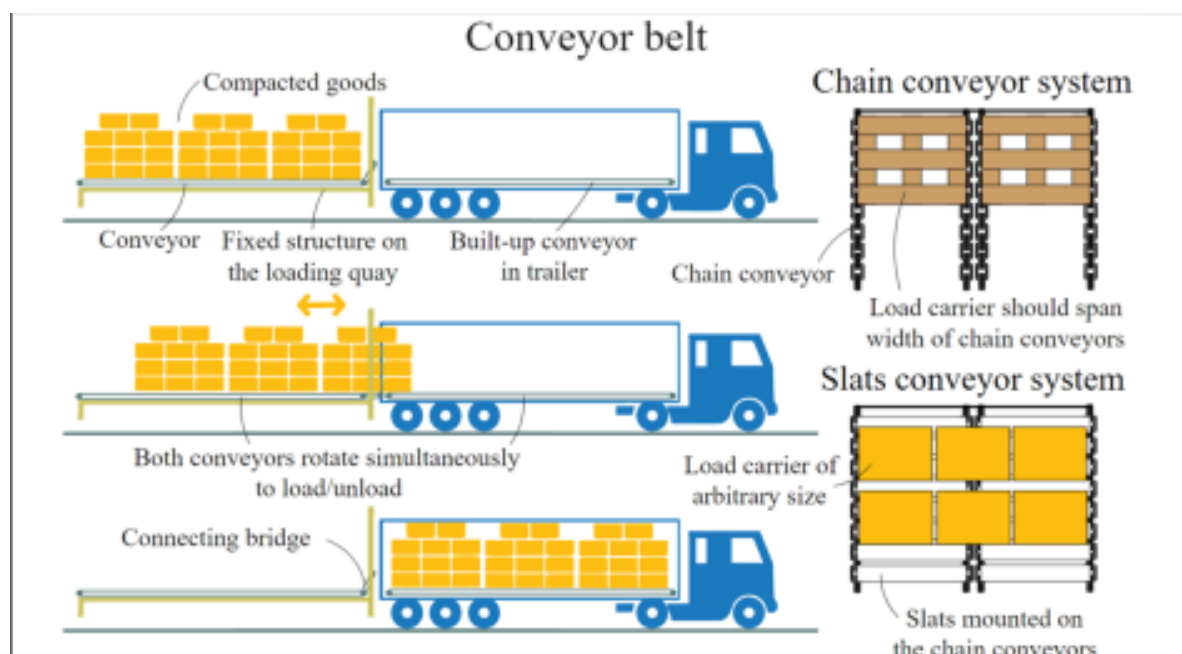


Figure 4.22: Illustration of how a conveyor belt can be used for loading.

Note. Retrieved from Carlan et al., (2023).

Table 4.19 illustrates the current processes involved in loading at DBI and analyses how conveyor belts can be integrated in the processes. Further on, the expected impact is analysed. The table was created through observing and documenting the state of loading at DBI, to understand the necessary processes. Next, it was analysed how conveyor loading as described by Carlan et al. (2023) could be implemented to improve performance. The study indicated that higher cargo volumes was positive for return on investment and since many of DBIs goods are physically large with high sales quantity

a fast return on investment can be assumed. DBI owns both the loading bays and vehicles which supports the argument for implementing automated loading in this case as this facilitates implementation.

With the barriers for automated loading in mind (Agrawal et al., 2023), a semi-automated approach is suggested since a fully automatic solution is concluded to be unfeasible. A fully automatic solution would require automatic arrangement of goods to ensure ease of access at customer site, fill rate and stability of goods. Proper placement of straps for lifting goods with crane and support beam arrangement on trailer is also unfeasible for automation. For this reason, the loading process will not be fully automated however many benefits are expected from integrating conveyor loading based on the analysis. The approach suggested in Table 4.20 solves the challenges related to fully automated loading, non-uniformity of goods, transportation off and onto the trailer and securing and arranging the goods, by suggesting a semi-automated approach. The legal aspects and IT system integration however was not addressed since it was outside the scope of this study, however it must be considered before implementation.

Table 4.20: Analysing how the loading process at DBI can be automated.

Step	Process	Current state	Improved future state	Expected impact
1	Transport packed goods to the loading buffer zone close to trucks.	Manual handling using forklifts. Buffer zone is on racks or on the ground.	Semi-automated handling using conveyor belts. When goods arrive at the loading bay they are manually arranged. The loading bay with conveyors serves as a buffer zone. Goods are placed directly on loading bay conveyors.	Less labour intensive. Shorter loading time. Loading can be prepared when the truck is operating.
2	Prepare goods with straps for crane unloading.	Manual handling	Manual handling	-
3	Prepare trailer with suitable support beam arrangement for goods stability.	Manual handling	Manual handling	-
4	Loading and arranging goods to ensure ease of access at customer site, fill rate and stability.	Using forklifts. Arranging goods only possible when truck is docked.	Goods are manually arranged on loading bay conveyors using forklifts or overhead cranes. After this they are loaded onto the trailer using conveyors.	Faster loading. Improved utilization rate of truck fleet through shorter waiting times. More even workflow for loading operators. Arranging goods while truck is operating allows more time to ensure ease of access at customer site and fill rate.
5	Securing goods on trailer	Manual handling	Manual handling	

5 Discussion

This chapter discusses the key findings from the study, highlighting how modern technologies can impact DBI's future logistics centre operations. The discussion is structured as follows: first, summarise the most important insights from the research are summarised, followed by an analysis of practical implications for DBI, theoretical contributions to the academic field, and societal, ethical, and ecological considerations. Lastly, the chapter outlines the study's limitations and suggests directions for future research.

5.1 Key Findings

As stated in literature review by He & Turner (2021), there is a research gap regarding the application of Industry 4.0 in warehousing of forestry products. Both in academia and industry, there is limited research on automation in the construction material sector, including products such as sheet materials, steel bars, cement bags, and roof tiles. This sector faces high product variety, with significant differences in size and physical characteristics. This diversity makes automation challenging, especially for non-standardised products.

However, based on in-depth insight into DBI's assortment and material flows, this study indicates that automation is indeed possible. The large volumes of certain product categories, combined with the availability of modern technologies, suggest that automation can be beneficial. Efficiency gains can be achieved in picking, internal transport, packing and loading, potentially leading to improved delivery accuracy and customer satisfaction.

These findings partially align with the research gap identified by He & Turner (2021). While their study emphasised complexity and diversity as barriers for automation, our findings suggests that specific products categories, such as wooden planks and sheet materials, are particularly suitable for automation due to their high volume and homogeneity. This complements their findings through showing that this area could beneficially adapt automatic solutions.

5.2 Practical Implications

DBIs supply chain includes the manufacturing of forestry products. Combined with the strong market demand in Sweden, this results in consistently high-volume flows through the logistic network. High volumes are a critical enabler for automation, as they justify investment costs and enable efficient material handling processes. Market studies show that sheet materials and wooden planks, because of their high-volume sales quantity and standardised dimensions, are especially suitable for automation. This offers a promising opportunity to enhance logistics performance at DBI's future logistics centre. Moreover, this study offers insight into how product categories suitable for automation can be identified, and how analysing expected material flows can support strategic warehouse planning.

5.3 Theoretical Contributions

In addition to the practical implications, this study contributes to the theoretical understanding of automation adoption within the construction materials sector. While previous research has focused primarily on automation in manufacturing, logistics operations in this field have remained underexplored (He & Turner, 2021). This study addresses this gap by analysing operational challenges, identifying product categories suitable for automation, and highlighting the potential and current limitations of applying Industry 4.0 technologies in construction material logistics. The findings support the view that while production processes in forestry manufacturing, have advanced significantly through automation (He & Turner, 2021), logistics operations have remained

traditional. By offering a practical categorisation of product suitability and identifying where picking, loading, and packing technologies can be applied, this study extends current knowledge and offers a foundation for future research.

5.4 Social, Ethical and Ecological considerations

The development of a new logistic centre with higher levels of automation is likely to have notable societal effects. In the short term, automation may reduce the demand for manual labour as routine tasks are increasingly performed by machines (Autor, 2015). However, automation often complements human labour by raising productivity, which can in turn create new tasks that demand problem-solving (Autor, 2015). Moreover, automation can improve working conditions by eliminating physically strenuous and ergonomically risky tasks, thereby lowering the risk of injuries associated with heavy material handling. Overall, while the new logistics strategy may have short-term challenges, the long-term aim is to create improved workplace safety sustainability.

From an ethical perspective, the research conducted in this study has been with respect for integrity. Participants were informed about the purpose of the study, and how information would be used. Sensitive information that could influence strategic business decisions or affect the company's reputation has been excluded from the final report to ensure responsible handling of proprietary information.

From an ecological perspective, the project is expected to yield benefits. Centralising logistics operations can enhance transport efficiency and reduce overall environmental impact (Kohn & Brodin, 2008). Energy efficiency has also been considered in the logistics centre design, with potential use of renewable energy sources as solar panels. Additionally, efficient resource use and thoughtful material selection during construction can minimise environmental footprint. However, automation systems may increase in energy consumption, which must be managed through careful system design and energy planning.

In conclusion, while the shift towards a more automated and centralised logistics offers operational and environmental advantages, it must be implemented with attention to social responsibility, ethical considerations, and sustainable design. Integrating these dimensions is essential for achieving growth that is both responsible and future oriented.

5.5 Limitations of the Study

Despite offering several insights, the study has limitations and knowledge gaps that need addressing before implementation.

One limitation is that sales quantity calculations are based on historical data from the Mölndal regional warehouse. The logistics centre is intended to serve both the Derome and Trollhättan regional warehouses, and including their data might yield different results from these. However, empirical evidence suggests that relative sales quantities are not significantly different between these warehouses, which justify this approach. Although no formal sensitivity analysis was conducted, the authors argue that even with a 50% variation in sales data for key categories like wooden planks or sheet materials, the conclusion would only be marginally affected. For the remaining categories, which are less significant in volume and not included in the final analysis, the potential impact is minimal.

Another limitation is that the number of order lines was calculated using only data from a three-month period. A longer dataset would likely yield more accurate result. The reason for this is that

seasonal variations are prevalent at DBI, based on empirical evidence (D. Ahrling, personal communication, February 11, 2025). The lack of long term data is due to availability constraints.

The study also does not deeply investigate technical specifications or compare technologies across all product categories. The justification is that limitations had to be made because of time constraints, and an analysis of the expected performance impact of the most relevant categories was made, to justify the focus. Additionally, the SKU categorisation was based on DBI's internal system, which may not align perfectly with how automation vendors categorise product specifications. Goods receiving and storage automation were excluded from detailed analysis. While valuable for academics and practitioners, the focus was limited to picking, packing, and loading due to the resource intensive nature of picking (De Koster et al., 2007).

While viable automation solutions are explored, only a few technologies were examined due to time and data constraints. More detailed comparison including several different options, matched to the different product characteristics, would be highly valuable to academia and practitioners. There was also a lack of detailed operational data for the automated technologies investigated, despite contact attempts. More extensive data and detailed data analysis would benefit future research and practical application.

Based on theoretical evidence, it is known that there are many barriers for implementation of automation (Rathore et al., 2022; Hardy & Brougham, 2022). Important barriers brought up in literature include legal and regulatory frameworks, lack of top management support, resistance to change, information system infrastructure, lack of process knowledge and technical barriers. This study focuses on improving understanding within the areas of process knowledge and technical barriers, because these are most relevant to the field of supply chain management.

Finally, the study contributes to warehouse design literature by applying following steps 1-6 of the Baker & Canessa (2009) method. Steps 6-12 were not covered due to time constraints.

5.6 Future Research Directions

This research highlights a need for future research into automation and Industry 4.0 for construction materials.

Future studies could improve product categorisation at DBI to better align with the technical requirements of automated solutions. A more detailed comparative analysis of available technologies could also be valuable. Access to more operational and cost data would improve the quality of such research.

Among many gaps, as referred to in the limitations and scope which was not addressed in this study is how these technologies could be integrated in a warehouse design. For future research it is recommended to continue with steps 6-12 of the warehouse design method by Baker & Canessa (2009) to discover how the automated technology can be integrated in a layout.

It is also suggested to further investigate automated storage and retrieval, which was only briefly discussed in this study, but is important for a more complete understanding of warehouse design and technology integration.

Another recommendation is to study relevant legal and regulatory frameworks related to the automated technologies considered in this study. In addition, future studies could investigate how barriers to automation implementation could be overcome. In literature barriers include lack of top management support, resistance to change, and IT system infrastructure affect the feasibility. Before

implementation it would be valuable to investigate how these barriers can be overcome. It is also recommended to explore additional risks and mitigation strategies related to automation, such as selecting the wrong process for automation, loss of manual skills, and the risk of high maintenance and update costs (Hardy & Brougham, 2022).

6 Conclusion

This thesis investigates warehousing of construction materials as a part of the building industry's supply chain. The thesis has been part of a plan for a new logistics centre, part of a strategic goal for DBI. The study followed a structured approach with strong academic foundation in the framework for warehouse design by Baker & Canessa (2009) and investigated implementation of modern technology and robotics. Conducting the study together with a company such as DBI, the possibility of studying a real-life case made it possible to follow the method and to evaluate different technology solutions in the context of a construction material supplier.

The study began with an analysis of DBI's current state, their strategic goals and business targets. A literature review and supplier research of available automation solutions on the market were conducted to identify a gap between theory and practice. This showed that little has been made within Industry 4.0 for warehousing of construction materials, both in the literature and in practice. Therefore, this study has evaluated how Industry 4.0 technology can be adapted into this sector, and what are the challenges.

The next step was to select the assortment to include in the logistics centre. Based on the assortment selection and geographical scope, the logistics centre sales volumes for 2029 were forecast. The different product categories' characteristics within DBI's new logistics centre were analysed. In the next stage, their suitability for automation was analysed. De Koster et al., (2007), states that picking is the costliest operation within warehousing, and thereby automated picking solutions of the product categories within DBI's future logistics centre were a focus in this study.

The pre-study of DBI indicated that little has been researched within automation of construction materials in warehouse operations. In the context of DBI, wooden planks are forecast to have a high sales quantity in the future logistics centre, and there are existing automated picking solutions within the market as well as in Derome's own production facility. The transition from manual to automated picking solutions at Derome's production facility has, according to P. Andersson (personal communication, April 7, 2025), resulted in increased productivity by 30% with a maintained workforce. Therefore, a solution for picking wooden planks was assessed, and a solution has been presented in this thesis.

Sheet materials were also forecast to have a high sales quantity in the future logistics centre, and automated picking machines were found on the market. Therefore, an evaluation of how to handle sheet materials by automatic solutions was conducted, and a proposed solution has been presented. The results also indicated that a third product category, thin steel profiles, were possible to automate, in terms of medium sales volume and available picking solutions. However, with a more detailed evaluation the findings indicated that the SKUs within that product group had a too high variation in its characteristics in terms of shape and material type, and thereby it was concluded not to be suitable for automation. Other product groups were also analysed, however because of low sales quantity or no available picking solutions found on the market, the opportunity to automate these was found not to be as attractive.

To summarise the thesis, it shows that there are challenges in warehouse automation for construction materials, because of the high variety of products. Large and irregular products characterise a major part of the assortment, and there is a lack of research in automation in this field. However, when studying the market, findings indicate that there are automated solutions feasible for this context. Companies that proactively explore and adapt automation solutions may be better positioned to meet future demand, enhance operational efficiency, and secure long-term competitiveness in the construction materials industry.

RQ1: What SKU categories in construction material warehouses are most suitable for automation, and for which of these categories do automation offer the greatest potential improvement in overall warehouse performance (productivity, cost-efficiency, and quality)?

Based on the analysis it was found sheet materials and primarily wooden planks are those categories where the most significant performance increase can be expected through automation. The reason for this conclusion is that these categories represent a high sales quantity, which creates a high leverage for a high total performance improvement, compared to other categories. The other reason for coming to this conclusion is that the technical feasibility for these categories is high. These categories are homogenous, indicating that they can be handled by a standardised automated solution. Also, when scanning the market, automated solutions for these materials were found, strengthening the thesis of high technical feasibility. It was also concluded that automated picking of full packages of sheet materials and wooden planks, however, is not likely to improve performance, since the picking of these are highly effective in the current state. Instead, it is the picking of these materials piece by piece, where a performance increase from automation can be expected.

RQ2: In what ways can automation be implemented within the picking, packing, and loading processes of a construction material warehouse, specifically targeting the SKU categories identified as most suitable?

After the most relevant categories had been established through answering RQ1, technology for automated picking, packing, and loading of these categories was investigated. The findings indicate that an automated picking machine, designed specifically for picking wooden planks, can be used. This technology uses wood stacked on the floor, combined with a picking arm mounted in the ceiling, gripping with suction. A machine with the same principle can be used for the picking of sheet materials. It was also indicated that packing of these materials can be automated using a machine specifically designed for this purpose. The picking machine can place picked order lines on a conveyor leading to a packing machine. The stacks of sheet material and wood can pass through the packing machine where they are wrapped by plastic. When the length of the stack has passed through, and is fully covered in plastic, the packaging is fused and cut. This process is expected to be faster and with a lower operational cost than the current process. Finally, loading can be semi-automated using conveyor loading, which is applicable to almost all SKUs, including but not limited to those that are automatically picked and packed. Conveyors are placed on the loading bays and the truck trailers are also equipped with conveyors. The goods can be arranged on the loading bay when the truck is operating. Loading using this method is expected to take six minutes compared to 20-60 minutes in the current state.

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