CHALMERS

Selection of Automated Order Picking Systems

Automated Storage and Retrieval Systems within Contract Logistics

Master's thesis in the master programme Supply Chain Management

ACHIM DÖLLINGER
TOVE LARSSON

Department of Technology Management and Economics
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Technology Management and Economics
Division of Supply and Operations Management
Chalmers University of Technology

SE-412 96 Göteborg, Sweden
Telephone: + 46 (0)31-772 1000

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ABSTRACT

Increasing demands on contract logistics providers have led to an increasing interest in warehouse automation. Warehouse automation is expected to result in improved efficiency and effectiveness. The warehouse activity typically in focus for automation is order picking as it accounts for the majority of operational costs. The purpose of this study is to provide a guideline for the selection of an automated order picking system. The automated order picking systems in focus of this thesis are eight different automated storage and retrieval systems, which reduce or eliminate the non-value adding travelling in the order picking process. The guideline was developed alongside a specific case of an order picking process in a warehouse in Norrköping operated by Kuehne + Nagel AB. In order to achieve the purpose relevant literature is presented, the current order picking process is analysed and a market research of four different suppliers, namely Constructor, Kardex Remstar, Swisslog and Weland Lagersystem, and their respective systems is conducted. The study results in a guideline for the selection of automated storage and retrieval systems and a recommendation towards KN. Factors relevant for the selection of an automated storage and retrieval system are identified and eight different systems are evaluated. The guideline can be transferred and applied to other contexts and can be considered as a valuable tool in the selection of an automated order picking system.

Keywords: contract logistics; warehouse automation; automated order picking systems; automated storage and retrieval system; AS/RS

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List of Abbreviations

AGV	Automated Guided Vehicle
ANSI	American National Standard Institute
AS/RS	Automatic Storage and Retrieval System
B2B	Business-to-Business
B2C	Business-to-Customer
FPA	Forward Picking Area
FTE	Full-Time Employees
HU	Handling Unit
ICT	Information and Communications Technology
I/O point	Input and Output point
KN	Kuehne + Nagel AB
ROI	Return On Investment
SKU	Stock Keeping Unit
S/R device	Storage and Retrieval device
VLM	Vertical Lift Module
WMS	Warehouse Management System
3PL	Third-party logistic

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1. Introduction

This chapter provides an introduction to the master thesis, starting with a brief description of the logistics industry and a background to the topic. Following, the purpose is defined and the underlying problem is analysed out of which six research questions are identified. Finally, the chapter describes the outline and structure of the thesis.

1.1 Background

Literature suggests that it is becoming increasingly popular to outsource complex logistics services and large parts of the logistic operations. By outsourcing logistic functions to a Third Party Logistics (3PL) provider, companies can focus on their core business and potentially reduce costs (Hertz and Alfredsson, 2003; Marasco, 2008). A 3PL provider can be defined in many different ways, in this report it refers to an external company that provides logistic operations to its customers. 3PL includes many different areas, ranging from highly complex logistics network design to simple logistic operations, such as transportation and warehousing (Cahill, 2007). In this report the area of contract logistics is in focus. Contract logistics describes the planning, implementation and control of a logistic system through a 3PL provider under contract. Those contracts are characterized as being highly customized with durations ranging from one to several years (DHL, 2016). Today 3PL providers are facing increasing demands from customers, such as shorter lead times, improved service levels, increased number of stock keeping units (SKUs) and on-time delivery, whereby they are still expected to lower costs continuously (Bendoly et al., 2006). This puts further pressure on the already low-margin business of logistics. Even though a 3PL provider can utilize labour and equipment more efficiently than other companies by being specialised in the area and employing economies of scale, they are required to continuously improve the logistic operations (Andersson and Norrman, 2002).

One of the most impacting areas for logistic operations is warehousing. Warehousing can be defined as a planned process to bridge distance and time between production and consumption, with the aim to achieve logistic optimization (Hompel and Schmidt, 2007). If managed well, warehousing can provide a competitive advantage, since it highly impacts other logistic operations (Richards, 2014). Literature suggests that spending for warehouse automation increased. The associated benefits with warehouse automation reach from reduced operational costs, increased service levels and reduced picking errors, to the ability to cope with future business growth (Baker and Halim, 2007). The changing labour demographics have led to a situation where it becomes increasingly difficult to find operators that are willing to work in a warehouse. In addition, wages are increasing and the health and safety requirements from authorities are becoming stricter (Hamberg and Verriet, 2012; Sowinski, 2013). Sowinski (2013) identifies, besides the changing demographics in labour force, the constant strive for increased efficiency, productivity and cost reduction and the increased use of e-commerce as the main reasons for warehouse automation.

Even though warehouse automation could technically be applied to any warehousing activity, the order picking process is typically in focus. The selection of a suitable order picking system is one of the key decisions to be made in warehousing and has a significant impact on logistic costs and service levels (Marchet et al., 2014). The order picking time accounts for up to 50% of the operation time in a warehouse, out of which up to 55% are spent on non-value adding travelling (Hompel and Schmidt, 2007; Koster et al., 2007). Automated order picking systems that focus on reducing travelling are called Automated Storage and Retrieval Systems (AS/RSs), but other automated order picking systems are available as well. Despite the increasing interest in warehouse automation, the considered literature does not provide any clear guidance in selecting an automated order picking system.

1.2 PURPOSE

The purpose of this master thesis is to provide a guideline for selecting an automated order picking system, including a description of what factors are important to consider in the selection process. The context is framed by a specific case of an order picking process in a warehouse in Norrköping operated by the contract logistics provider Kuehne + Nagel AB (KN). The specific case is used to develop the guideline and to allow an analysis of different systems. Thus a recommendation for the specific case, and the contract logistic provider in focus, is also included in the thesis.

1.3 RESEARCH QUESTIONS

In order to fulfil the purpose, six research questions are defined. The first three questions are related to creating the guideline, and the remaining three questions are linked to answering the specific context in order to provide a recommendation. To create a guideline for selecting an automated order picking system, available systems and their limitations must be identified. Evaluation criteria relevant for the selection must therefore be defined in order to assess and compare the identified systems. The research questions are as follows:

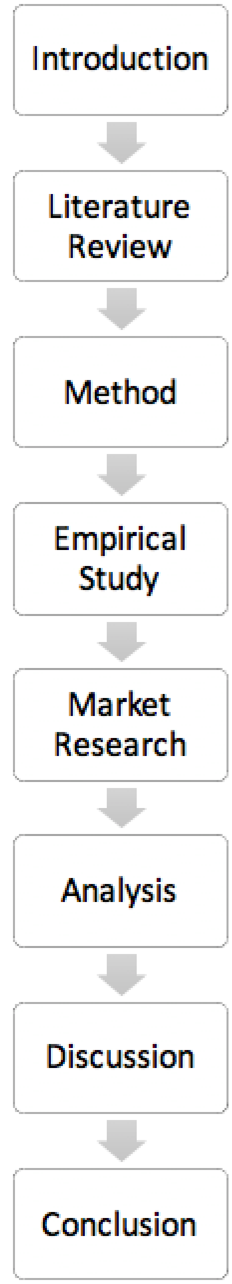
- What automated order picking systems are available?
- What factors are important to consider for the selection of an automated order picking system?
- How do the available systems perform in regards to these factors?

After the guideline is established, it is applied to the case in focus. This provides the reader with an understanding of what needs to be known to apply the guidelines to other contexts as well. Therefore, the current situation of the order picking process must be analysed and key measurements identified. The current situation should be evaluated focusing on what factors might limit or impact the choice of an automated order picking system. Further it needs to be known if there are any other expectations that must be met with implementing an automated order picking system. When this is understood the choice of the system can be made. The research questions are as follows:

- What does the current order picking process at KN in Norrköping look like? Are there any limitations?
- What are the expectations of implementing an automated order picking system?
- What system should be implemented?

1.4 THESIS OUTLINE

This section describes the outline of the thesis so that the reader gets an understanding of what to expect from the different chapters and how the thesis is structured.



Introduction - The introduction provides a background to the topic, describes the purpose and formulates relevant research questions.

Theoretical Framework - This chapter covers the relevant literature in order to create a frame of reference for the thesis. Relevant terms are defined, order picking systems are classified and three different automated storage and retrieval systems are described in more detail.

Method - This chapter presents the underlying research design and describes how the literature review, data collection and market research have been carried out.

Empirical Study - The warehouse layout is illustrated and the current inbound/replenishment, order picking and packaging processes are described and illustrated as process maps. Thereafter, the product characteristics are presented together with shipment data both in written form and illustrated in graphs for a better overview. Finally the chapter covers the claims received. The necessary data is gathered through warehouse visits and raw data from the Warehouse Management Systems (WMS).

Market Research - Twelve AS/RSs out of eight different system types and their respective providers are described. The market research aims to complement the theoretical framework.

Analysis - This chapter compares the findings of the literature review, empirical study and the market research. The guideline is established and different systems are evaluated, before their feasibility for the considered case is analysed. Out of the analysis a recommendation for the specific case is formulated.

Discussion - The discussion reflects on the findings of the report. The applied research methodology is critically discussed, by investigating underlying reasons for result uncertainty and indicating possible improvements. Lastly, areas of potential future research are pointed out.

Conclusion - The final chapter summarizes the major findings of this thesis.

2. THEORETICAL FRAMEWORK

The theoretical framework is divided into three sections. The first section describes different warehousing activities and flows, as well as organisational and operational policies. The following section classifies different order picking system categories and points out implications of implementing automated order picking systems. Subsequently, the decision steps in selecting and designing an order picking system are described and the focus is laid on AS/RSs. The section ends with a brief outlook of Information and Communications Technology (ICT) automation. The final section describes the general operation principle of AS/RSs and elaborates on three types of systems, i.e. carousels, Vertical Lift Modules (VLMs) and miniload systems in more detail.

2.1 WAREHOUSING

This section describes different warehousing activities and the respective flows in order to clarify the scope of this thesis. The section ends by describing different organisational and operational policies of zoning, batching, accumulation and sorting, which is required to explain differences between order picking systems later on in the chapter.

2.1.1 Warehouse Activities and Flows

Five main activities of warehousing can be distinguished: receiving, storage, order picking, accumulation and shipping (Hompel and Schmidt, 2007). An illustration of the different warehousing activities and the corresponding flows can be found in figure 2.1.

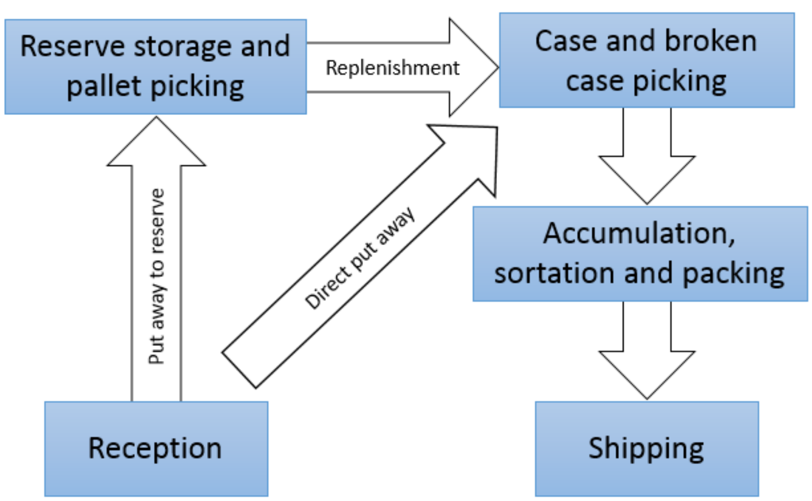


Figure 2.1 Illustration of warehouse activities and flows (based on Koster et al., 2007).

The first activity in warehousing is the reception which involves the arrival and unloading of goods from the transport carrier. Often an inspection is included at this stage which is supposed to validate that the goods arrived in the right quality and quantity. Simultaneously the inventory records are updated (Koster et al., 2007). In some cases goods are also repacked due to damage or storage reasons (Hompel and Schmidt, 2007). As a next step the goods are transported and placed in their respective storage location, which is known as the put away process (Koster et al., 2007). Once an order has been received the order picking process starts. Order picking can be defined as the activity of gathering a prepared range of items following a set of customer orders. Items can be picked either as a full pallet, case or broken case (Reif and Günthner, 2009). For case and broken case picking the items can either be picked loose, in a special picking container or directly in their shipping container (Hompel and Schmidt, 2007). The order picking process, illustrated in figure 2.2, includes the sub-activities of clustering and scheduling orders, assigning stock to order lines, releasing orders to the floor, order retrieval and disposal of picked articles. The actual order retrieval consists of traveling, searching, and extracting, together with paperwork and other activities.

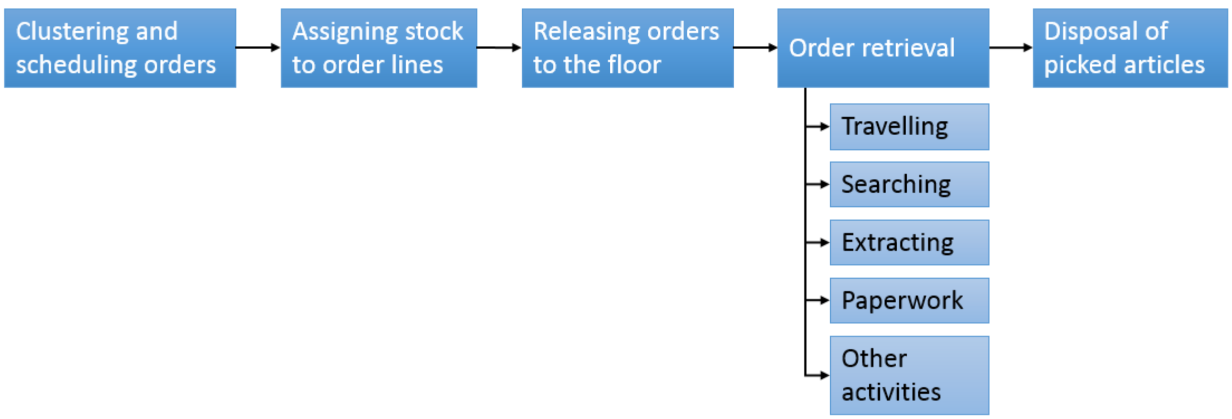


Figure 2.2 The order picking process (based on Koster et al., 2007).

Subsequent to the picking the finished orders are packaged and packed on the shipping unit load (e.g. pallet) before the actual shipping takes place. In certain cases, which are discussed in the following section, the orders might have to be accumulated or sorted before packaging. At last the packaged goods are shipped (Koster et al., 2007).

2.1.2 Organisational and Operational Policies

In order to guarantee a satisfactory warehousing performance, the organisational and operational policies to be used within the warehouse must be selected. As these are highly interrelated, it is important that they are coordinated. The following paragraphs present the organisational and operational policies of storage assignment, zoning and batching.

Since items need to be put into storage before they can be picked, a set of rules on how to assign them to storage locations needs to be established, these are known as storage assignment policies. Important factors to consider include the volumes, the routing policy, the number of SKUs per pick route, and the warehouse size with available locations (Baudin, 2004; Koster et al., 2007). Generally it can be distinguished between dedicated and dynamic storage assignment policies. In a dedicated storage assignment policy, each item has a dedicated storage location. In this case locations must be reserved even for products out of stock and each location must guarantee sufficient space for the maximum inventory to be stored, resulting in the lowest space utilization. Nevertheless, a dedicated storage assignment policy has the benefit that items can be grouped logically and a good stacking sequence, e.g. placing heavy items in the bottom shelves, can be obtained. In difference, a dynamic storage assignment policy assigns storage locations for incoming items dynamically. There are several different methods on how to assign storage locations in a dynamic storage assignment policy, ranging from a simple random assignment to more complex methods, such as class based storage. If implemented correctly a dynamic storage assignment policy could significantly increase the space utilisation and picking productivity (Koster et al., 2007).

In zoning the warehouse is divided into different zones and orders are split up accordingly. The aim is to reduce the travel distances and traffic congestion in aisles, which should increase the picking productivity. Two different approaches can be distinguished, firstly progressive assembly and secondly parallel picking. In progressive assembly the order picking is initiated in one zone and passed on to the next zone after completion. Alternatively in parallel picking an order is picked simultaneously in different zones and accumulated after picking. The biggest challenge in zoning is to balance the workload amongst zones. Zoning is naturally applied if product characteristics vary within one order, e.g. temperature or safety requirements (Koster et al., 2007).

One special type of zoning is to implement a forward-reserve allocation. In this allocation, the bulk stock is kept in a reserve area, from which a picking stock is internally replenished to a Forward Picking Area (FPA). By doing so the FPA can be restricted in size and travel distances can be significantly reduced. The size of the FPA and the number of SKUs in it will determine the trade-off between additional replenishment and savings in picking effort. Therefore, it needs to be decided which items, to what quantities and where they should be placed in the FPA. In order for an item to be suitable to be stored in the FPA, the savings in order picking must outweigh the additional replenishment costs. Certain SKUs might be entirely stored in either the reserve or the forward area, depending on demand quantities and frequencies (Koster et al., 2007).

One last organisational and operational policy that is often used when order sizes are small is called batching. In batching several orders are batched together instead of picking each order separately, which can reduce travel times. Batching can follow either a proximity batching approach or a time window batching approach. In proximity batching orders are batched according to the proximity of storage locations within the different orders. This can be done via multiple heuristic algorithms. In time window batching, orders are batched according to the time window they arrived in or are to be shipped out (Choe and Sharp, 1991). If orders are not sorted while picked, a subsequent sorting might be required to split batches again and to consolidate items to complete orders. This can be done either manually or automated (Koster et al., 2007).

2.2 Automation of Order Picking Systems

This section begins by classifying different order picking system categories and states implications of an automated order picking system. Afterwards the objectives and decision steps in selecting and designing an order picking system are described and the focus is laid on AS/RSs. At last ICT related applications and devices are presented with a focus on Warehouse Management Systems. This section introduces relevant terms and aims to make the reader familiar with the implications of automated order picking systems.

2.2.1 Classification of Order Picking Systems

The literature provides several different approaches on how to classify order picking systems (e.g. Koster et al., 2007; Van den Berg, 1999). This study is based on a classification by Dallari et al. (2009), which uses four main drivers to distinguish between five different system categories. The four drivers are; (i) who picks the goods, (ii) who moves within the picking area, (iii) if conveyors are used to connect different picking zones, and (iv) the picking policy employed. The five system categories are picker-to-parts, parts-to-picker, pick-to-box, pick-and-sort, and completely automated picking. The level of automation is gradually increasing from picker-to-parts to completely automated picking systems (Dallari et al., 2009). The classification is illustrated in figure 2.3.

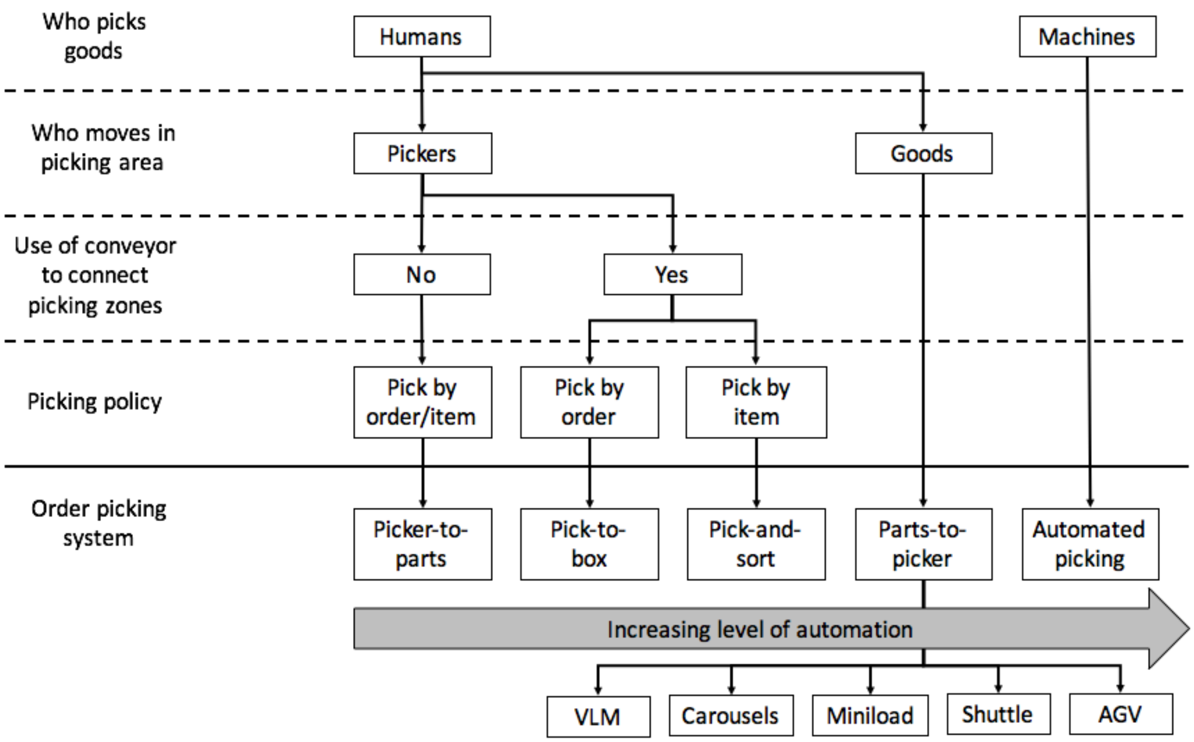


Figure 2.3 The classification of order picking system categories (Dallari et al., 2009).

The most common system in today's warehouses is the picker-to-parts system, where the picker walks or drives along the aisles and manually picks the items from the storage locations. It can further be distinguished between low-level and high-level picking. In low-level systems the items are stored in storage racks or bins that can be easily reached. In high-level systems high storage racks are used and a lifting truck or crane is required to reach the items (Koster et al., 2007). Picker-to-parts system are easy to implement, adapt and scale, but the productivity is low and labour costs are high (Hamberg and Verriet, 2012; Sowinski, 2013). The most appropriate application is for low picking volumes and a limited amount of SKUs (Marchet et al., 2014).

In pick-to-box systems, also known as pick-and-pass systems, the picking area is divided into zones that are connected through conveyors. Orders are picked sequentially by zone and sorted according to destination when completed. Each customer order corresponds to one picking box, which is passed on to the next zone as soon as all required items are picked in the current zone. As always with zoning, the difficulty with pick-to-box systems is to balance the workload amongst the multiple picking zones (Dallari et al., 2009). Pick-to-box systems are preferable in contexts with a high number of small-sized items, medium-size flows and small order sizes (Marchet et al., 2014).

A pick-and-sort system consists of a picking and a sorting area. Multiple customer orders are batched, and after the order picking the items are put on a transport conveyor which forwards them to the sorting area. Pick-and-sort systems are normally operated in picking waves, where all orders are sorted before the next wave is released, this requires big batch sizes of at least 20 customer orders per wave. Due to the high amount of orders, the sorting mechanism must be quite advanced. A common setup is to use a circulation conveyor with an automated divert mechanism (Dallari et al., 2009). An exemplary system is shown in figure 2.4.

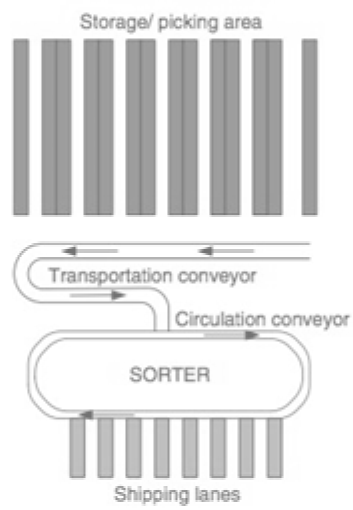


Figure 2.4 Advanced sorting system with circulation conveyor (Koster et al., 2007).

All items enter the circulation conveyor via the transport conveyor before being sorted into shipping lanes. To avoid blocking of shipping lanes items circulate on the conveyor until all items of an order are picked. When an order is complete it is assigned to a shipping lane (Dallari et al., 2009; Koster et al., 2007).

As the name suggests, in a parts-to-picker system the goods are transported to the operator. An automated Storage and Retrieval (S/R) device brings unit loads from the storage area to picking stations, where pickers extract the required amount of each item. Subsequently, the unit loads are conveyed back to the storage area (Marchet et al., 2014). The underlying technology in parts-to-picker systems is described as AS/RSs, which include vertical carousels, horizontal carousels, VLMs, miniload systems, shuttles or Automated Guided Vehicles (AGVs) (Koster et al., 2007). The picking costs can be reduced with parts-to-picker systems due to higher space utilization and less man hours required (Marchet et al., 2014). According to Dallari et al. (2009) a parts-to-picker system should be used for low picking volumes, small order sizes and a high number of SKUs.

Fully automated picking systems are usually separated from other warehousing areas and connected via automatic conveyors. In fully automated picking systems either automatic dispensers (A-frame or V-frame) or robots are used (Baker and Halim, 2007). These systems are still implemented very rarely, due to the high investment costs and the limited, highly specific, application area. Those systems are expected to be feasible for high-speed retrieval activities (Dallari et al., 2009) and special cases with small relatively uniform goods with high values (Koster et al., 2007).

2.2.2 Automated Order Picking Systems

The implementation of an automated order picking system is expected to result in a variety of benefits. Generally the associated benefits can be separated into efficiency and effectiveness improvements (Marchet et al., 2014). The efficiency improvements found by all sources are space savings and reduced operational costs. Space savings can be achieved since items can be stored denser and higher, if automated order picking systems are used. Reduced operational costs are linked to the savings in human labour (Baker and Halim, 2007; Koster et al., 2007; Marchet et al., 2014; Sowinski, 2013). Improvements related to effectiveness are reduced picking errors and quicker process times, which result in improved service levels (Baker and Halim, 2007; Marchet et al., 2014). The underlying idea is that the faster an order can be picked the earlier it is ready for shipping, which increases the probability to be ready at due time. This also allows for an increased flexibility in handling late changes, which could result in a competitive advantage (Koster et al., 2007).

Even though great improvements can be achieved with partial automation, certain aspects accelerate the more automated the order picking system becomes. By reducing human involvement, automated systems are typically less error-prone and provide higher accuracies (Dukic et al., 2013; Hamberg and Verriet, 2012; Koster et al., 2007). The less operators are involved the greater will safety and security improve. With fewer operators the chance of getting into an accident decreases, as well as the risk of theft (Baudin, 2004). Furthermore Baudin (2004) emphasizes that automated systems will not require as much labelling, scanning and administrative work as a manual systems.

Some sources also mention benefits that cannot directly be linked to efficiency and effectiveness improvements. Koster et al. (2007) point out that automated systems tend to continuously improve themselves, e.g. by applying dynamic storage and relocating goods overnight. Further the accessibility and the real-time overview of the inventory is expected to be improved. Due to the improvements in efficiency and effectiveness, automated order picking systems are expected to increase the ability to cope with future business growth (Baker and Halim, 2007).

Even if the benefits of automated order picking systems are very persuasive, there are also certain limitations and drawbacks to consider. The most common barriers are connected to investment costs and the flexibility of the systems. Automated order picking systems require high initial investment costs, which increase with size and level of automation. The flexibility refers to adaptability to changing contexts, such as changes in volumes, number of SKUs or even a complete change of products. The combination of requiring a high investment while being inflexible to change, is often what inhibits the implementation of automated order picking systems (Baudin, 2004; Marchet et al., 2014).

Other concerns relate to the implementation phase and the risk of interruption in case of a system failure. If an automated order picking system gets installed retrospectively, a common concern is that the remaining warehouse operations are interrupted during the implementation phase and targeted service levels can't be met (Marchet et al., 2014). The second concern regards interruption in case of a system failure and is linked to the characteristic of most automated order picking systems being closed, meaning that the system as such is not accessible for visual inspection or manual picking.

2.2.3 Selection and Design of an Order Picking System

The selection of a suitable order picking system is one of the key decisions to be made in warehousing and has a significant impact on the overall logistics cost and service level provided (Marchet et al., 2014). The aim is to maximise the service level under resource constraints in regards to labour, machines and capital. The service level can be expressed in terms of average delivery time, deviation of order delivery time, or the order accuracy (Goetschalckx and Ashayeri, 1989). The selection and design of an order picking system is a process with several interdependent steps, taking place at a tactical and operational level (Koster et al., 2007).

Literature provides several different approaches concerning what factors and variables should be considered for selecting an order picking system. Dallari et al. (2009) identify three key parameters for the selection; the number of order lines picked per day, the total number of items and the average order size. This is in line with Marchet et al. (2014), which however also include product characteristics in their decision-making. Goetschalckx and Ashayeri (1989) in turn distinguish between external and internal influential factors. They argue that external factors, such as the demand and replenishment patterns, affect which service level is aspired and hence what the order picking system is required to deliver. The internal factors on the other hand relate to the current state. Firstly the financial state of the company influences the likelihood and size of an investment. Secondly the characteristics of the current system, as mechanisation level, information availability, warehousing dimensions and even the current organisational and operational policies are considered to influence the selection (Goetschalckx and Ashayeri, 1989). In line with Dallari et al. (2009), table 2.1 provides a very simple comparison of the different automated order picking system categories based on the two key parameters total number of SKUs and order lines picked per day. The table shows ranges for the two parameters derived from several existing implementations. The underlying cases can be found in more detail in Appendix I.

Table 2.1 Comparison of automated order picking systems (based on Marchet et al., 2014 and Schrüfer, 2015).

	Number of SKUs	Throughput (order lines/day)
Pick-to-box	10,000 - 60,000	40,000 - 120,000
Pick-and-sort	40,000	35,000
Parts-to-picker	3000 - 700,000	60 - 480,000
Fully automated	850 - 60,000	6600 - 480,000

Even though, the table depicts only two parameters for the selection of an automated order picking system, it is already possible to identify different fields of application for the different order picking systems. For the case considered in this thesis, the number of SKUs amount to 17,500 and the throughput amounts to 3600 order lines per day. Considering the ranges in the table parts-to-picker systems is the only system category in range for both parameters, and hence in focus for this study. After a system category is selected additional parameters, as described by Goetschalckx and Ashayeri (1989), can support the selection of an automated order picking system type.

In a next step, the layout design needs to be planned, whereby both the facility layout and the internal layout within the order picking system must be considered (Koster et al., 2007). Three important decision steps can be distinguished. At first a decision regarding zoning must be made. A typical consideration could be to either use one zone or to separate two functional areas, one for fast-moving case picking and one for slow-moving items. In the next step a decision must be made regarding the equipment within the zones. At last the organizational and operational policies must be set for each of the zones, e.g. whether to batch or not (Marchet et al., 2014).

To guarantee a satisfactory selection and design of the order picking process, it is important to consider other warehousing activities that influence the order picking process. If value-adding activities, such as kitting, labelling or assembly, are to be included in the warehouse, they need to be scheduled and integrated in the order picking process, and hence would influence the design of the order picking system (Koster et al., 2007). Further the order picking system should be adjusted to deal with peak demands and it should preferably be scalable for later growth as well (Sowinski, 2013).

2.2.4 Information and Communication Technology Automation

Several ICT based applications and devices are available to complement automated or non-automated order picking systems. ICT includes IT systems (e.g. WMS), mobile devices (e.g. hand-held scanner) and fixed applications (e.g. laser pointer). Some of the advanced organizational and operational policies, such as item allocation policies or routing optimisation algorithms, require one or more ICT systems for coordination and optimisation of picking activities, tracking of customer orders, and managing of inventories (Marchet et al., 2014). It is common that modern warehouses are monitored by several ICT systems, which are continuously updated with latest information (Connolly, 2008). One of those is the WMS, which controls the operations within a warehouse. The WMS processes real time data to provide accurate information about inventory levels and item locations. It handles the movement and storage of goods in the warehouse and keeps track of the activities needed for this, such as shipping, receiving and picking. A WMS optimizes stock levels based on information about current stock, upcoming orders and historical data. More advanced WMSs are also capable to propose picking orders and routes (Ramaa et al., 2012; Richards, 2011).Three complexity levels of WMSs can be distinguished, ranging from basic to complex (Ramaa et al., 2012). The three complexity levels of WMSs are displayed in table 2.2.

Table 2.2 Different levels of Warehouse Management Systems (Ramaa et al., 2012).

Basic WMS	Only used for stock and location control. Used mostly to register information. The information is simple and focuses on the throughput. The system can generate storing and picking instructions for the workers.
Advanced WMS	Offers the same functions as a basic WMS but also includes planning functions for both resources and activities. This system focuses on throughput, stock and capacity analysis.
Complex WMS	This system allows for optimization of warehouses. Information on the exact storage location as well as intended destination for each product is available.

In order for a WMS system to work properly, it needs to be fed with real time data. This can be achieved by connecting mobile ICT devices (e.g. handheld scanners) to the WMS (Reif and Günthner, 2009). Those ICT devices are used to inform the WMS about activities (e.g. an order pick) taking place in the warehouse. Handheld scanners are widely used in warehouses today and a great variety of models exists, whereby a simple barcode scanner is the most common one (Hompel & Schmidt, 2007).

More advanced systems are pick-by-voice and pick-by-light. In a pick-by-voice system the picker wears a headset and gets vocal instructions of where to find the item and in which quantity the item should be picked. The main advantage of pick-by-voice solutions is that they are hands free which is particularly useful for bulky and heavy products, and can lead to a considerable rise in productivity (Marchet et al., 2014). Limitations are that the environment cannot be too noisy, and pickers might interfere each other. Lastly, the monotonous voice might be demotivating and tiring for the picker (Reif and Günther, 2009). In a pick-by-light system a light source is connected to each picking slot, which shows the picker what item and sometimes quantity to pick. Pick-by-light systems enhance productivity, decrease picking errors and simplify personnel training, which all results in reduced operational costs (Marchet et al., 2014). However, the initial investment costs are relatively high (Reif and Günthner, 2009).

In automated order picking systems advanced ICT applications become more feasible, since all items are picked through a limited number of picking stations and hence investments will have a greater impact. Three common picking aids can be distinguished, namely picking displays, LED strips and laser pointers. A picking display allows to illustrate what good needs to be picked, where it is located and what quantity needs to be picked. Alternatively a small LED strip can be placed next to the picking area showing, the same information, except from the picture. At last, a pick-to-light system with a laser pointer that points at the exact location can be used (Arnold et al., 2008). The applicability of those ICT applications depends on the compartment size within the picking area, which is shown in figure 2.5.

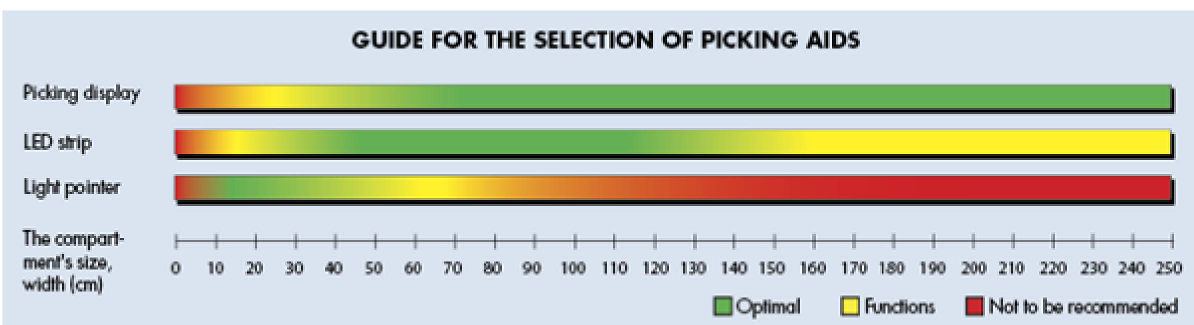


Figure 2.5 Guide for the selection of picking aids (Guide for the selection of picking aids, 2016).

2.3 Automated Storage and Retrieval Systems

This section begins with a general description of the operation principle behind AS/RSs and the respective limitations. In the following subsections three different AS/RSs are described in more detail, namely carousels, VLMs and miniload systems. AGVs and shuttles will not be considered, since existing research is still very limited. All sections begin with a more specific description of the operation principle for each system and subsequently respective pros and cons are described. The section aims to provide the reader with a basic understanding of the available AS/RSs, whereas specific systems from different suppliers are presented in the market research.

2.3.1 General

AS/RSs are partially automated order picking systems, where the movement of goods is automated, but the extraction is still performed manually. In most systems an automated S/R device retrieves unit loads filled with items from the storage area to the picking stations, where pickers extract the required amount of each item. Subsequently, the unit loads are conveyed back to the storage area before the next load is retrieved, which often leads to idle changeover times between two picks. However, in comparison to non-automated order picking systems, the operating costs can be reduced due to the higher space utilization and reduced man hours (Marchet et al., 2014). Since the picker does not need to retrieve the items, the process time can be shortened and the ergonomics for the picker improve (Arnold et al., 2008).

The Material Handling Institute of America (MHIA) distinguishes between two major groups of AS/RSs. Group 1 includes horizontal carousels, vertical carousels and VLMs. The systems of group 1 can be used individually or grouped in small to medium sized applications. Each subsystem typically has a single picking opening and items cannot be conveyed between subsystems. In order to reduce the changeover times between two picks it is common that one picker operates several subsystems (Arnold et al., 2008; Bartholdi and Hackman, 2014). In turn, systems in group 2 are structured as one big entity with several picking stations. Group 2 includes miniload, shuttle and AGV systems, which are normally used in larger applications. As the systems consist of one big entity, it is common to employ buffers at each picking station in order to reduce the changeover time between two picks (Bartholdi and Hackman, 2014).

For group 1 systems the efficiency is highly dependent on the stocking and it is very important to spread popular items and work amongst different subsystem, to avoid bottlenecks and to protect operations in case of a subsystem failure (Bartholdi and Hackman, 2014). Often AS/RSs are operated as an FPA, and hence require frequent replenishment. This can become a problem for AS/RSs with a single Input and Output (I/O) point, i.e. carousels and partially miniloads. In difference to picking stations, an I/O point is not only used for order picking but also for the replenishment of the system. Even though small demand variations can be counterbalanced to a limited degree, by switching between the order picking and replenishment activity (Arnold et al., 2008), it is not possible to speed up the order picking by assigning additional operators. Hence those systems are prone to become bottlenecks (Bartholdi and Hackman, 2014).

2.3.2 Carousels

A carousel can be described as a closed system with a rotatable circuit of shelving and a single I/O point. In order for parts to be picked, the carousel rotates until the required shelf reaches the I/O point (Bartholdi and Hackman, 2014). To reduce the travel distance carousels can rotate in both directions (Vickson, 1996). Carousels provide the goods sequentially, meaning it might take just as long for the system to bring the part to the picker, as it would take to retrieve it manually (Buley and Knott, 1986). To overcome this limitation, it is common to arrange two to three carousels in groups, which are called pods. This allows one operator to access several carousels from the same location and reduces waiting times (Bartholdi and Hackman, 2014).

Carousels can achieve very high space utilizations, since all of the space within the system is used for storage rather than transportation of the parts. Furthermore, a carousel system can achieve very high picking productivities for certain demand patterns, where several items have a joint demand. Since carousels move entire shelves, it is possible that several order lines can be picked without any changeover as more than one article can be stored on the same shelf (Arnold et al., 2008). The shelves are rather flexible regarding product dimensions, as they can be easily divided into smaller compartments retrospectively (Vickson, 1996).

Carousels are prone to weight imbalances. If heavy goods are stored and the weight distribution is not taken into account, the system can become imbalanced, as illustrated in figure 2.6. To avoid imbalances and reduce the danger of tipping over, most systems provide load recommendations, restrict operators or require reallocations (Industore, 2016).

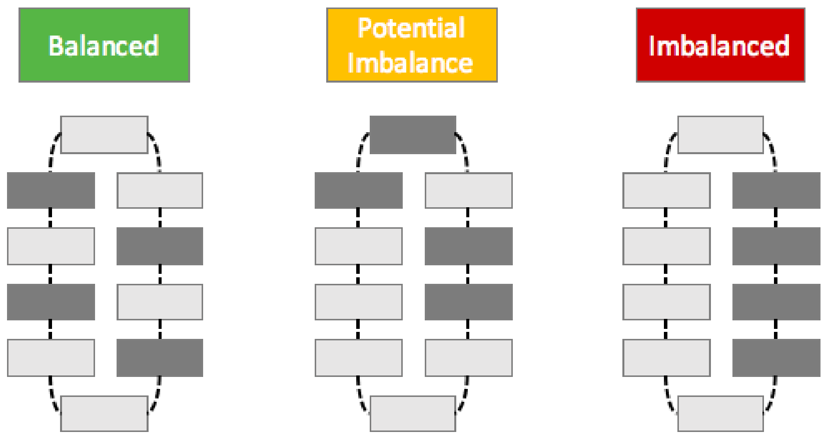


Figure 2.6 Weight imbalances in a carousel, ranging from balanced to highly imbalanced (based on Industore, 2016).

However, there are several limitations that cannot be overcome as well. Since carousel pods use a single I/O point, they perform poorly with demand surges (Bartholdi and Hackman, 2014). Another limitation is the scalability. It is not possible to increase the number of racks or to add another I/O point to a carousel system, hence to scale up an entire new carousel would be required (Arnold et al., 2008). Conclusively carousel system should be implemented in contexts with a continuous demand and low variations, a low to middle weight of goods and a high number of SKUs (Arnold et al., 2008).

Dependent on the direction of the rotation, two types of carousels can be distinguished. Vertical carousels, also known as paternosters, where the shelving rotates vertically and horizontal carousels which rotate on a flat circuit (Arnold et al., 2008). The two different principles are illustrated in figure 2.7.

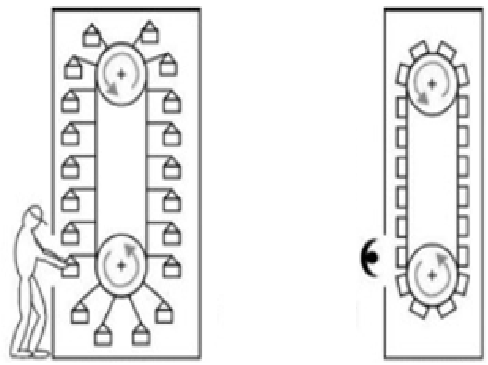


Figure 2.7 Comparison of a vertical and a horizontal carousel (Baudin, 2004).

Vertical carousels can make good use of the height in a warehouse. One big advantage over the horizontal carousel is that all items are presented in an ergonomic picking height, and hence the workplace ergonomic is superior compared to a horizontal carousel (Buley and Knott, 1986). Vertical carousels are commonly used for storage of small parts, because the shelves can be adapted with small compartments (Arnold et al., 2008).

Horizontal carousels are typically limited in height, as the picker must be able to reach all storage locations within a rack. In difference to the vertical carousels, the items are not always presented in an ergonomic picking height, making the horizontal carousel less ergonomic. Horizontal carousels can either consist of a single carousel body, or multiple sub carousels, with the simplest being a double carousel system. The difference is illustrated in figure 2.8. Generally a horizontal carousel with multiple sub carousels can achieve a higher throughput than standard carousel, due to the extra driving mechanism, which allows quicker access to storage locations (Hwang et al., 1999).

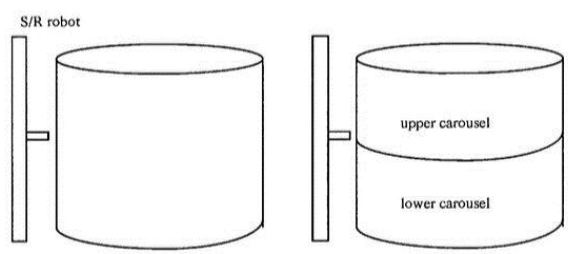


Figure 2.8 Single and double carousel in comparison (Hwang et al., 1999).

2.3.3 Vertical Lift Modules

A VLM can be seen as a development of the vertical carrousel where goods are stacked vertically on trays (Dukic et al., 2013). As can be seen in figure 2.9 a VLM consists of three columns for which the front and the back are used for storage and the one in the middle works as an elevator shaft through which the trays move.

Figure 2.9 Vertical Lift Module with two rows of storage trays, one shaft in the middle and one picking area in the front (Picture of Vertical Lift Module, 2016).

The items are moved via an S/R device that brings the trays to and from their position in the column, as illustrated in figure 2.10. The S/R device collects the tray and brings it down through the middle column and then lets it travel horizontally underneath the front column in order to reach the picker. When the operator is done with the tray, i.e. has extracted or replenished, the tray is returned to it's storage position (Dukic et al., 2013).

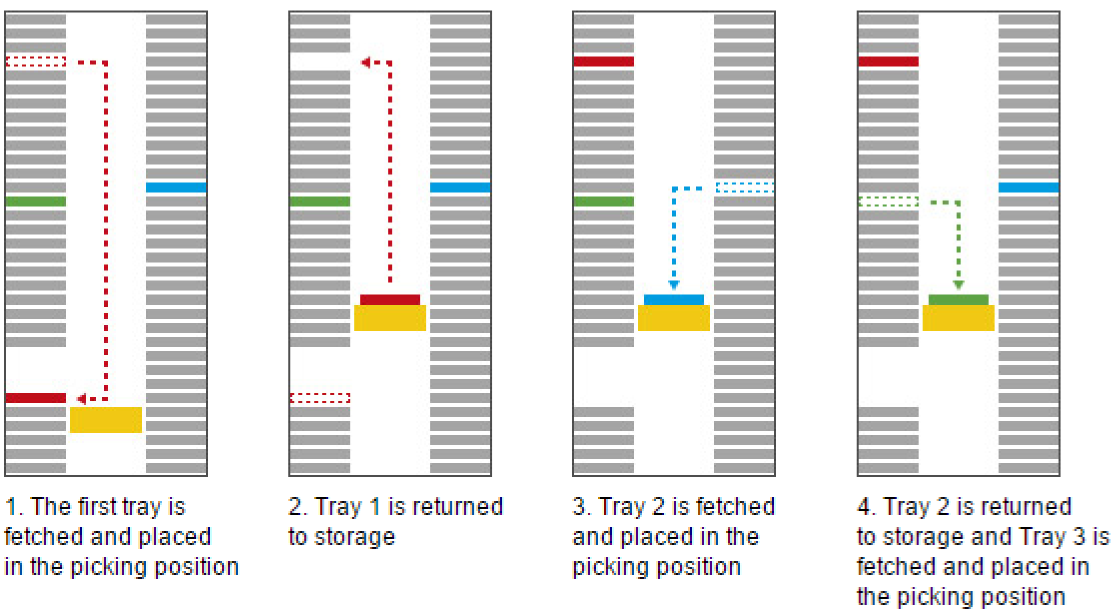


Figure 2.10 Vertical Lift Module operation principle, as seen from the side (This is how Compact lift works, 2016).

VLMs present all goods in an ergonomic picking height. To increase the picking productivity of a single picker, it is common that one picker operates several subsystems at once. Waiting time can further be reduced using a dual-tray mechanism that allows for two picking positions at different levels. Thus the picker can pick from one of the trays while the S/R device switches the other one (Dukic et al., 2013). This is illustrated in figure 2.11.

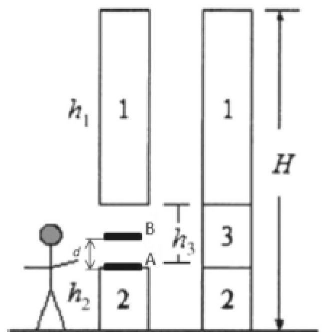


Figure 2.11 Vertical Lift Module with dual-trays. The operator can pick from tray A whilst tray B is being swapped and vice versa (Dukic et al., 2013).

2.3.4 Miniload Systems

The term miniload system describes an AS/RS consisting of several parallel positioned storage racks with narrow aisles between, in which one to several S/R devices operate (Bartholdi and Hackman, 2014; Lerher et al., 2011). Items are stored in small plastic bins, called miniloads. In those systems racks can typically be very high and aisles extremely narrow, often marginally wider than the miniload itself (Bartholdi and Hackman, 2014). The S/R device moves on rails that are attached to both the ceiling and the ground. It can move both horizontally and vertically to convey items between storage locations and the picking station (Arnold et al., 2008). The build-up and movement of a miniload system is illustrated in figure 2.12.

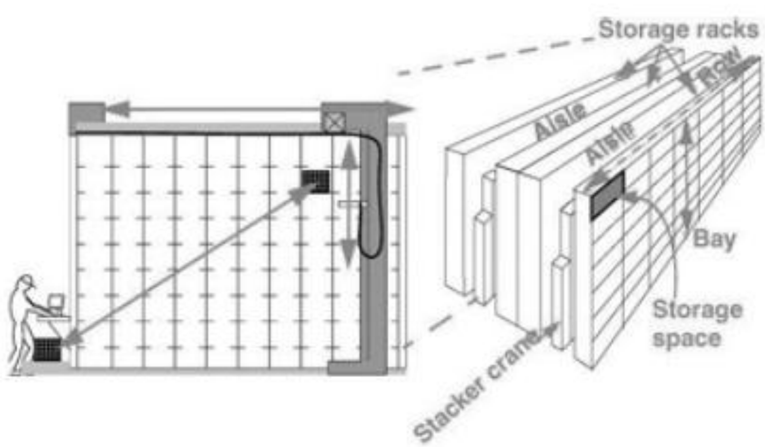


Figure 2.12 Build-up and movement of a miniload system (Baudin, 2004).

A miniload system can be operated either in single, dual or multiple command cycles. In a single-command cycle the S/R device executes either a put away or a retrieval of a unit load, which means the

S/R device always travels back to the I/O point after a put away or retrieval. In difference, in a dual-command cycle the S/R device puts away one unit load and then retrieves another before returning to the I/O point. Naturally it is more productive to operate dual-command cycles, but if retrieval is urgent, it might be advisable to run only retrieval SC cycles and postpone the put away (Bartholdi and Hackman, 2014). Lastly, with multiple command cycles more than one shuttle is used and within one cycle several loads can be retrieved or dropped off (Koster et al., 2007). So even though a miniload system has technically only one I/O point, there are ways to counteract the associated drawbacks. One way is to include a buffer before the picking station, to ensure a high picking productivity (Lerher et al., 2011).

Lerher et al. (2011) describe the system as fairly inflexible and difficult to adapt to future demand changes. The flexibility is further limited due to the fixed measurements of the storage bins, which cannot be changed retrospectively (Karlsson, 2016).

3. METHOD

This chapter describes how the thesis was conducted in order to fulfil the purpose. It aims to enable the reader to recreate the procedure and to evaluate the reliability of the project and the results. In order to answer the defined research questions a literature review, empirical study and market research were conducted. The empirical study was focussed on one specific case to clearly define the scope and to test the findings. In order to provide a holistic view, a variety of evidence such as observations, interviews and raw data was used (Yin, 2014). The research design is expected to be easily replicable and can thus be used in other industries and operations.

At first the initial plan of the study is described and later the actual steps are explained in more detail. The project began with a literature review to get a fundamental understanding of the subject. Following, data was collected through interviews, observations and information retrieved from the WMS systems at KN. At last, a market research was conducted to identify potential suppliers of automated order picking systems. Each part is described in more detail in the following sections.

3.1 PLAN

The initial plan to conduct this thesis, was highly influenced by KN's task description. It was planned to start off with a visit to Norrköping in order to fully understand the task and context. In the beginning the scope was extremely broad. Besides a system overview and current situation analysis, it was planned to consider investment and operational costs, perform a risk and opportunity analysis and develop an implementation approach to ultimately create a business case. This scope was gradually narrowed down to fit the scope of a master thesis, resulting in the current purpose.

It was planned to conduct a thorough literature research to identify relevant literature in the research stream of warehouse automation and to gain a fundamental understanding of the subject. The authors expected to finalize the theoretical framework within several weeks. Afterwards the empirical study and market research were planned to be conducted in parallel. The empirical study was planned to begin with a data analysis of the outbound data and a second visit to the warehouse in Norrköping. The authors initially expected to perform detailed time studies for the current order picking process in order to create the business case. The market research was expected to provide a broad overview of potential suppliers of automated order picking systems. It was planned to research several provider catalogues and perform supporting interviews for few selected suppliers. As a last step it was planned to analyse the findings and to identify one specific system best suitable for KN.

3.2 Literature Review

A thorough literature review was performed in order to gain a fundamental understanding of relevant subjects and prior research, and to create a theoretical frame of reference for the thesis. The theoretical data was obtained from multiple sources, including the database of Chalmers Library, Google Scholar and ScienceDirect as well as further sources identified through the tool "EEXCES". The search for relevant literature was based on keywords, such as warehouse automation, automated order picking as well as automated storage and retrieval systems. The literature review was regarded as an ongoing process and relevant theory was added and withdrawn continuously during the study.

3.3 Data Collection

Data collection and empirical research can be divided into qualitative, quantitative and mixed research (Bryman and Bell, 2015). This study entails both qualitative and quantitative methods. In the beginning a qualitative approach was used to gather primary data through discussions, interviews and process observations. This supported the understanding of the current situation, which was necessary for creating process maps. At a later stage a variety of quantitative methods were used, in order to analyse secondary data from the WMS.

A basic understanding of the context and current situation was achieved through a two-day visit to the warehouse in Norrköping in December 2015. The visit was used to observe the current warehouse processes and address open questions. A variety of unstructured interviews were held with both the steering group and team leaders of the operation to deepen the understanding of the project. On the first day a tour was conducted to introduce the operations and to provide detailed information about the warehouse characteristics and operations (e.g. zones, average number of workers, productivity goals). On the second day initial observations of order picking process were made and the authors performed some picking by themselves to get a better understanding of the processes.

The secondary data from the WMSs of Bosch and KN was not obtained before the beginning of 2016, to ensure that the data received, covered all of 2015. The data received included reporting regarding claims against KN in January 2016, the article master files for Bosch and Casall as well as the respective outbound data for the year 2015. The raw data was fed into Microsoft Excel to allow sorting, data analysis and visualization. The data was still updated several times as the first set of data was incomplete which required some rework of the calculations.

A second two-day warehouse visit took place in February 2016. This visit was used to create a detailed warehouse layout of the mezzanine and to develop process maps for the inbound/replenishment, order picking and packaging processes. The process maps, as a graphical representation, were created in order to understand linkages between different activities and to identify deviations from the desired condition to the actual state (Klotz et al., 2008). The considered processes were broken down into activities with clear boundaries, whereas each activity had to be clearly defined and distinguishable (Damelio, 2011). All maps were created as standard flow charts, following the American National Standard Institute (ANSI) principle, which is commonly used to illustrate decision steps and alternative process paths. Before the actual mapping, involved parties were interviewed and relevant information was collected. The process maps were developed according to the approach described by Conger (2011). At first an initial draft of activities that occur during the process was created, out of which a first map was drawn. As recommended, the first drafts were made on paper during the observation to directly identify missing information and to allow for quick changes. The first map was then reviewed and validated iteratively in regards to completeness and level of detail. After approval, a digital map using Microsoft PowerPoint was created that was shown to involved parties for final approval. The mezzanine layout was created in a similar manner. The measurements were taken with the help of a laser rangefinder and first drafts were created on paper, before the final layout was created in Microsoft Visio.

3.4 Market Research

After a basic understanding of order picking systems was established and the context was clear, the authors engaged in a market research. Different systems were identified and basic information was gathered through web research and catalogue screening. The market research found Kardex Remstar, Weland Lagersystem, Constructor and Swisslog as the most reasonable suppliers to include. The market research can be understood as an additional source of information to complement the theoretical findings.

Semi-structured interviews, which use open-ended questions from which a dialog continues, were conducted (DiCicco-Bloom and Crabtree, 2006). At first Mark Waldemarson from Kardex Remstar, was interviewed in January 2016. As part of the interview two complementary site visits were performed to showcase a Kardex Remstar VLM. In February 2016, further interviews and site visits took place with Björn Karlsson from Weland Lagersystem; Joel Hallén from Constructor and Hans Sparf from Swisslog. The site visits provided useful insights about what aspects and measurements should be taken into consideration for the design of an order picking system.

4. EMPIRICAL STUDY

This chapter presents the information gathered from both site visits and data received from KN regarding shipments, product characteristics and claims. It starts off with a short description of KN and moves on to describing the warehouse. It further provides a description of the processes involved including process maps and warehouse layouts. Subsequently the chapter presents the characteristics of the shipped goods as this sets restrictions on what systems that can be implemented. Finally the chapter covers a brief section regarding the claims received by KN from their customers.

This chapter explains both the layout, processes and product characteristics very thoroughly. The current situation is important to understand as that is the main incentive for automation in this case. The widespread layout and somewhat inefficient processes is what is expected to improve the most with automation, the claim rate is also expected to be affected. The product characteristics imply limitations for the automated order picking system and thus must be described in high detail ensure that the system can handle all requirements.

4.1 KUEHNE + NAGEL AB

KN is one of the largest freight forwarder and logistics service provider in the world, and is ranked as the second largest global contract logistics provider. Their logistics services include all activities from logistics planning to control and execution (KN1, 2015). In Sweden KN operates on seven different locations and is divided into several operating segments. One of these segments is Contract Logistics which includes the operation of warehouses; this thesis focuses on the Contract Logistics operations in their warehouse in Norrköping. In Norrköping KN handles both small and larger goods, but this thesis focuses on the smaller ones, ranging from sport clothes and accessories, to spare parts and drill bits for power- and gardening tools.

KN’s main goals with an implementation of an automated order picking system is, on the short term, to increase the productivity and thus reduce the number of man hours required for the picking, hence lowering the operational costs. On the long term their goal is to reduce the space required for storage, thus freeing up space within the warehouse allowing to take on additional customers. The thesis takes this into account as it is expected to highly influence the final recommendation.

4.2 THE WAREHOUSE IN NORRKÖPING

The warehouse in Norrköping was built in 2004 and extended in 2007. Today it has a ground level of approximately 21,000 m^2 and a mezzanine of 4000 m^2. There are possibilities to extend the warehouse with another 6000 m^2 on the ground level if necessary. The ceiling height is 10.9 meters on the ground level and 4.6 meters on the mezzanine. The ground level of the warehouse is used for inbound and outbound logistics and bulk storage in high racks for 10 different customers. The ground level is used as bulk storage for large goods whilst smaller items are stored on the mezzanine.

The mezzanine is 196 meters long and 18 meters wide, the layout is shown in figure 4.1. It is roughly divided into four parts, one for each customer. The majority is dedicated to Bosch and Casall and the remaining area is mixed, partially used for Ericsson, Samsung and as buffer storage for Casall. There are four pallet reception areas in which goods are lifted up and down via pallet lifts. The mezzanine and ground level are linked via two circular staircases and one slide in which is used to send the packaged goods down.

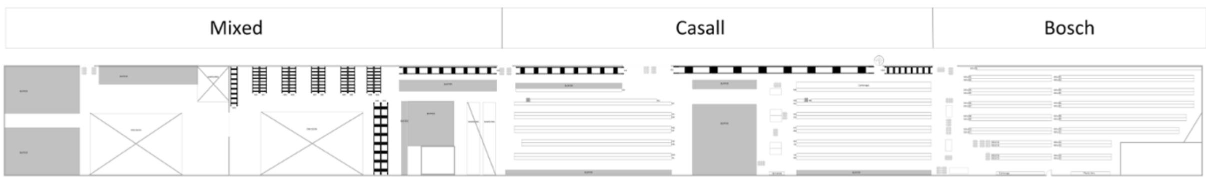


Figure 4.1 Layout of the mezzanine at KN. The area to the right is dedicated to Bosch and the area adjacent is dedicated to Casall. The area to the left of the mezzanine is a mixed zone. The white rectangles represent standard racks, the black and white striped areas represents pallet racks and the grey area are buffer zones. The crossed out white zones in the left are used for Samsung and Ericsson and disregarded in this report. The holes in the wall with pallets in front represent pallet lifts. This figure can be seen in a larger version in Appendix II.

The layout is based on the authors own measurements of the area, hence some measurements might contain slight errors. However, it still provides an overview of the area and it is possible to get a rough understanding of the distance travelled by the pickers. As can be seen the area belonging to Casall stretches all the way along the mezzanine. As the thesis focuses on Bosch and Casall more detailed figures and descriptions of those areas are presented in the following subsections.

The goods from Bosch range from smaller drills to spare parts needed for gardening tools. The processes are operated in Bosch's own WMS and all shipments are Business-to-Business (B2B) only. The goods for Casall range between sports clothes and other training equipment. KN uses its own WMS for Casall and besides B2B, Business-to-Customer (B2C) shipments related to e-commerce occur to a limited degree as well. The B2C orders are predominantly small and consist of only a couple of items.

4.2.1 Bosch

The Bosch picking area is shown in more detail in figure 4.2. It consists of 15 rows of racks with 8509 storage locations and three desks on which the products are packed and scanned for both inbound and outbound operations. In the area around the desks the material required for the packing, such as boxes and wrapping, is stored on pallets. The goods are delivered on pallets via a pallet reception area and the packed boxes are sent down through a slide located next to it. The entire area is 45 meters long and 18 meters wide, summing up to 900 m^2.

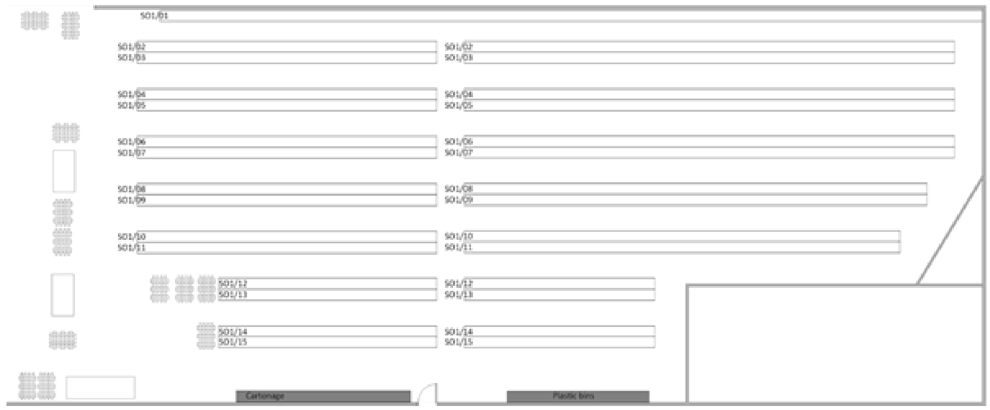


Figure 4.2 Layout of the area in the mezzanine reserved for Bosch. The smaller white rectangles to the left represent desks and the "grids" beside them are pallets.

4.2.2 Casall

The area dedicated for Casall measures 70 meters in length and 18 meters in width, accounting for 1400 m^2. The area is shown in figure 4.3.

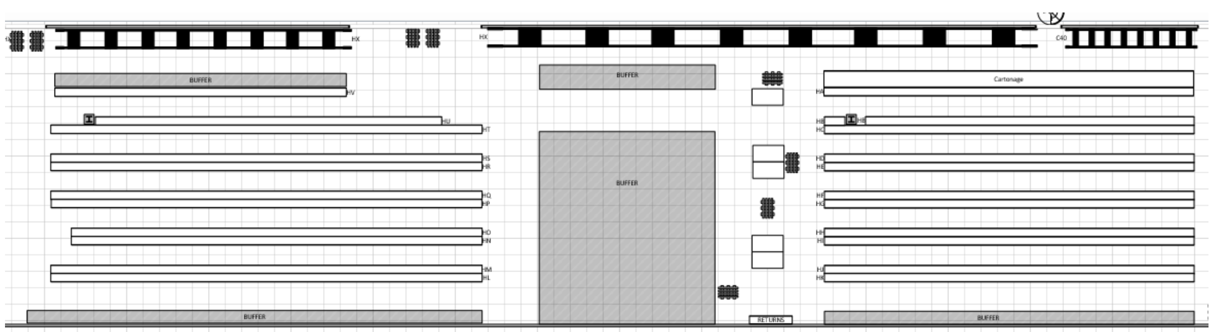


Figure 4.3 Layout of the area in the mezzanine reserved for Casall.

The area assigned to Casall contains two zones of 11 rows of racks, which are all used for storing clothes. In the middle of these areas there is a reception and packing area. This area contains five desks and similar to Bosch packaging material is stored here on pallets. The racks are used for storage of clothing and the pallet racks are used for storage of training equipment. The pallet racks continue in the mixed area as shown in figure 4.4.

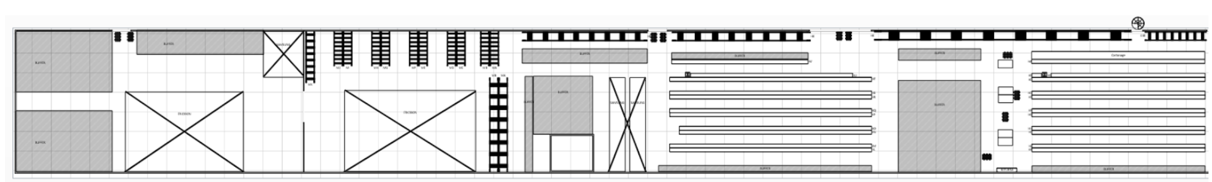


Figure 4.4 Layout of the area in the mezzanine reserved for Casall including all the buffer zones.

As seen in figure 4.4 Casall also uses a lot of the other area on the mezzanine for buffers. The distance between the dedicated Casall area and the far left side of the mezzanine is 84 meters. The buffer is stored on pallets and the size of it varies depending on season.

4.3 WAREHOUSE PROCESSES IN NORRKÖPING

The order picking system for both Bosch and Casall can be defined as a low-level picker-to-part system. This section describes the order picking process for Bosch and Casall and the respective steps they contain. If the processes differ amongst them, they are described in separate subsections. The section describes the activities in the same order they occur in the warehouse. At first the planning is described, then inbound and replenishment, order picking and finally the packaging process.

4.3.1 Planning

KN has 25 Full-Time Employees (FTEs) in the warehouse, whereas 13 are employed by KN and 12 are employed by the employment agency PEMA. Figure 4.5 shows the number of workers employed on the mezzanine throughout 2015. In addition to the FTEs, KN uses several flex time employees from PEMA that can be called in according to the need. There is a higher turnover of these employees and whenever someone new arrives they are in need of training. KN tries to plan for this and schedules the workers to start a couple of days before the peak seasons start. Although this is not possible to do for unexpected demand changes.

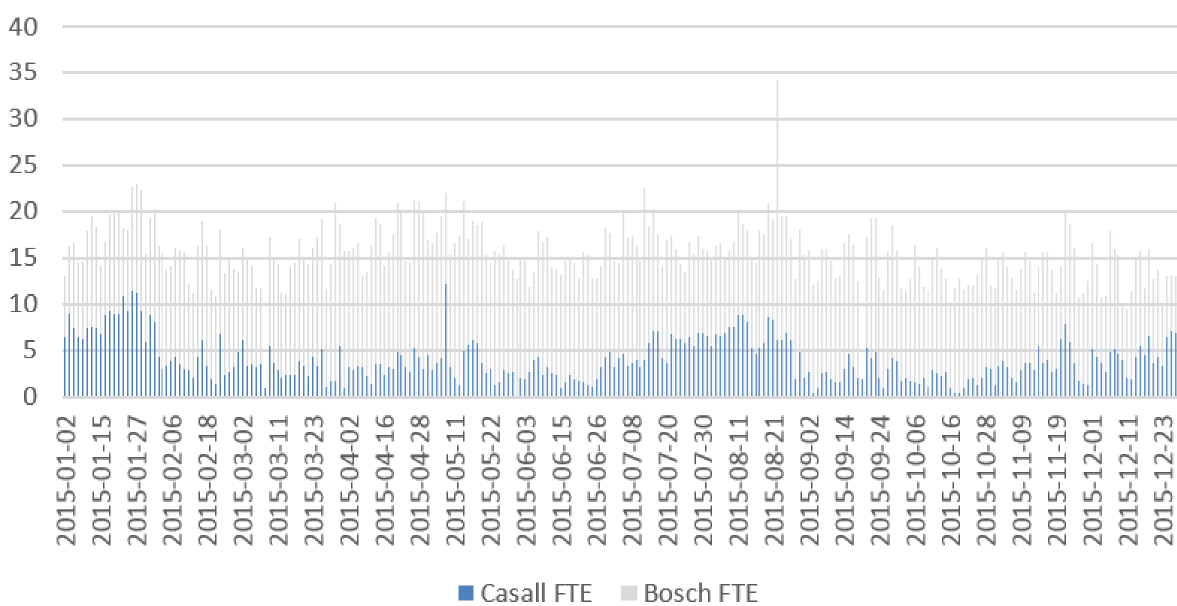


Figure 4.5 Stacked graph of the daily amount of workers assigned to the mezzanine in 2015.

The data for figure 4.5 has been calculated from the total amount of working hours. An assumption has been made that Casall always has one FTE working on the ground level and two thirds of the workers assigned for Bosch work on the ground level. As can be seen in the figure there is on average 15.5 workers employed on the mezzanine of which 4 are dedicated to Casall and 11.5 to Bosch.

The scheduling of workers is done on a seasonal, weekly and daily level. The final daily schedule is only decided one day in advance, as it depends on the information received regarding inbound and outbound shipments. The information regarding the inbound deliveries is received at least 24 hours prior to the arrival of the truck. If the information is not received in advance KN is allowed to prolong the inbound delivery time by one day. The information regarding the outbound deliveries are received at different times during the day. At 14:00, the day before the deliveries, KN receives a forecast from Bosch and Casall of what needs to be sent out the next day. At 16:00 they receive their first actual orders, a second batch of orders is received at 17:00, the third at 00:00 and the final batch is sent to KN 06:00 for delivery the same day. KN can also handle express deliveries that are to be sent out the same day, these orders arrive to KN at 10:00 and 13:00.

4.3.2 Inbound Deliveries and Replenishment

Inbound deliveries are done for both Bosch and Casall upon goods reception. As Casall uses a buffer, replenishment to the picking area takes place when necessary. For both Bosch and Casall, the replenishment of the packaging material is done by the shift leader when required. There are no exact times or quantities as when to replenish the packaging material. It is done by visual inspection and experience of how high quantities are needed. The item inbound and replenishment processes of Bosch and Casall vary slightly both due to the quantities delivered and also the WMS systems used. They are described in more detail below.

Bosch

KN receives inbound deliveries from Bosch four times a day at the following times: 07:15, 09:00, 11:00 and 14:00. All parts for the mezzanine arrive in mixed pallets with different items and SKUs, and need to be available on stock within 24 hours. All the items are directly stored in the picking area on the mezzanine upon arrival and no buffer storage is used.

Bosch's goods arrive in three different SKUs, transport pack, master pack and single pack. Single pack is the smallest unit and can be fitted into master packs in quantities of five, ten, twenty etc. The master packs can in turn be fitted into transfer packs which is the biggest package except from full pallets, a transfer pack contains approximately five to ten master packs. The location in which the goods are to be stored is chosen by the WMS system. Each part can be stored in a maximum of three different storage locations, thus if possible the system tries not to break the transport pack. But if necessary the transport pack can be divided into master packs and the master packs placed in different storage locations. Although, the master pack must not be broken into single packs.

The inbound process for Bosch is shown in figure 4.6. The process starts with worker scanning the item barcode and placing the item on a push cart. The scanner provides the worker with information regarding the quantities on the delivery order and the worker confirms the delivered quantity. In case of a deviation the hand-held scanner gives a warning signal to the worker. When the part is scanned and the quantity is confirmed a barcode label is printed containing information regarding which location the item is to be stored. The label is placed next to the unpacked item on the push cart. When the push cart is filled with items and their corresponding labels, another worker takes the push cart and scans all the labels. The scanner automatically provides the picker with the items in the optimal picking route. The operator walks to the correct storage location, scans the item barcode, followed by the storage location and places the item on the shelf. This is repeated for all parts until the push cart is empty.

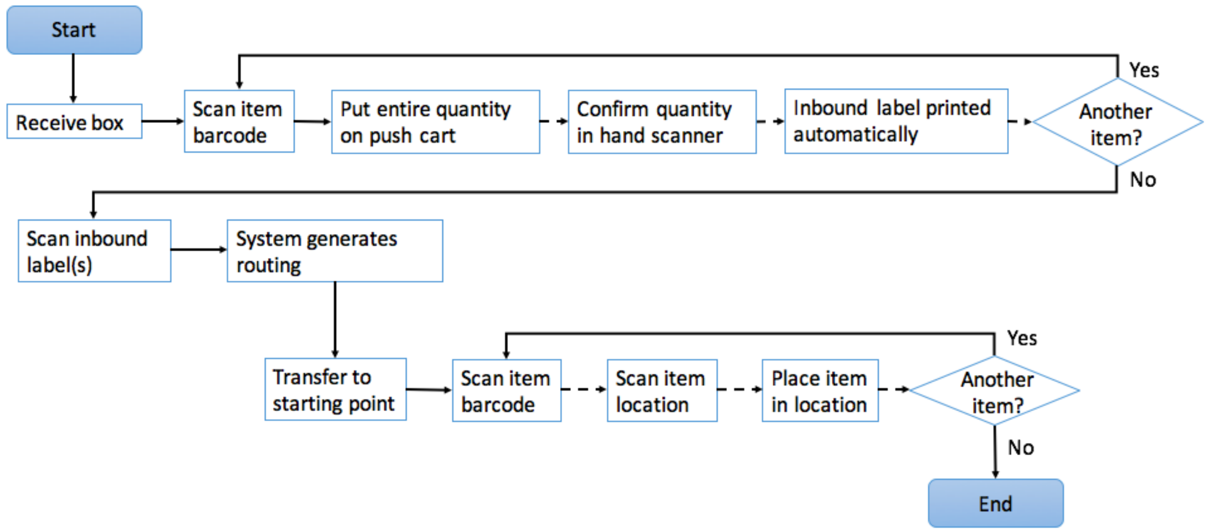


Figure 4.6 Process map of the inbound process for Bosch.

Casall

The articles for Bosch arrive in containers with large quantities, which do not fit into the FPA, thus there is a need for buffer storages. All clothing items arrive in standard size boxes of 30 x 40 x 30 cm. When an inbound delivery contains an article that has not previously been handled by KN, it is measured and an assigned to an appropriate storage location. If articles arrive in full pallets, they are put straight into buffer storage, whereas all less-than-pallet-load are directly replenished in the shelves. In the replenishment process the article number is scanned and the article placed in the storage location without any further scanning. The entire inbound and replenishment process for Casall is illustrated in figure 4.7.

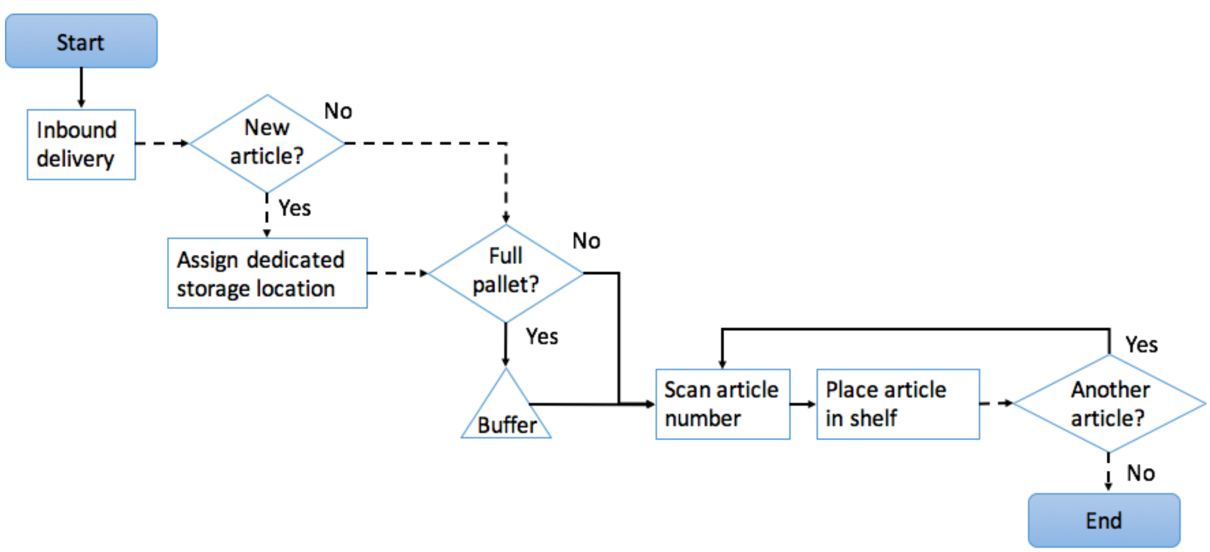


Figure 4.7 Process map of the inbound and replenishment process for Casall.

Sometimes handwritten notes are used to keep track of buffer locations, see figure 4.8. The replenishment from buffer is initiated by the WMS. The WMS checks the daily orders and asks for replenishment if the current picking stock does not suffice for all orders.

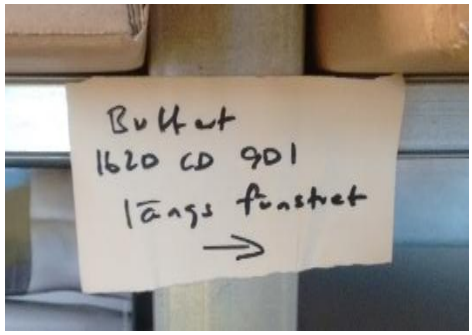


Figure 4.8 Handwritten sign on a shelf indicating where the buffer is for part number 1620 CD 9D1.

The boxes in which the items arrive usually only contain one type of goods, but sometimes they can contain two different colours or sizes of the same model. If so, these boxes need to be split before the replenishment can take place as each size and colour corresponds to a different article number and is to be stored in a different storage location. Normally items of different sizes are stored close to each other, whereas one size is stored on each shelf. To avoid confusion for the pickers similar items, such as two types of black leggings, are rarely stored directly next to each other.

Due to fashion seasonality, products are phased out on a regular basis and at the end of each season KN receives a list from Casall of which articles is affected by the phasing out process. Phased out products are assigned a new storage location where more than one part can be put on the same shelf in order to save space. In reference to figure 4.3 showing the layout of the Casall area, the fast moving goods are stored at the racks to the right and the slow movers are stored to the racks at the left. This allows for the articles with the highest frequency to be placed close to each other, reducing the travel distance for the picker.

4.3.3 Order picking

The order picking process of Bosch and Casall differ, due to the different WMS systems used and the fact that the picking process for several of Bosch’s orders are continued on the ground floor. The section begins with describing the picking process for Bosch, and afterwards the one for Casall.

Bosch

Figure 4.9 shows the entire picking process for Bosch. The process starts with the picker choosing between one to nine orders to pick in the hand-held scanner. Orders are batched according to the time window batching approach in combination with route planning. The routing algorithm recommends an s-shape route with a fixed starting aisle, whereas aisles can be skipped and cross aisles can be used. The items to be picked are shown on the scanner in the correct routing order. Interviews with KN indicated that each picker walks a total distance of 15 to 20 km and the picking productivity is assumed to be somewhere between 50 and 70 picks per picker and hour.

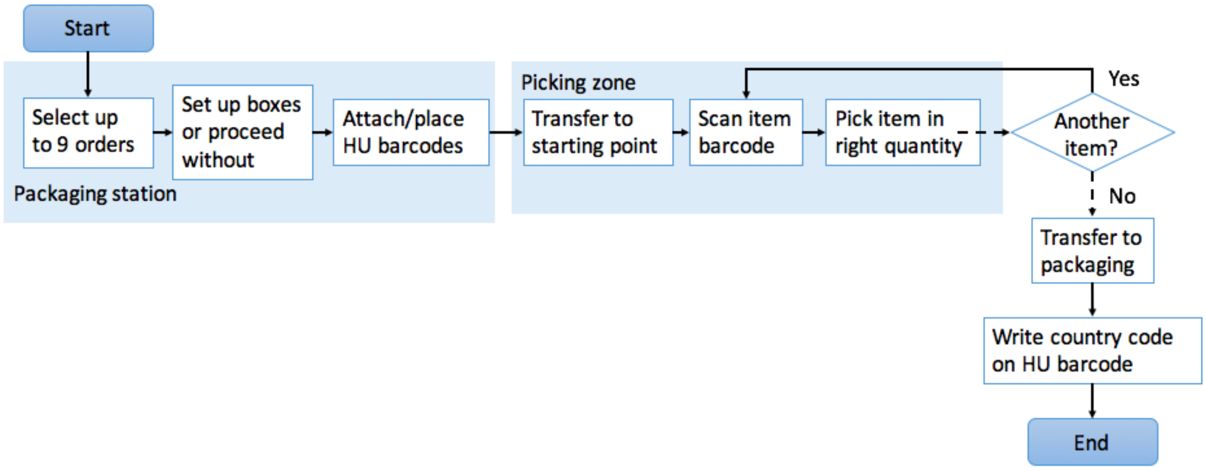


Figure 4.9 Process map of the order picking process for Bosch.

When the orders are selected the hand-held scanner provides the picker with recommended box sizes for each order. The calculation of box size is based on the total order volume and does not take individual measurements of the products into consideration, hence there are some cases where the items don't fit into the box and the picker has to choose a bigger box retrospectively. The picker usually begins the picking process by setting the appropriate boxes onto a push cart. In order to keep track of which items belong to which order, handling unit (HU) barcodes are used and attached to the boxes. In some cases the picker chooses to place the items on the push cart without boxes, in this case the HU barcodes are placed on the push cart and the picked parts are placed loose next to it. When this variant is used the picker chooses the correct box size at the end of the order picking, attaches the HU barcode to the box and places the picked parts in it.

The scanner provides the picker with information regarding the rack row, rack number, shelf level and also the position on the shelf. At this stage the picker brings the push cart and moves to the picking zone. The picker goes to the correct aisle, finds the right rack, looks at the correct level and position and finds the desired article there. The picker scans the barcode of the product and picks the required quantity as shown in the scanner, even if the quantity is more than one unit the barcode only needs scanning once. The parts are then placed in the correct box and the picker scans the HU barcode as well, in order to make sure that the parts belong to that order. If the required amount matches with the amount in a master pack the barcode of the master pack can be scanned instead of the barcode of a single item. When only one part is needed and the product comes in a master pack of more than one part the master pack is opened and the part taken from there. If a transport pack or master pack is emptied the picker should bring the cartonage back so that it is not left on the shelves. If the picker picks what the system believes is the last item on the shelf the hand-held scanner gives a notification, to which the picker can answer if the last item was actually picked. These locations are always double checked by the team leader at the end of the shift, to quickly notice deviations. However, if the picker picks the last item on the shelf and the system believes that there are still more products left the picker does not notify anyone about this. According to the working instructions the team leader should be informed, but according to interviews with the pickers this is most often not the case.

When the picker picks the last item of an order the hand-held scanner provides the picker with information regarding what country the order is to be shipped to. This information should be written on the HU barcode in order to simplify the prioritization of the orders that are to be completed with bigger parts on the lower floor. However, this is not always done.

Casall

The picking for Casall is done manually using paper lists of the orders. The picking process is shown in figure 4.10. As can be seen the process begins with the picker choosing the desired amount of orders to pick. This is done by the picker taking the printed orders from a pile and placing it on a clipboard attached to a push cart. As the orders are printed according to priority the picker is supposed to always take the order from the top of the pile. If the orders are small and located close to each other the picker can choose to pick up to 15 orders at a time, depending on how experienced the picker is and how many orders fit on the push cart. In this case the picker might deviate from the priority list. The picking productivity is estimated at 50 picks per hour and picker.

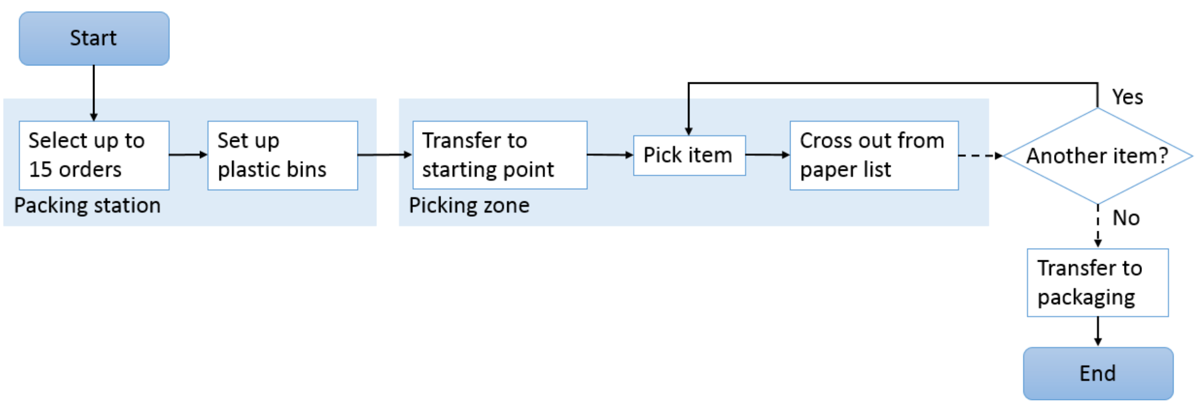


Figure 4.10 Process map of the order picking process for Casall.

The picker places plastic bins, used as picking boxes, on the push cart. The estimation of how many are needed is based on experience. In case of a small order the picker might decide not to use the push cart at all but instead just carry the items by hand. The picker is supposed to move through the aisles in an s-shape. The order lines in the order are printed according to the way the picker passes them in the aisles. Although, as the orders are printed one by one on a paper the picker has to find the optimal route if more than one order is picked at once. The printed order provides the picker with information regarding the rack row, rack number, shelf level and also the position on the shelf. The picker picks and places the right quantity in the box on the push cart and crosses out the item on the printed order. In some cases there is more than one item on each shelf, if so the picker needs to check the part number before choosing the article. The article number consists of three parts; a unique number, a colour code and finally the size. By experience the pickers roughly learns the colour codes thus simplifying the process of identifying the right part.

In some cases the boxes are not placed carefully on the shelves and therefore stick out risking the push cart to get caught. This also happens if the lids of the boxes are not properly closed, which is often the case as the pick is a lot smoother if the lids are left open. If the packages are emptied the picker is supposed to bring the cartonage back and throw it away.

Some Casall items are extreme fast movers and are usually ordered in quantities of full boxes or more, in this case the item is picked directly from the buffer storage. The location of the buffer location is in this case learnt by experience.

4.3.4 Packaging

The packaging process for Bosch and Casall is explained in this subsection. The process is described separately to the point of which shipping labels are attached to the boxes. For both companies the packed boxes are placed on a pallet which is plastic wrapped before shipping. The outbound shipping is done three times daily, one to each country served from this warehouse. At 16:00 the truck for Finland departs, at 16:00 and at 16:30 a truck for Sweden departs and the Norway truck departs at 17:00.

Bosch

After the order is picked it gets packaged, the process for this is shown in figure 4.11. In most cases the parts are already placed in the correct shipping boxes during the picking process, otherwise this is the first step taken at this station. The picker scans the HU barcode on the box to see if the order is finished at this stage or if it is supposed to be continued on the ground floor. Those boxes are sealed and sent down via the slide to the ground floor with the HU barcode attached to the box. The final check of these orders are done on the ground floor after the order is complete.

If the order is complete at the mezzanine the weight is checked in order to encounter deviations. In case of a deviation the picker manually checks the order to identify the mistake. A weight deviation of a few percent is accepted by the system to account for the weight of the packaging material. When the order has been confirmed the box is sealed and a shipping label is printed and attached to the box. The box is then sent down the slide to be shipped out.

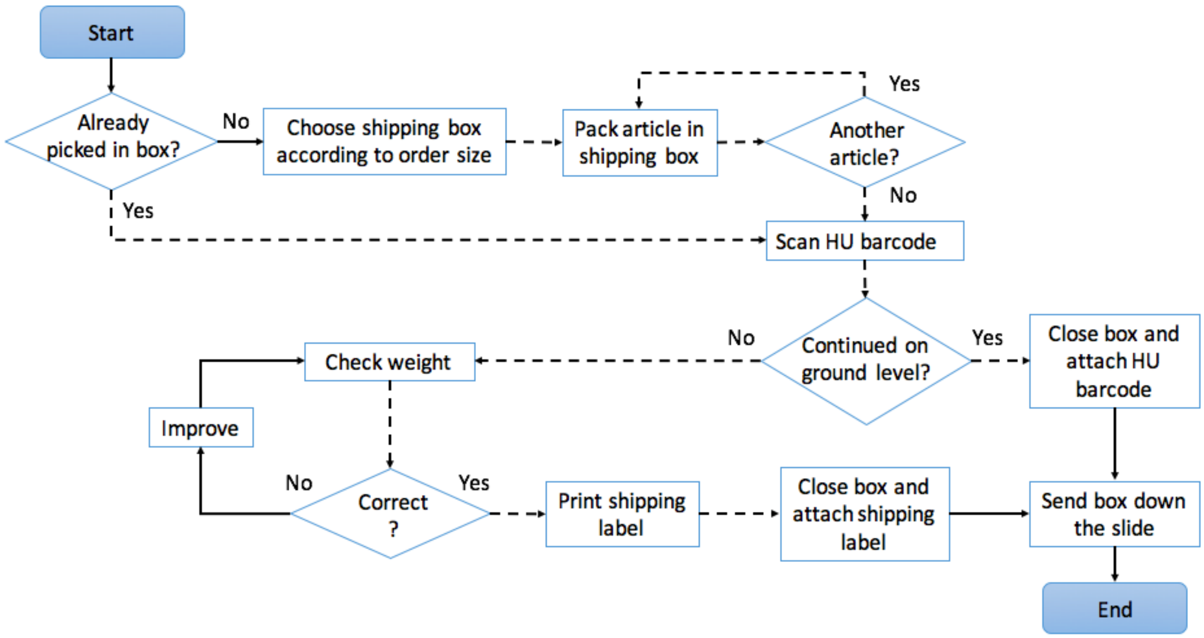


Figure 4.11 Process map of the packaging process for Bosch.

Casall

When the picker has picked all goods, the order is handed over to a packager at the packing station. The process for the packing station is shown in figure 4.12. The packager estimates the right box size based on experience and places the items in the box. Before placing the parts in the box they are scanned using a hand-held scanner to make sure that they match the order. If an incorrect item is scanned the computer notifies the packer of this and the packer has to correct the error by e.g. swapping the part to the correct one if that is the issue. When the order is completed a shipping label is automatically printed and the packager attaches it to the box. The packed boxes are stacked on pallets which are lifted down to the ground level via the pallet lift when full.

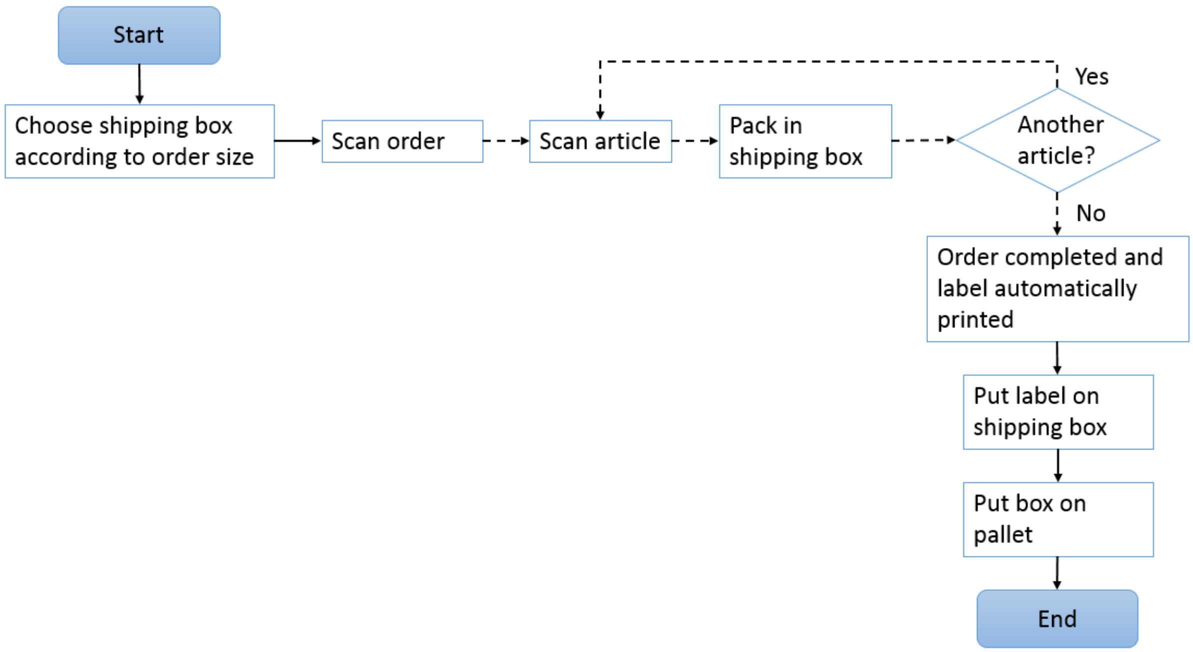


Figure 4.12 Process map of the packaging process for Casall.

4.4 Characteristics of goods shipped

KN handles small to medium sized goods on the mezzanine. The amounts, types and sizes differ slightly between Bosch and Casall. To find out what capacity the system has to handle the amount of goods sent out has to be known both in terms of weight, volumes and numbers. All of these add constraints that need to be considered when selecting an order picking system.

The subsections below show the amount of order lines shipped per day in terms of numbers, weight and volume. It further presents a weight and volume distribution of all goods shipped in 2015 and a pareto analysis on how many articles account for the majority of the orders. The section is divided into two subsections, one for Bosch and one for Casall.

4.4.1 Bosch

In 2015 KN handled 7195 different SKUs from Bosch. In total 4,773,722 articles were shipped from KN to the customers spread on a total of 83,619 orders and 649,308 order lines. This gives an average of 344 orders and 2672 order lines sent out per day. The average order consisted of 7.8 order lines and 57 articles. There are some variations throughout the year, April being the busiest month with a total of 66,675 order lines. A pareto analysis of the order lines for Bosch shows that 18.92% of the parts account for 80% of all picks. The numbers presented in this section are displayed in table 4.1 for a better overview.

Table 4.0.1 Key measurements Bosch.

Analysis	Total
# of different SKUs	7195
# of storage locations	8509
# of orders in 2015	83,619
# of order lines in 2015	649,308
# of item picks	4,773,722
Average # orders/day	344.11
Average # order lines/day	2672.05
Average # order lines/order	7.77
Average # articles/order	57.09

Figure 4.13 shows the number of order lines and total weight and volume of the goods sent out per day from Bosch in 2015. The graph can be seen in more detail in Appendix III and the individual graphs for the order lines, weight and volume can be found in Appendix IV. As can be seen in the figure the weight and volumes shipped correspond with the number of order lines. The busiest days were 31 March and 7 April from all perspectives. From an order line perspective those days accounted for 6722 and 6241 order lines respectively. The weight shipped out these days were 1092 kg on 31 March and 1034 kg on 7 April and the volumes were 3050 and 2910 dm³. This is a lot higher than the average weight and volumes, the average weight in 2015 was 404 kg per day and the average volume was 1111 dm³.

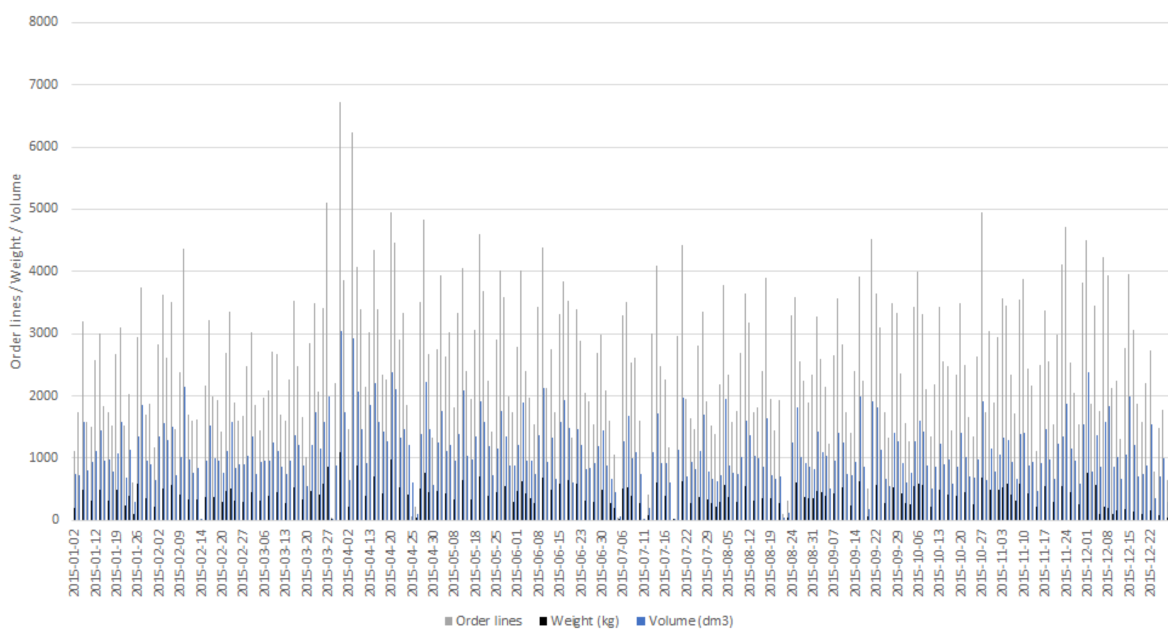


Figure 4.13 Number of order lines, total volume and total weight sent out per day in 2015 for Bosch.

The volume of the goods shipped by Bosch is shown in figure 4.14. As can be seen from the figure the volume of the goods vary a lot but are still low volume. A total of 74% of the articles have a volume of less than 1 dm³ and 97.3% have a volume of less than 2 dm³. Graphs of the length, width and height of the goods can be found in Appendix V.

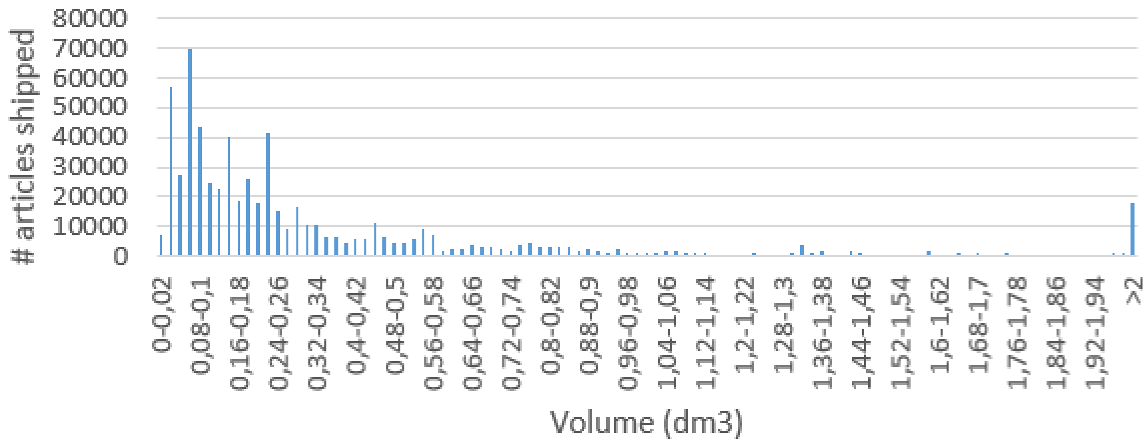


Figure 4.14 Volume distribution of all articles shipped from Bosch in 2015.

Figure 4.15 shows the weight distribution of the goods shipped out from Bosch. As can be seen the majority of the goods are light weight. 93% of the goods weigh less than 0.5 kg. An analysis of the goods with weights over 0.5 kg shows that only 2% of the goods weigh more than 1 kg.

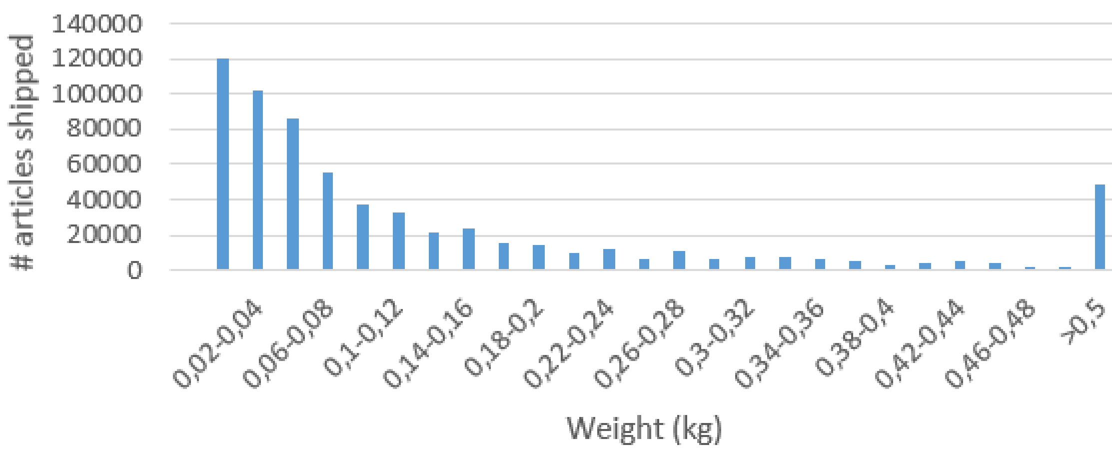


Figure 4.15 Weight distribution of all articles shipped from Bosch in 2015.

4.4.2 Casall

In 2015 a total of 931,748 Casall articles passed through KNs warehouse and were shipped out. These articles were of 10,307 different SKUs and were spread on a total of 22,543 orders and 222,639 order lines. 184,752, or 83%, of the order lines were clothing and 37,887, 17%, were training equipment. On average, 93 orders were shipped per day and each order consisted of approximately 10 order lines and 41 articles, giving an average of 916 order lines per day. There are some variations throughout the year and the busiest month in 2015 was January with a total of 41,081 order lines shipped. A pareto analysis for the order lines from Casall shows that 23.8% of the articles account for a total of 80% of the order lines. The numbers presented above are displayed in table 4.2.

Table 4.0.2 Key measurements Casall.

Analysis	Total
# of different SKUs	10,307
# of orders in 2015	22,543
# of order lines in 2015	222,639
# of item picks	931,748
Average # orders/day	92.77
Average # order lines/day	916
Average # order lines/order	9.88
Average # articles/order	41.33

The amount of order lines sent each day also varies, as can be seen in figure 4.16. The graph has been made disregarding the four highest values as to become legible. The graph can be seen in more detail in Appendix VI and the entire graph with all dates can be found in Appendix VII. The individual graphs for order lines, weight and volume can be found in Appendix VII. The peak concerning the amount of order lines was in 2015 was on the 27 February when a total of 4220 order lines were sent out. This is connected to three major orders jointly accountable for 30% of the orders that day that are likely due to a new store opening. In cases like this the order has been picked during several days. The figure also shows the weight and volume distribution of the goods sent out from the mezzanine per day from Casall. The highest amount was measured on 24 Aug 2015 with a total of 14,459 kg and 71,239 dm^3. This can be set in comparison to the average weights and volumes of 878 kg and 4100 dm^3.

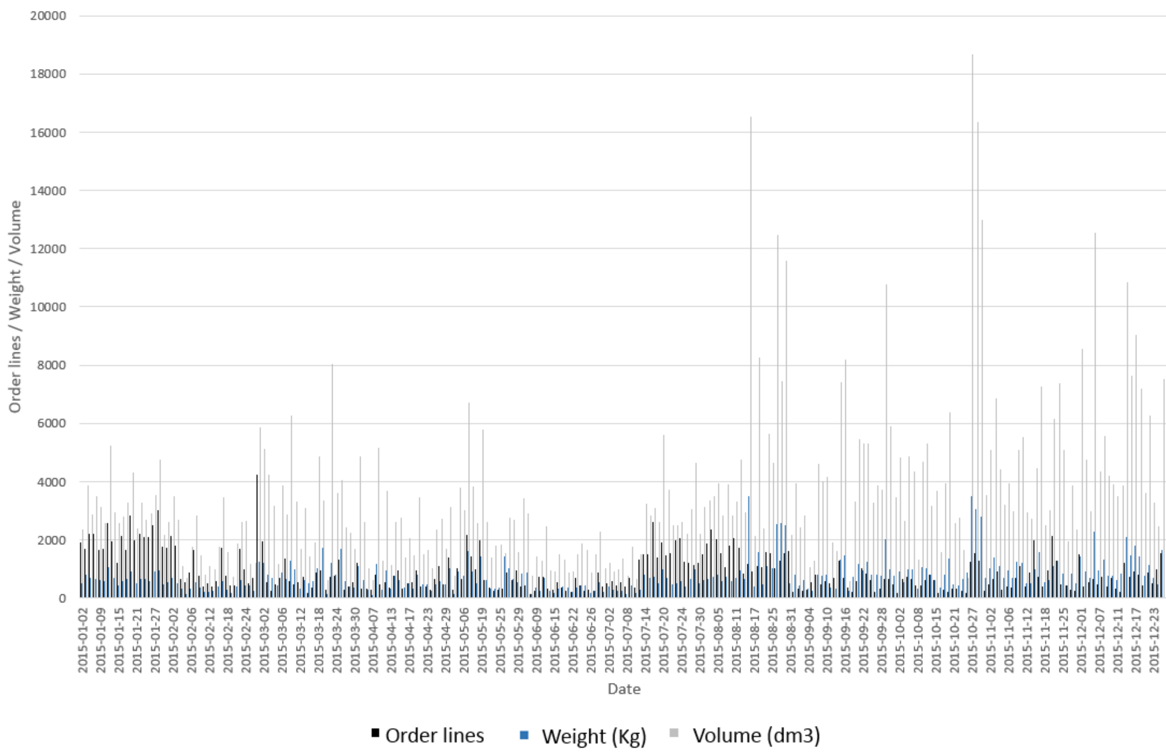


Figure 4.16 Number of order lines, total volume and total weight sent out per day in 2015 for Casall. The graph disregards the values noted on 21 Aug, 24 Aug, 12 Oct and 20 Nov as those values were so high they impacted the legibility of the graph.

The different types of articles handled indicate that there are certain differences when it comes to the weight of the goods. Figure 4.17 shows the weight distribution of the Casall goods. It can be seen that a majority of the goods, 83%, weigh between 0.2 to 0.25 kg and 8.6% weigh more than 0.5 kg. A further analysis of the articles that weigh more than 0.5 kg shows that a majority of these items are still lightweight and don't exceed 2.5 kg. In total only 2% of the articles from Casall that pass through the mezzanine weigh above 5 kg.

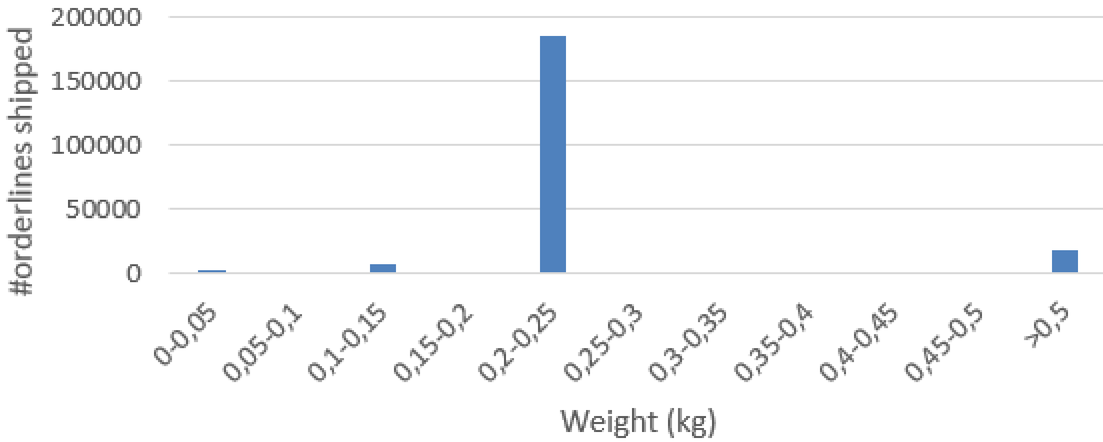


Figure 4.17 Weight distribution of all articles shipped from Casall in 2015.

The volume of the goods shipped by Casall is shown in figure 4.18. It is important to note that for all clothing articles Casall had a volume of zero saved in the master data. For this report a measurement of 1 dm³ per garment was used. As can be seen from the figure 98% of the goods sent have a volume of 0.004 to 0.005 dm³ and 2% have volumes that are larger than 0.005 dm³.

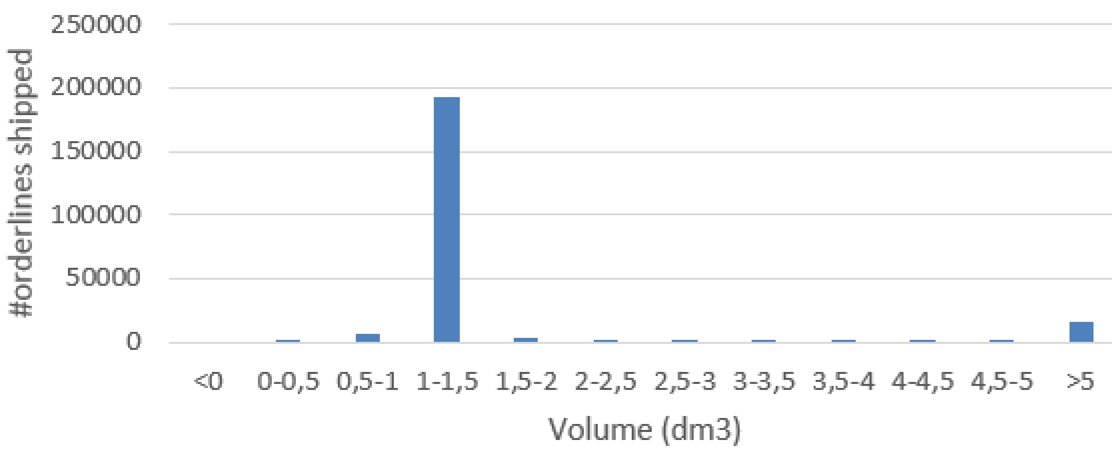


Figure 4.18 Volume distribution of all articles shipped from Casall in 2015.

4.5 Claims

Since automated order picking systems are expected to result in an increased picking accuracy, a review of the current claims has been conducted for both Bosch and Casall. The result is presented below.

The claims are handled differently depending on what the claim concerns. If a wrong part is received the customer can either exchange it or decide to keep it and place a new order for the missing part. When a claim is received regarding incorrect quantities the process differs depending on if an over or under delivery has been made. For under deliveries there are three available options on how the issue is handled. The customer can either accept the lower quantity without issuing a new order for the remaining pieces, accept the lower quantity and issue a new order for the remaining pieces or require

KN to complete the order. For over deliveries there are only two available options, either the customer accepts the extra quantity or returns it to KN. For all cases where the customer accepts the error the order is adjusted accordingly to match the invoice.

Bosch

KN started measuring the claims for Bosch as of 2016. In January they received a total of 201 claims out of which 92 were accepted. With a total amount of order lines being 73,169 this gives a claim rate of 0.13%. The goal set by Bosch is a maximum of 0.05% claims, indicating that for January 2016 a maximum of 36 claims would be acceptable. All of the accepted claims were due to wrong quantities delivered, 77% due to under delivery and the remaining 23% due to over delivery.

Casall

In 2014 KN received a total of 30 claims for the Casall goods, out of these 19 were due to wrong quantities, 8 were due to wrong articles and 3 due to incorrect addressing/marking. In total 261,559 order lines were shipped during 2014 giving a claim rate of 0.01%.

In 2015 the claims were reduced to only 6 claims of which 4 were due to wrong quantities, 1 due to wrong articles and the last one due to an incorrect delivery note. As 222,639 order lines were sent out in 2015 this gives a claim rate of only 0.003%.

5. Market Research

The market research presents examples of AS/RSs currently available on the market. The first section describes the general purchasing process for an automated order picking system. This provides the reader with a background of how the choice between different systems is made without solely comparing the technical specifications. The chapter thereafter describes eight different AS/RSs types in a separate section each. Table 5.1 provides an overview of the considered systems.

Table 5.0.1 Overview of considered systems.

	Constructor	Kardex Remstar	Swisslog	Weland Lagersystem
Vertical Carousel	Paternoster	Megamat RS		
Horizontal Carousel	HOCA	Horizontal		
VLM	Tornado	Shuttle XP		Compact
Vertical Buffer Module		LR35		
Miniload			Tornado	
Shuttle			Cyclone	
AGV AutoStore			AutoStore	
AGV CarryPick			CarryPick	

If more than one system is described in a section, the section begins by describing general characteristics of the system type, before the actual systems are described. The findings in this chapter are based on interviews made with different suppliers together with information provided on their webpages and in brochures. The selection of suppliers has been made based on the authors own perception of what suppliers are most commonly found on the Swedish market. The suppliers are always presented in alphabetical order without any evaluation.

5.1 Purchasing an Automated Order Picking System

Different AS/RSs are suitable for different contexts and preconditions. Figure 5.1 shows a bubble graph of the different system types in relation to number of SKUs and order lines picked per hour.

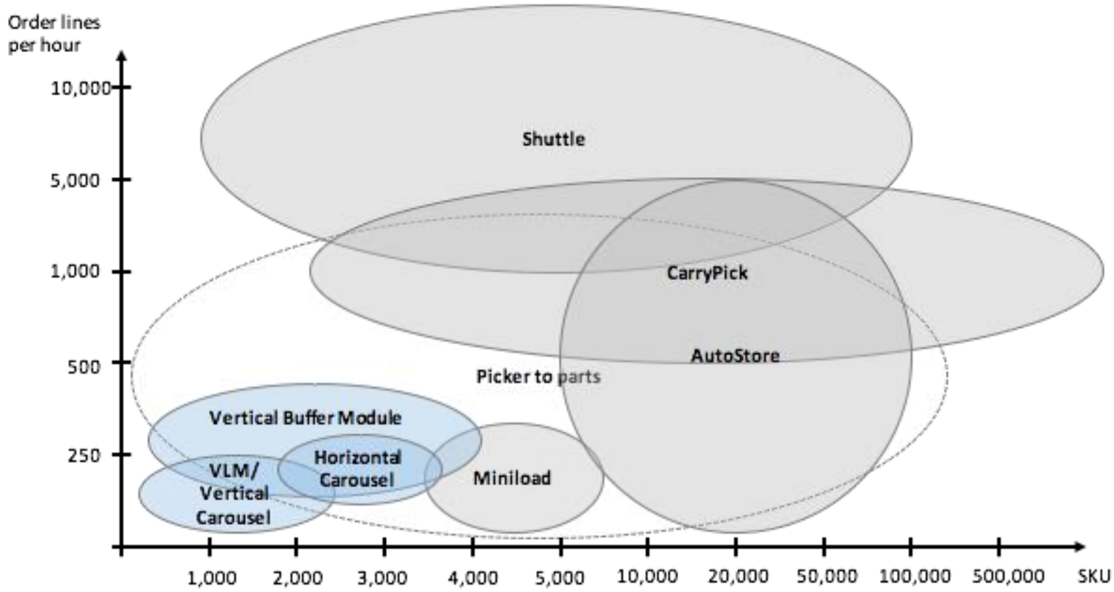


Figure 5.1 The field of application for AS/RSs in relation to the number of SKUs and picking productivity. The blue bubbles represent system types of group 1 and the grey bubbles represent system types of group 2. For better readability the axes are not evenly scaled (based on Das Einsatzfeld des Vertical Buffer Module, 2016; Sparf, 2016). The original graphs can be found in Appendix IX.

It is important to notice that the blue bubbles for the group 1 systems illustrate the application field for a single subsystem. Thus if several subsystems are combined, the bubbles would expand in terms of SKUs and order lines per hour. The comparison only takes number of SKUs and picking productivity, measured in order lines per hour, into account. For a sound comparison of the systems several other factors related to the context must be considered, but the overview clarifies that AS/RSs are designed for different fields of application. This section describes the steps involved in purchasing an AS/RS from the first initial contact with a supplier to the implementation to the follow up service and maintenance.

5.1.1 Sales and Implementation Process

The sales and implementation process starts off with an investigation made by the supplier of what system is best suited for the context in question. The investigation regarding the optimal system is done based on factors such as facility layout, product characteristics and demand pattern. The facility layout is used to identify limitations that must be considered for the implementation, such as height limitations. The product characteristics are investigated due to that sizes and weights can provide restrictions concerning what system can be implemented. Finally the demand pattern is used to calculate the needed efficiency both in peak and non-peak season (Hallén, 2016; Karlsson, 2016; Sparf, 2016; Waldemarson, 2016). An example of the initial template used by Constructor when investigating the customer requirements can be found in Appendix X. Waldemarson (2016) and Sparf (2016) indicate that the demand is the most important part to consider. Thus a pareto analysis of the goods is always performed in order to find the best suitable system and also to help calculate the number of storage locations and assign products accordingly.

Both Karlsson (2016) and Sparf (2016) emphasise the importance of putting the reason for the implementation in focus when selecting a system, whether space savings or picking efficiency is in focus will highly affect the system selection. Sparf (2016) further states that it is more important to focus on the problem that should be solved, rather that the technology used to solve it.

Once a system has been chosen there are several ways in which the payment could be made ranging from standard up-front payment to leasing models to loan models. However, the exact payment terms are not included in this study as they are subject to contract specifics and project size (Hallén, 2016; Karlsson, 2016; Sparf, 2016; Waldemarson, 2016).

5.1.2 Service Offerings

Service is needed for all automation systems both in the form of scheduled maintenance and immediate assistance, in case of a system breakdown. All interviewed suppliers provide such services to different degrees depending on how the system is used and the service level required by the customer (Hallén, 2016; Karlsson, 2016; Sparf, 2016; Waldemarson, 2016). Hallén (2016) emphasises that the frequency of maintenance is highly dependent on the usage and could differ between two to four times a year.

In case of errors or even system breakdowns all companies provide service within a set amount of hours, the longest being 24 hours and the shortest 2 hours. Although, this varies depending on how proximate the customer is to the supplier's service centres. If the distance is far, the suppliers can further assist via either phone or in some cases logging on to the system from a distance (Hallén, 2016; Karlsson, 2016; Sparf, 2016; Waldemarson, 2016).

When implementing an automated order picking system future adaptation and configuration of the IT systems are needed in order to achieve the maximum effect. For example, recalculations might be needed concerning the storage locations and what items that are to be stored within the system. Many suppliers therefore provide education of the personnel and even possibilities to connect with other companies that are experiencing the same problems (Karlsson, 2016; Waldemarson, 2016).

5.2 Vertical Carousel

Vertical carousels are good for storing many small high frequent articles as they allow quick access to the goods. A vertical carousel provides maximum utilization of the storage space as every part of the system is used for storage. In vertical carousels no transportation aisle is needed and the picking opening does not block any storage locations. Hallén (2016) regards this as a major advantage of the vertical carousel, especially when applied in settings with low ceiling heights. To secure a high fill rate there are several interior layout options available for the shelving such as built in drawers, customized boxes and vertical or horizontal partitions (Constructor, 2016; Kardex Remstar 1, 2016). To prevent articles from falling off the shelves and to increase the space utilization, Hallén (2016) suggests that a vertical carousel should not be used without storage containers.

All vertical carousel systems can be equipped with all types of different ICT applications at the picking station. This can be information screens, showing where the item is located, what quantity to be picked, what size the package is and even a picture of the product. Otherwise a LED strip, a pick-to-light or a pick-by-voice system can be used as well. They are further equipped with emergency hand cranks and can thus be operated despite of electricity failure.

All vertical carousels are limited by maximum weights both for the shelves and for the entire unit. The maximum weight is limited due to the risk for imbalances and the fact that the entire shelving moves for each retrieval, which puts high pressure on the construction. To help dealing with the issue of imbalances the WMS takes this into account when calculating the positioning of the goods within the system. (Constructor, 2016; Kardex Remstar 1, 2016). A downside of vertical carousels is that the entire shelving rotates for each retrieval, which results in a high wear out (Karlsson, 2016). The subsections below provide a description of two vertical carousels; the Paternoster from Constructor and the Megamat RS from Kardex Remstar.

5.2.1 Constructor - Paternoster

The Constructor Paternoster comes in two different widths: 3703 and 4953 mm and three different depths: 1836, 2036 and 2236 mm. The height ranges from 3040 to 14,890 but normally they are not higher than 9 meters due to that the maximum weight allowance for the entire unit is usually reached at this point. The shelves can handle up to 600kg each and the entire system has a capacity of up to 16 tons. The Paternoster is built to be able to handle imbalances within the system of up to 3 tons, which according to Hallén (2016) is highest on the market. The system is further equipped with warning systems to prevent this limit being exceeded (Constructor, 2016; Hallén, 2016).

5.2.2 Kardex Remstar - Megamat RS

The Megamat RS is the vertical carousel line of Kardex Remstar. The models available are Megamat RS 180, Megamat RS 350 and Megamat RS 650 named after how much weight each shelf can contain. The Megamat RS 180 is best suited for storing and picking textiles or other lightweight parts in industry. The RS 350 is optimal for storing tools and spare parts whilst the RS 650 allows for more flexibility and storage of either parts or semi assembled products. A Megamat RS can also be run without any kind of IT system if the operations are simple (Kardex Remstar 1, 2016).

The width of the system can be adjusted from 1875 to 4275 mm and the depth comes in fixed sizes between 1251 and 1671 mm, although special measurements can be realised upon request. The height ranges from 2210 to 10,010 mm. The total weight the systems can handle including the weight of the shelving is 6 tons, 12.5 tons and 19 tons respectively for the RS 180, RS 350 and RS 650 (Kardex Remstar 1, 2016).

5.3 Horizontal Carousel

Horizontal carousels are best suitable in contexts with very limited ceiling height (Constructor, 2016; Waldemarson, 2016). Hallén (2016) states that they would be perfect to implement in, for example, a long and unused corridor. Karlsson (2016) argues that a horizontal carousel does not present the goods in an ergonomic picking height as they are not moved vertically. As for the vertical carousel, the entire shelving must rotate for retrieval, which wears out the system faster than others (Karlsson, 2016).

Horizontal carousels should be grouped in pods to allow access to several subsystems without travelling between subsystems, which results in very high picking productivities. They can further be designed as a double carousel. All terminals in horizontal carousel systems can be equipped with multiple ICT applications. The exterior of the horizontal carousels can be fully customized, including different colours depending on the design required by the customer (Constructor, 2016; Kardex Remstar 3, 2016). The subsections below provide a description of two horizontal carousels; the HOCA from Constructor and the Horizontal from Kardex Remstar.

5.3.1 Constructor - HOCA

HOCA is the name of the horizontal carousel provided by Constructor. The HOCA has a rack capacity of 100 kg and the entire system can handle up to 40 tons. The racks can be 60 or 120 mm wide, the width of the entire system is 1700 to 1900 mm. The HOCA can be either 2150 to 4350 mm high and up to 50 meters long (Constructor, 2016).

5.3.2 Kardex Remstar - Horizontal

Kardex Remstar provides horizontal carousels individually or in pods of up to four systems. One picker can handle up to 400 order lines per station and hour. The shelf height can be chosen between 2200 and 4100 mm. Kardex horizontal carousels are closed from the side to increase safety and only self-lubricating bearings are used, which are very robust and reliable and decrease the maintenance effort (Kardex Remstar 3, 2016).

5.4 Vertical Lift Modules

A VLM system can be equipped with a single or multiple openings for picking, whereas openings can be incorporated at any height. Thus, if the VLM reaches over several floors picking openings can be incorporated at every level. It is also possible to include openings opposite of each other to use one for picking and the other one for replenishment. However, each picking opening takes up a bit of storage space which has to be accounted for. All systems have a modular design allowing for adaption of the height, number of trays and number of access openings even after the initial implementation. In practice a minimum height of 5 to 6 meters is recommended, since the most expensive part is the S/R device which is required independent of the height (Hallén, 2016; Karlsson, 2016; Waldemarson, 2016).

The exterior of the VLMs can be fully customized, including different colours, plexi glass windows or LED lights on the inside depending on the design the customer desires. All systems can be operated with any storage assignment policy and it is possible to adapt the interior of the tray depending on the goods to be handled. The trays can be divided with partitions, bins, containers, folding boxes etc. and it is recommended to repack goods into this storage systems. Waldemarson (2016) points out the risk of storing goods in the same boxes they arrive in as there is a risk that the lid gets stuck or tears down other goods when the tray is retrieved. This can be avoided by carefully removing the lids, but to ensure that this is always done it is safer and more ergonomic to repack items. In addition, the space utilization can be increased through repacking (Hallén, 2016; Karlsson, 2016; Waldemarson, 2016).

The systems further allow for different types of ICT applications to help the picker keep track of what goods and quantities to pick (Hallén, 2016; Karlsson, 2016; Waldemarson, 2016). This section presents an overview of three Vertical Lift Modules available on the market. The Tornado by Constructor, the Shuttle XP by Kardex Remstar and finally the Compact by Weland Lagersystem.

5.4.1 Constructor - Tornado

Constructor provides a VLM called Tornado. The Tornado is capable of handling both small and large products with a maximum load weight of up to 600 kg per tray, whereas the entire system can handle maximum 60 tons. The trays can be placed in intervals with a maximum gap of 850 mm. The Tornado comes in various widths and sizes, the tray width ranges from 1250 to 4250 mm and the tray depth can vary from 520 to 1220 mm. The height ranges from 4 to 15 meters and up to four access points can be incorporated. The trays in the Tornado are lifted via a tooth belt drive. The system has no separate lifting device to retrieve the trays, instead the trays themselves attach to the tooth belt drive when moving through the shaft. The Tornado uses a light barrier at the access point as a safety mechanism that prevents the machine from operating if something reaches into the picking zone (Constructor 1, 2016; Hallén, 2016). Constructor also provides a system called Tornado DT, which is illustrated in figure 5.2.

Figure 5.2 The Tornado DT system by Constructor (Picture of Constructor Tornado DT, 2016).

The Tornado DT system consists of two standard VLMs in tandem, which are connected via an automatic conveyor in the bottom of the VLMs. In this setup trays can be retrieved in the rear system and conveyed to the picking station in the front system. This system often has a lower picking productivity compared to a standard system but an improved space utilization (Constructor, 2016; Hallén, 2016).

5.4.2 Kardex Remstar - Shuttle XP

Kardex Remstar provides VLMs in different sizes and with different configurations under the name Shuttle XP. They provide five different models; Shuttle XP250/500, Shuttle XP 700, Shuttle XP 1000, Shuttle XPlus and Shuttle XPmultiple. All models of the Shuttle XP lift the trays via a tooth belt drive. The first three mentioned systems are named after the maximum weight the trays are capable of handling. The systems can all be built to handle a total of either 67 or 120 tons. The XPlus uses an S/R device that can move both horizontally and vertically and can hence be operated on a wider VLM allowing access to additional storage locations, see figure 5.3. The XPlus requires less picking stations which results in increased space utilization (Kardex Remstar 2, 2016).

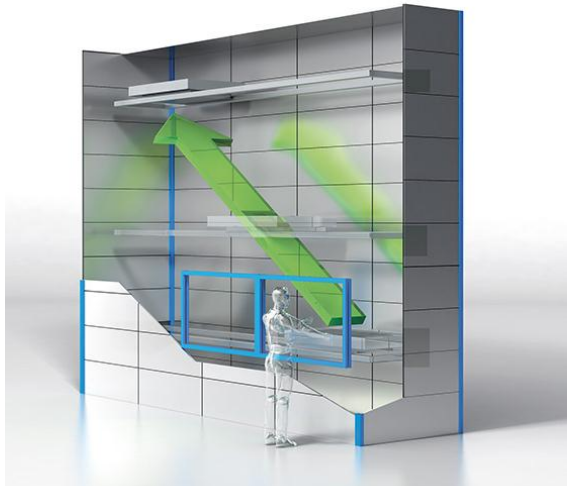


Figure 5.3 Operation principle behind the Shuttle XPlus (Picture of working principle behind Kardex Remstar XPlus, 2016).

The Shuttle XPmultiple in turn connects two VLM subsystems in a tandem configuration with only one I/O point, allowing for further space savings, see figure 5.4 (Kardex Remstar 2, 2016).

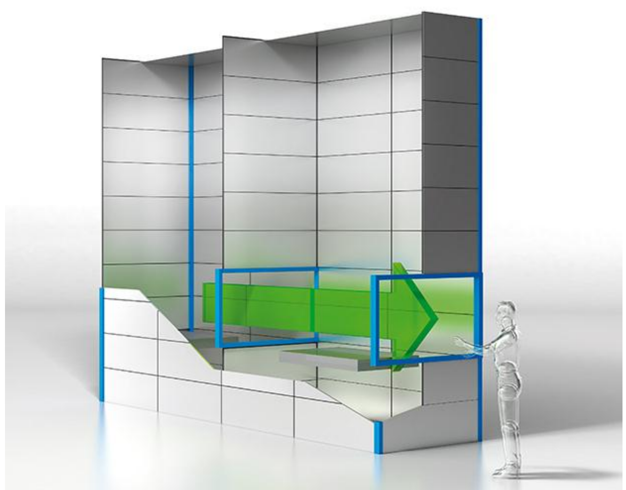


Figure 5.4 Operation principle behind the Shuttle XPmultiple (Picture of working principle behind Kardex Remstar XPmultiple, 2016).

The Shuttle XP can be configured to the needs of the customer in several ways. Each Shuttle XP can have up to 6 access points. The systems can also be equipped with a dual tray function (Kardex Remstar 2, 2016). The Shuttle XP comes in fixed sizes with a width that varies from 1580 to 4380 mm and a depth from 2362 to 12,296 mm depending on which model is chosen, whereas the XPmultiple is the deepest one as it combines several VLMs. The height ranges between 2550 and 30,050 mm and can be adjusted in intervals of 100 mm. The trays within the Shuttle XP are stored based on the height of the goods in intervals of 25 mm. The Shuttle XP calculates the optimal storage for the tray based on an automatic scanning of the height, allowing for optimal space utilization within the system. The system also measures the weight of the tray to avoid overloading (Kardex Remstar 2, 2016).

5.4.3 Weland Lagersystem - Compact

Weland Lagersystem's VLM is called Compact and includes five different standard models with several variants, each of which can be fully customised according to the customer needs. All standard Compact systems are built to handle trays with a maximum load of 300 or 600 kg, but there is also a special variant that can handle trays of up to 1500 kg. A standard system can contain a maximum load of 50 or 100 tons, whereas a customized system can contain even more. The Compact system uses a lifting system driven by cog wheels providing a stable movement of the tray and allowing for high loads. The cog wheel construction further allows for an uneven weight distribution on the tray. The sound implied by using this cog wheel construction is limited, since two steel components are never in direct contact with each other. Further it is possible to telescope the retrieved tray out of the machine to allow better access while saving space when the machines is not in use (Karlsson, 2016; Weland Lagersystem, 2016).

Besides being highly flexible to customer demands, Weland provides five different standard models: Compact Lift, Compact Deep, Compact Slim, Compact Twin and Compact Double Deep. The Compact Lift, Deep and Slim all work as a standard VLM. The Compact Slim is a smaller version suitable for areas with limited space, whereas the Compact Deep is a deeper machine increasing the storage area by 50% compared to the standard Compact Lift. The Compact Twin system is similar to a dual tray but instead uses a S/R device that can store two trays at once, of which one works as a waiting position. When the picker is working with one tray the S/R device can retrieve the next tray and put it in the waiting position, see figure 5.5. The tray is always extracted at the same height, as opposed to a dual tray. Karlsson (2016) emphasizes that the Compact Twin system can reduce waiting times for the picker and hence this system becomes feasible when labour reduction is in focus. However, he also states that the Twin system cannot achieve the same throughput as two separate subsystems.

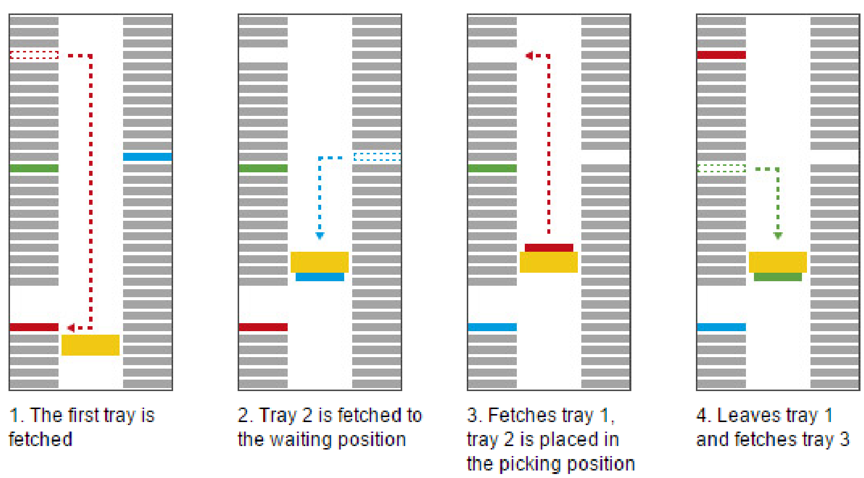


Figure 5.5 Operation principle of the Compact Twin (This is how Compact Twin works, 2016).

The Compact Double Deep system, shown in figure 5.6, is based on the same principle as the Compact Twin but with two load trays in depth resulting in a higher space efficiency (Weland Lagersystem, 2016). Karlsson (2016) recommends the Compact Double Deep system in contexts where space utilization is in focus and the product range includes a high amount of slow movers.

Figure 5.6 Operation principle of the Compact Double Deep (This is how Compact Double Deep works, 2016).

Each of the models comes in various standard sizes ranging from 1697 to 4137 mm in width, 2998 to 4878 mm in depth and 3000 to 16,000 mm in height. Besides those standard sizes Weland claims that all systems can be designed entirely to the customer needs and has already delivered several systems exceeding the standard measurements. The design can also be customised both with regards to the interior and exterior. Goods are stored within the system based on height of the goods in intervals of 25 mm (Weland Lagersystem, 2016).

5.5 Vertical Buffer Module: Kardex Remstar - LR 35

The Kardex Remstar LR 35 belongs to a new system type called vertical buffer module, which is introduced by Kardex Remstar. The information regarding the operation principle is still very limited as the construction is hidden. It is only known that the construction consists of some type of shelves with narrow aisles in between and that it is possible to handle both miniload containers and trays within the same system. A subsystem is operated via an advanced picking station, which enables 500 picks per hour and depending on the demand pattern even a lot more. Multiple less advanced picking stations that cannot reach the same picking productivity can also be added to the system. The main picking station presents the container 20° tilted, which can be seen in figure 5.8. Waldemarson (2016) states that the tilt allows an eased extraction even at the backside of the container. All picking stations utilize buffers and are operated with a two-sided turning table, one side facing the picker and the back side used for preparing the container needed for the following pick. After the picking of the current container is finished, the table simply turns around and the subsequent container is brought to the picker. As a result, the changeover time between two boxes can be significantly reduced (Kardex Remstar 4, 2016).

Figure 5.7 The picking station of a Kardex Remstar LR 35 (Picture of picking station at Kardex Remstar LR35, 2016).

The LR 35 can measure between 1920 and 10,470 mm in width and between 3000 and 12,000 mm in height. The depth is fixed to 2350 mm. One system can be loaded with up to 63 tons and each miniload/tray can carry up to 35 kg. The size of the containers can either be 60 x 40 cm or 64 x 44 cm. The system is expected to be especially useful for a high number of SKUs that are picked in small volumes (Kardex Remstar 4, 2016, Waldemarson, 2016).

5.6 Miniload System: Swisslog - Tornado

The Tornado by Swisslog is a modular miniload system that consists of several parallel positioned storage racks with narrow aisles in between, in which one to several S/R devices operate. The Tornado can handle both standard and customized bin sizes, which can contain loads of either 70 or 120 kg. It is also possible to use totes, boxes or trays for the storage or combine different bins within the same system. The Tornado can be configured with single, double or quadruple deep bin storages. Two different S/R devices are available, the standard version capable of carrying one bin only or a specialized double version that can carry two bins at the same time. The Tornado can be adapted to customer requirements in many more ways, e.g. a less noisy variant, if work stations are situated close to the S/R devices (Swisslog 2, 2016).

In general, miniload systems are described as being highly limited in terms of maximum throughput, since only one I/O point can be used per aisle. Sparf (2016) estimates that each S/R device is capable of 130 to 150 storage and retrieval operations per hour. Furthermore, the rather fixed bin size is seen as another limitation. However, miniload systems provide comparably cheap storage locations and can easily be scaled retrospectively. As a result, miniload systems are rather recommended as a storage system than a competitive order picking system (Sparf, 2016; Waldemarson, 2016).

5.7 Shuttle System: Swisslog - Cyclone

The Swisslog Cyclone is a shuttle system, shown in figure 5.7, and the successor of SmartCarrier (Sparf, 2016). A Cyclone system consists of three components; racks with aisles in which the items are stored, shuttles that move the goods horizontally through the aisles, and lastly a lift at the end of each aisle for the vertical movement. The Cyclone system allows several shuttles on the same level and all lifts are capable to handle two shuttles at once (Sparf, 2016; Swisslog 4, 2016).

Figure 5.8 A shuttle moving in an aisle to retrieve goods (Swisslog Cyclone Carrier, 2016).

Shuttle systems can obtain extremely high picking productivities of 500 to 1000 order lines per double lift per hour. In addition the system provides great scalability, since either additional racks, shuttles or lifts can be added retrospectively, depending on the needs. A shuttle system can use a variety of storage containers, ranging from bins to trays, which allows to store goods without any repacking. Sparf (2016) therefore regards shuttle systems as highly flexible. Shuttle systems are mostly used for high frequent light goods handling. A common application is for e-commerce, since many small orders need to be shipped out at high speed (Sparf, 2016).

5.8 AGV: Swisslog - AutoStore

The Swisslog AutoStore can be classified as a special type of AGV system. An AutoStore system consists of an aluminium cubic grid construction in which storage bins are stacked on top of each other. On top of the aluminium grid several AGVs, called AutoRobots move around retrieving the bins. The grid guarantees that the bins are aligned and also functions as a track for the AutoRobots (Swisslog 1, 2016). The build-up of an AutoStore system is illustrated in figure 5.9.

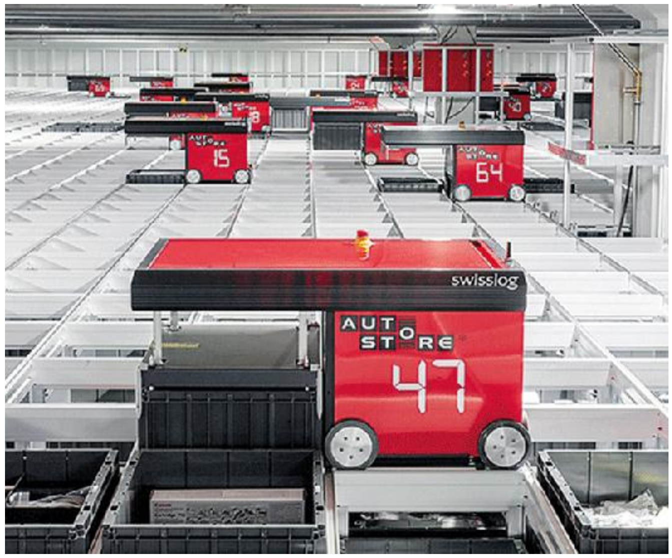


Figure 5.9 AutoRobots running on top of the AutoStore grid construction (Efficient small parts storage with AutoStore, 2016).

The AutoRobots retrieve bins from the grid construction and transport them to a picking station. Since bins are stacked on top of each other, it is often necessary to relocate several bins before the required one can be retrieved and thus “dig up” the required bin. Due to this, bins will automatically be sorted in a pareto allocation, as bins with high picking frequencies will remain in the top of the grid construction and less frequent at the bottom. If required, it is possible to rearrange boxes within the grid overnight to increase the efficiency the following day (Sparf, 2016; Swisslog 1, 2016; Swisslog Warehouse & Distribution Solutions WDS 1, 2016).

The bins are available in two different sizes of 601 x 401 mm in width and length and a height of either 200 mm or 310 mm. Each bin can be divided in a maximum of 32 compartments, although Sparf (2016) argues that a maximum of 16 should be used for a good picking experience. An AutoStore system has typically a size of 5,000 to 100,000 bins. The AutoRobots are radio controlled and powered by batteries. A full battery charge provides up to 20 hours of operation time and each AutoRobot can retrieve and store about 25 bins per hour. The picking stations are equipped with a turning table and a three bin buffer, which reduces the changeover times. Sparf (2016) states that a well operated picking station can reach up to 500 order lines per hour. The replenishment is often handled at a separate replenish station.

The AutoStore construction has a maximum height of 6.5 meters, which would allow for 16 large bins to be stacked on top of each other. The modular design allows to highly adapt the AutoStore construction to the context. One further advantage of the modular design is that the AutoStore is easily scalable, especially in terms of storage locations. Sparf (2016) states that a new row of bins could easily be added to the system without interrupting the running operations. However, adaptability in terms of throughput is somewhat limited since only a certain amount of AutoRobots can operate simultaneously. Currently there are about 60 AutoStore systems worldwide implemented, of which two are in Sweden and Norway (Sparf, 2016; Swisslog 1, 2016).

5.9 AGV: Swisslog - CarryPick

The Swisslog CarryPick is an AGV system that consists of mobile racks, box shaped AGVs and picking stations. The AGVs are extremely manoeuvrable and can even spot turn. They navigate with the help of barcodes that are printed on the floor and are charged through electromagnetic induction, which is incorporated in the floor. This inductive charging allows them to operate without stops. Each AGV is capable of carrying a maximum of 600 kg, which allows relative freedom in the design of the mobile racks. A common configuration is to use two-meter high racks with easily adjustable shelves, which allows to store a wide range of products (Swisslog 3, 2016). An exemplary build up can be seen in figure 5.10.

Figure 5.10 A Swisslog CarryPick AGV travelling in an aisle with another CarryPick AGV retrieving a mobile storage racks (CarryPick Storage System, 2016).

The mobile racks could be placed very space efficient without any aisles in between, since the AGVs move underneath the racks. In the retrieval process an AGV stops under the rack, lifts it up and travels to the picking station. In order to achieve a high picking productivity, it is common that a small buffer is implemented before the picking station, meaning a few AGVs are waiting in line. Sparf (2016) states that each picking station can achieve up to 600 order lines per hour. The CarryPick system can easily be adapted to changing contexts, since the mobile racks are easily adjustable and the entire system provides great scalability. Depending on the demands, each component, i.e. racks, AGV, picking station, can be scaled up to the desired improvement. Nevertheless, the system is very costly and difficult to implement in an existing warehouse, since the entire floor must be transformed. In Sweden only one CarryPick system is implemented so far (Sparf 2016; Swisslog Warehouse & Distribution Solutions WDS 2, 2016; Swisslog 3, 2016).

6. ANALYSIS

This chapter analyses the findings from the literature review, empirical study and market research. The first section recaps and links the major findings of the empirical study and provides a critical perspective of the current situation. The second section summarizes KN's expectations regarding the implementation of an automated order picking system and deduces key requirements based on the current state. Afterwards the different system types described in the market research are compared using the identified factors relevant for the selection of an automated order picking system. In the fourth subsection, financial considerations and their implications are elaborated upon. The final section transfers the system comparison to the specific case in focus of this thesis and concludes with a recommendation to KN.

6.1 CURRENT SITUATION ANALYSIS

The current order picking system is a low-level picker-to-parts system. The analysis of the outbound deliveries and article master data shows that all products handled on the mezzanine are small or medium sized and lightweight. Table 6.1 presents an overview of the key measurements for Bosch and Casall and in combination, which is considered relevant as goods for both customers are likely to be mixed in an AS/RS. In 2015 a total number of 17,502 different SKUs was handled by KN. It was not possible to identify the total number of storage locations in the current situation, due to a lack of data for Casall, but to get a rough idea, a similar amount of storage locations for Bosch and Casall can be assumed. This assumption presumes that less storage locations than number of SKUs are required over the year, due to the seasonalities of fashion products indicating that some items are only available for a couple of months. KN handles on average 3588 order lines per day, which corresponds to roughly 450 order lines per hour with a standard 8 hour shift. The average number of order lines per order are quite similar for Bosch and Casall, being 7.77 and 9.88 respectively with an average of 8.21. The average volume sent out per day is 5211 dm^3 and the average weight is 1282 kg. All analysed systems are easily able to handle those amounts, hence weight and volume limitations are not further discussed in this analysis.

Table 6.1 Overview of key measurements for Bosch and Casall combined.

	Bosch	Casall	Combined
# different SKU	7195	10,307	17,502
# storage locations	8509	N/A	< 17,000
Average # order lines/day	2672	916	3588
Average # order lines/order	7.77	9.88	8.21
Average volume/day (dm³)	1111	4100	5211
Average weight/day (kg)	404	878	1282

The current order picking process is quite inefficient, the main deficiencies being long walking distances, low picking productivity and inconsistencies regarding the material handling. As common for picker-to-parts system the order pickers spend a lot of time travelling to the storage locations. This becomes apparent considering the warehouse layout, where a single pick for Bosch can account for up to 45 m, and for Casall even 105 m, one way. It is estimated that order pickers travel a total distance of 15 to 20 km each day, which results in a picking productivity of only 50 to 70 order lines per picker and hour for Bosch and about 50 for Casall. It is important to notice that these numbers are calculated based on several assumptions and could deviate from reality. In conclusion the current order picking process is very labour intensive and operational costs are high. A few non-compliances are also observed and seem worth mentioning as they could affect both the current and future state. Firstly the pickers do not always bring back empty cartonage, and secondly they don't inform the team leader when they encounter an empty storage location.

Another deficiency is found in relation to the picking accuracy, whereas the amount of claims can be seen as a good measurement. There are big differences between the claim rate for Bosch and Casall. For Bosch KN received a total of 201 claims, of which 92 were accepted in January alone. This corresponds a claim rate of 0.13% of the total number of order lines. Considering that Bosch expects a claim rate of 0.05% or lower KN must decrease their current number of claims by almost two thirds. In contrast, for Casall KN managed to reduce an already low 30 claims in all of 2014 to a total of 6 claims in 2015, which corresponds to a claim rate of less than 0.003%. It can be seen that the majority of claims both for Bosch and Casall are caused by wrong quantities. The analysis is based on claims sent to KN by their customers and picking deviations that are noticed during the packaging process remain disregarded. Unfortunately, there is no data available on how many order lines fail the control, but it is fair to assume that the actual picking accuracy is even lower than the analysis of claims indicates.

It is unclear what causes the big difference in the number of claims between Bosch and Casall, especially since the order picking process is similar. Considering that a paper list is used for Casall, whereas hand-held scanners are used for Bosch, this difference is even more surprising. It is therefore fair to assume that the order picking process and/or the control process for Bosch do not work properly. In the order picking process it can be observed that, regardless of the quantity, items are only scanned once and counted by hand subsequently, whereas for Casall all individual items are scanned at the packaging station. In addition, some order pickers prefer to pick Bosch's orders without using the recommended shipping box, which could cause errors in the packaging process. In relation to the control process, the weight check might be too imprecise leading to deviations passing unnoticed. Small deviations are accepted to account for the packaging material, but considering how lightweight many of the goods are, this acceptance range might be too high. This is especially true for the orders that are continued on the ground floor without a weight check on the mezzanine. Deviations for lightweight goods could easily pass unnoticed in the final weight check together with heavier items.

6.2 KN's Expectations and System Requirements

KN have both short and long term expectations of an automated order picking system. In the short term, KN wishes to increase the picking productivity, thus reducing man hours and cutting operational costs. This can be easiest achieved by eliminating the currently high travel distances for each picker, thus requiring less man hours for the same amount of picks. In the long term KN is also interested in an increased system throughput and space savings, which would enable to include additional customers in the warehouse. A different project related to the reduction of claims for Bosch was recently kicked-off with the aim to reduce the claim rate. It can therefore be assumed that an increased picking accuracy is also of interest for KN. A beneficial side effect of an increased picking accuracy would be to further reduce man hours, as incorrect picks cause additional non-value adding correction work.

From the current state analysis and KN's expectations some basic requirements can be derived. In order to eliminate the non-value adding travelling and increasing the picking productivity an AS/RSs should be implemented. The key measurements presented in table 6.1 can be regarded as an estimation of what the system must be capable of. The required average number of order lines per day might be somewhat lower as well, since high quantity order lines for Casall are picked straight from the buffer and hence might be handled separately in the future as well. In relation to demand patterns, it is difficult to analyse if the system would be required to handle peak demands retrospectively, since information what caused them are unknown. Those peaks might have been known in advance and could have been balanced or eventually a big part of the orders were picked straight from the buffer and would not be required to be stored in the system. Nevertheless, peak demands should be considered as a system requirements, since they might cause problems in an automated order picking system, even though they do not impose any problem in the current situation. This becomes clear considering that to handle such large orders, it is crucial to apply a continuous batching approach, since fixed batching would risk blocking a picking station for several hours.

Some requirements highly specific to this case can be identified. The warehouse imposes height limitations of 10.9 meters on the ground level and 4.6 meters on the mezzanine. Since both Bosch and Casall are to be included in the system, it must be possible to connect the order picking system with two different WMSs. Furthermore, Bosch policies require that each article is stored at a maximum of three different storage locations. On top of this, none of the garments for Casall include any volume measurements, making it difficult to assign correct storage locations. Although it might be possible to receive this data from Casall if necessary. At last, it would be good if the system could reallocate and merge storage locations, due to the high seasonality of fashion products and the implied phasing out process.

6.3 System Comparison

In this section, the findings of the theoretical framework and market research are connected. Table 6.2 provides an evaluation of the eight different AS/RSs types described in the market research, namely vertical carousel, horizontal carousel, VLM, vertical buffer module, miniload system, shuttle system, and the two AGVs AutoStore and CarryPick. The first column depicts the current situation and serves as a starting point for the evaluation of the AS/RSs, and column 2 to 9 each represent one system type divided into the two different system groups. The table rows stand for factors considered relevant by the authors for the evaluation of automated order picking systems. The table rows are clustered into five different groups, the first two groups focus on system performance in terms of order picking and storage respectively. Group three, four and five address the replenishment, implementation and ergonomics. Each of the groups are analysed in a separate subsection. Table 6.2 can be used as a simple overview of different AS/RSs and their respective strengths and weaknesses to support the selection of an automated order picking system.

Table 6.2 Evaluation of the different AS/RSs. The evaluation is illustrated with signs ranging from "- -", being the worst, to "++", being the best. The sign "o" represents the middle value. The sums are calculated by translating the symbols into numerical values, where - - stands for -2 and ++ stands for +2.

			Group 1				Group 2			
		Current Situation	**Vertical Carousel**	**Horizontal Carousel**	**VLM**	**Vertical Buffer Module**	**Miniload**	**Shuttle**	**AGV AutoStore**	**AGV CarryPick**
System performance: Order picking	**Picking productivity**	- -	+	+	o	+	-	++	+	++
	Peak demands	++	+	o	+	o	-	-	-	-
	Picking accuracy	-	+	+	+	+	+	+	+	+
System performance: Storage	**Space utilization**	- -	++	o	+	N/A	+	+	++	o
	Flexibility in product	++	o	+	+	N/A	-	-	-	+
	Maximum number of SKUs	- -	o	o	o	o	++	++	++	++
Replenishment	**Replenishment time**	- -	+	+	+	+	+	+	+	+
	Replenishment interference	++	-	-	o	o	-	+	+	+
Implementation	**Installation & Relocation**	++	+	-	+	+	-	-	-	- -
	Scalability	+	-	-	o	N/A	+	++	++	++
Ergonomics	**Walking distance**	- -	o	++	o	++	++	++	++	++
	Ease of pick	- -	o	-	o	++	+	+	+	-
	Working environment	- -	o	o	+	o	+	+	++	++
	Sum	**-6**	**5**	**2**	**7**	**8**	**5**	**11**	**12**	**10**

6.3.1 System Performance: Order Picking

One of the key criteria for the evaluation of system performance is how well the order picking can be performed. This can be measured in terms of average throughput, the ability to react to demand peaks and the picking accuracy. In the current situation the picking productivity is a maximum of 70 order lines per picker per hour, and the picking accuracy for Bosch orders must more than double in order to meet Bosch's requirements. However, the current setup allows to easily react to demand surges by assigning additional pickers to the picking area. Even though the picking productivity per picker might decrease with too many pickers, since they interfere each other, the overall system throughput can be increased.

The carousels and VLM enable picking productivities of 200 to 500 order lines per hour. The picking productivity for those systems is highly dependent on the demand pattern as no buffers are used. This means that the changeover of a storage unit results in waiting time for the picker, decreasing the picking productivity. To shorten those waiting times it is common to let one picker operate several subsystems. The VLM is rated lowest among all group 1 systems as the storage and retrieval of a tray takes more time than a short rotation in the carousels. This applies even for dual tray or twin mechanisms. Horizontal carousels are expected to perform better than VLMs and vertical carousels, as the grouping in pods enables one picker to access several subsystems without any travelling. In turn, a vertical buffer module is capable of more than 500 order lines per hour independent of the demand pattern. Due to the fast changeover times in the vertical buffer module one picker can be fully occupied at a picking station thus no grouping of the systems is necessary. Similar to the vertical buffer module, all systems in group 2 utilize buffers to enable short changeover times. The AGV systems are capable of picking productivities of 500 order lines per hour and the shuttle system can even reach up to 1000 order lines per hour. In contrast, the miniload system has the lowest picking productivity of 150 order lines per hour, since the S/R device imposes a bottleneck in those systems.

In relation to peak demands all group 2 systems perform quite poorly. The system throughput cannot be increased by assigning additional pickers due to the characteristics of a closed system in combination with the fact that one picker is already assigned to one picking station. Even though a vertical buffer module works similar, it is rated slightly better as additional less advanced picking openings can be incorporated in a system. These picking stations could be used for peak demands. VLMs and carousels can deal better with peak demands if operated in groups. In that case pickers can be assigned to operate one subsystem each. This inevitably reduces the picking productivity per picker but allows to increase the overall system throughput in the short-term. The VLM is rated best since several picking openings can be integrated within one subsystem allowing several operators to pick from one subsystem. The horizontal carousel is only ranked mediocre, as additional pickers are expected to interfere each other due to the limited space in pods. In general, AS/RSs are somewhat limited in terms of peak demands. Nevertheless, peak demands are not expected to impose any major limitation as they can be counteracted by either excluding fast movers from the AS/RSs and perform parts of the picking process manually or by running overtime hours.

One way to increase the picking accuracy is to implement ICT applications at the picking stations. Besides increasing the accuracy, this also leads to an improved picking productivity. In general, AS/RSs are expected to increase the picking accuracy, since the task of the picker gets limited to the actual extraction of the required item, leading to less distraction. As described in the market research, suitable ICT applications exist for all considered system types. No evidence was found that suggests one of the systems would perform extraordinary good when it comes to picking accuracy, which is why all systems are marked the same. The implementation of advanced ICT applications is a lot more feasible in AS/RSs in comparison to the current state, since the amount of picking stations is very limited.

6.3.2 System Performance: Storage

Another key criteria of system performance is storage capability. The storage capability can be evaluated based on the space utilization rate, the maximum number of SKUs and the flexibility to store different products. The space utilization rate determines how much floor space is required for storage in comparison to the amount of parts stored. It is influenced by both the system height and the storage density within the system. The storage density in turn is dependent on the amount of empty space between the stored parts. Empty space can be caused by aisles that are required for movement or by the interior design, which also affects the flexibility to store different products. Lastly, the maximum number of SKUs describes the capability to store many different items without negatively impacting the picking productivity. Vertical buffer modules are not considered in this subsection, since information about the operation principle is too limited.

In the current situation the space utilization is rated low, since a low-level picker-to-parts system cannot utilize the facility height and requires wide aisles to allow the order pickers to retrieve the items. As a result, a lot of floor space is required leading to a wide spread of the picking area, as can be seen from the warehouse layout. This affects the picking productivity negatively and hence low-level picker-to-parts systems are unsuitable to store high numbers of SKUs. However, the current state is the most flexible when it comes to product changes. The racks used today can easily be adjusted to new product measurements, without any major investments required.

In terms of space utilization the horizontal carousel and the CarryPick system perform worse than other automated order picking systems due to the imposed height restriction. However, they provide a significant improvement to the current state as no aisles for movement are needed. The other AS/RSs all achieve better space utilizations, as they can utilize the height in a facility. The theoretical framework finds vertical carousels as the most space efficient system, because the entire system is used for storage as no aisle for item movement are needed. This also applies for the AutoStore system, which however requires space on top of the grid construction. The market research emphasizes that the storage density is also influenced by the amount of empty space between items in the system. A VLM is the only system that can actively reduce this empty space by dynamically adjusting tray heights. As a result, VLMs can even outperform vertical carousels with their fixed storage compartments, in contexts where fill rates within systems are low and tray heights become adjusted dynamically. Although VLMs will always require an aisle for moving the goods and the space utilization will further decrease with every system opening.

The possibility to dynamically adjust tray heights in the VLM, however provides great flexibility in terms of different products as the height of products do not impose any restrictions. The market research further revealed that an immense variety of VLM systems exists and systems can even be customized. The initial decision obviously determines the maximum tray size, tray weight and overall system weight, although these restrictions are apparent for all other systems as well. The product flexibility is expected to be similar for horizontal carousels and the CarryPick system, since those systems use racks with adjustable shelves for storage. The shelves of a vertical carousel can also be divided into smaller compartments, but due to the fixed height of the shelves the flexibility is lower than for the CarryPick.

The AutoStore, miniload and shuttle system are expected to perform worst in terms of product flexibility due to the fixed size of the storage bins imposing restrictions in all directions. Items that exceed the measurements of the storage unit cannot be stored within the system. However, the market research finds that most systems can handle at least two different box sizes, which adds some flexibility. Further, replaceable partitioners can be used to divide storage units in smaller compartments, allowing to adapt to different product sizes.

The maximum number of SKUs that can be handled is directly linked to the previously defined system groups. For systems in group 1, which consist of several subsystems, the maximum number of SKUs is typically limited at some point. For each additional subsystem the travelling increases, hence the overall picking productivity decreases again. In turn group 2 systems, which consist of one entity are capable of handling very high numbers of SKUs without affecting the picking productivity negatively.

6.3.3 Replenishment

Due to the high investment costs of AS/RSs they are normally utilized as an FPA, hence frequent replenishments need to take place. In the current situation the Bosch picking area is replenished directly from the inbound deliveries and no buffer storage is used. For the evaluation of the replenishments two criteria are considered. Firstly, how much time the replenishment takes and secondly how much the order picking process is disturbed.

In regards to the time the replenishment takes, all AS/RSs are regarded as a significant improvement to the current situation, since the travelling required to replenish will be eliminated. Another factor that can influence the time needed is whether or not the items need to be repacked in order to be handled by the system. KN currently receives most of the Casall garments in standardised boxes of 40 x 30 x 40 cm, which could be regarded as a reasonable representative of package size. According to the market research all systems could most likely be customized to handle those boxes. Nevertheless, all AS/RSs have been graded the same as the authors identified several arguments why items should be repacked anyway. First of all the time savings of not repacking are expected to be marginal and if not repacked the cartonage must be disposed as part of the order picking process. It might be more efficient to dispose all cartonage at once. In addition, the space utilization can be improved as all storage units have well-matched sizes. Further repacking would allow to split quantities, which allows to divide quantities amongst two subsystems and reduces the impact of a system failure. It also allows to allocate two different SKUs of the same part, i.e. master packs and single units, to different storage locations, thus reducing the risk of picking errors. Lastly, the usage of storage units can be more convenient and ergonomic than picking from carton, and in some cases might reduce the risk of damaging the system. Conclusively, repacking is not regarded as a disadvantage.

For the second criteria, regarding how much the order picking is influenced by the replenishment, the different systems differ a lot more. In the current situation picking and replenishment can easily be performed simultaneously. Furthermore, it is possible to assign multiple operators to replenishment and increase the replenishment speed accordingly. In contrast for systems with a single I/O point, i.e carousels and miniload systems, system inbounds not related to the current pick cannot be performed simultaneously to the order picking process. To overcome this problem both VLM and vertical buffer module offer the option to implement an additional access point that can be used for system inbound. However, due to the single S/R device the order picking might be influenced by this. In general, the influence on the order picking will decrease with an increasing number of subsystems, since the S/R device is more likely to be idle and hence could perform replenish operations. Shuttle and AGV systems are expected to influence the order picking the least, since no traditional S/R device is used.

6.3.4 Implementation

The implementation is evaluated based on the installation and relocation processes as well as the possibility to scale the system. The installation considers how easily an AS/RSs could be integrated into an existing warehouse and how much the warehouse operations would be interrupted during the implementation. The installation and relocation processes are closely correlated and both are highly influenced by the modularity of the considered system. Modular systems are delivered in small segments and mounted on site allowing for easy implementation. Similarly they can be demounted for relocation. This modularity is also highly relevant for the scalability of automated order picking systems. It is important to understand the difference between short-term occurring peak demands and scalability, as the latter relates to an increased long-term need. AS/RSs can be scaled in terms of storage locations or picking productivity, whereas the picking productivity can either be scaled through additional picking stations or accelerated storage and retrieval.

The current situation represents a common low-level picker-to-parts system. Those systems mainly consist of standardized racks and some material handling equipment, hence they are easy to implement, scale and relocate. However, the scalability is somewhat limited in terms of number of SKUs, or else the picking area becomes too wide spanning.

The group 1 systems can, with an exception of the horizontal carousels, all be very well integrated into an existing warehouse. Their structure is modularized, which allows an easy build up and relocation. Since every subsystem for itself is rather small, they can be well integrated into existing rows of racks. In contrast, horizontal carousels require a lot of floor space, which might complicate the implementation. One aspect that needs to be taken into account for both carousels is that the initial item inbound might be slightly complicated due to the risk of system imbalances. Group 2 systems are expected to be more difficult to install. Those systems require a connected area in the warehouse, which might require a re-layouting of the warehouse. However, they are all highly modularized, which eases the build up and relocation. The CarryPick system is ranked the lowest, as the market research suggests that the entire floor needs to be equipped with inductive chargers. This will require a complete restructuring of the facility and highly interrupt running operations.

In relation to scalability the carousel systems are ranked lowest as an existing subsystem cannot be upgraded due to the structure design. Therefore, a scale-up will require an entire new subsystem. A VLM subsystem in turn can be somewhat scaled by increasing the height, the number of trays within the system and by adding or closing picking openings to increase picking productivity or storage locations respectively. A vertical buffer module cannot be evaluated in terms of scalability due to lack of information. A miniload system provides great scalability in terms of maximum number of SKUs as additional racks can easily be added. However the picking productivity will always be somewhat capped due to that there is only on S/R device per aisle. Conclusively, shuttle systems, AutoStore and CarryPick provide the best scalability in terms of storage locations and picking productivity. In difference to other systems the picking productivity can be increased either by adding further picking stations or by increasing the number of robots.

6.3.5 Ergonomics

The ergonomics are evaluated based on the required walking distance, the ease of pick and the working environment. In the current situation order pickers need to walk 15 to 20 km each day and need to bend down and stretch to reach the top and bottom storage locations on the racks. Further, the working environment is further perceived as rather dull.

All considered systems either greatly reduce or eliminate the walking distances. For vertical carousels and VLMs, some walking still occurs if one picker operates more than one subsystem. The ergonomics can further be improved by implementing anti-fatigue mats. As stated in the market research an investment in anti-fatigue mats is a lot easier for AS/RSs as the area in which they are needed is greatly reduced.

The ease of pick can be evaluated based on the picking height and the support through ICT applications. As all system types can be equipped with appropriate ICT applications, all AS/RSs are rated better than the current situation. However, the horizontal carousel and CarryPick system perform worst, as items are still presented in different heights. All other system types present all items in an ergonomic height for the picker, thus further improving the ease of pick. The vertical buffer module, AutoStore, miniload and shuttle system are ranked better than VLM and vertical carousel, as items are presented in storage units of limited size. It is expected that those storage units can easily be overseen and the back end can be reached without great effort. The vertical buffer module is ranked the highest as the storage unit can be presented slightly tilted which is expected to further increase the picking ergonomics.

The authors acknowledge that a certain "coolness" factor could influence the selection of an automated order picking system as well. It seems worth mentioning that a VLM system equipped with plexiglass and LEDs inside the system, allowing to observe the S/R device, are more appealing than systems only presenting the picking station. Generally, the more advanced the automation and the more visible the operation of the system is, the more impressive the system is perceived. This coolness factor is expected to improve the working environment and directly influence the employee satisfaction. Besides the visibility of the operation, the implementation of ICT applications at the picking station is also expected to improve the picking experience. But as all system types can be equipped with appropriate ICT applications no system is found to be better than others. One negative factor to consider is the increased sound level caused by AS/RSs as compared to traditional picker-to-parts systems. But this thesis has not included any measurements of the sound levels thus it is not possible to state which system is the loudest.

6.3.6 Financial Considerations and Other Factors

This subsection briefly elaborates on financial considerations and other factors that are worth considering, but could not be satisfactory analysed by the authors, or were not substantial enough to fill a separate subsection.

The theoretical framework states that companies are reserved about implementing an automated order picking system, due to the high initial investment costs. To evaluate the feasibility of an investment the payback time and ROI are commonly used for financial assessment. This implies that a higher investment can be justified if the operational savings increase proportionally as well. The operational savings are calculated by comparing the operational costs of the current situation with the operational costs of the potential future state. The operational costs of an order picking process are strictly linked to the man hours required to achieve the desired throughput. In automated order picking systems a small share of energy, maintenance and service costs needs to be taken into account as well, however the picking productivity will primarily determine the operational costs and potential savings. Conclusively, from a financial perspective the investment in an automated order picking system is only justified if the picking productivity increases sufficiently to guarantee a reasonable ROI in a desired payback time.

One of the factors that could not be sufficiently evaluated is the uptime of the different system types and in relation to that the frequency and extent to which maintenance is required. It can only be said that carousels are expected to have a higher wear out than other systems and that the required maintenance will highly depend on the extent of usage of the system. All analysed systems can be regarded as closed systems, meaning they are not accessible for visual inspection. The theoretical framework states this as a common concern amongst companies, as a power failure or breakdown would bring the entire order picking process to a halt. Only carousels could be operated without power, if they are equipped with an emergency hand crank. However, the concern related to a power failure is assumed to be negligible, since a power failure would imply that the WMS is not working either, meaning the entire order picking would come to a halt anyway. In turn, a closed system is expected to increase safety and security within the warehouse, since machinery and operators are separated and unauthorized picks become impossible.

Other factors that are disregarded in this study include the complexity of the WMS, the order process time, and the training of employees. A more complex WMS will be harder to operate and most likely harder to fix in case of system errors. This factor is especially important to consider for the integration of an existing WMS with the order picking WMS. A short process time is especially important in relation to e-commerce as it allows to offer express deliveries. Lastly, the training of employees is expected to become easier and quicker with AS/RSs, as the picker task gets limited to the actual extraction.

Factors not related to the systems but to their providers can play a significant role in the selection process as well. Three important areas are identified, namely the sales process, the service offerings and the payment terms. Those factors are not in focus for this study and hence are only mentioned briefly. Based on the market research no major differences are found between the providers. All begin the sales process by analysing the customer's situation and assessing their needs. All suppliers provide maintenance and offer service in case of failure, whereby the promised response time for service can vary a lot. It is important to notice that different service packages can be negotiated, depending on the customer’s need. Regarding the payment, offerings ranging from up-front payment to loan and leasing models are available. The authors sensed that all suppliers show a high degree of flexibility and willingness to match a competitor’s offer regarding these service offerings and payment terms.

6.3.7 Result

This subsection briefly summarises the findings of the system evaluation and elaborates on the applicability of table 6.2 as a guideline for selecting AS/RSs. Table 6.2 clearly shows that the current situation, as a fair representative of traditional picker-to-parts systems, bears a high improvement potential in comparison to potential parts-to-picker systems. All AS/RS types achieved higher scores than the current situation.

The vertical carousel performs great for order picking, but it brings the fewest improvements in ergonomics and has a limited flexibility in terms of product changes and scalability. The horizontal carousel achieves the lowest score of all system types and performs worst from an implementation perspective. However, the horizontal carousel can certainly perform very well in specific contexts and should be the preferred choice in contexts with very limited ceiling heights. The VLM is the only system without a negative rating, but it does not perform extremely well in any factor either. Even for advanced VLMs the picking productivity will be at the lower end. The vertical buffer module achieves the highest score of the group 1 systems and appeals very promising, as it is the only group 1 system utilizing a buffer resulting in a higher picking productivity. However, no final assessment can be made as the storage capabilities and scalability can't be satisfactory evaluated due to a lack of information.

All group 2 system perform better in terms of ergonomics, maximum number of SKUs and scalability than group 1 systems, but worse in terms of implementation and product flexibility. The miniload system performs well in terms of storage, but has the worst order picking performance. In contrast, the shuttle, AutoStore and CarryPick system achieve high to very high picking productivities and generally perform very well with scores of 10 and above.

The table clearly has its limitations, as certain aspects are not covered and others might be overrepresented, but the table can be seen as a useful guideline to support the selection process of an AS/RSs. Even though it uses the specific case of KN as a basis for comparison, it is expected to be transferable to other contexts as well. However, as the market research emphasises, the selection of an AS/RS should be highly dependent on what improvements are in focus. Therefore, it is recommended to use the table in combination with multipliers. By multiplying the values of certain table rows, different areas of the system can be emphasized. This allows to adjust the table to many different contexts with different improvements in focus. Furthermore factors that are excluded from the table, such as financial considerations, system uptime and order process time are expected to highly influence the final selection and hence should be considered as limitations. This also holds true for constraints related to product characteristics, facility layout, and key measurements as minimum SKUs and throughput the system needs to be capable of.

6.4 Concluding Remarks and Recommendation to KN

The selection of an automated order picking system is a time consuming and challenging task involving several steps. The selection of the best suitable system is influenced by many factors and the final choice highly depends on what improvements are in focus. The interviewed suppliers advise that the selection of an automated order picking system should begin very broad. Suppliers prefer to analyse the entire context and decide what parts should be considered for automation subsequently. In this study however, the focus was set on the mezzanine from the beginning, which might impact the authors recommendation. The sales process of all considered suppliers begins with an analysis of the provided data, out of which initial recommendations are formulated. Therefore, the authors advise to prepare data for the entire warehouse and consult several different providers. This is expected to result in an improved understanding of the implications of each system type in the specific context. In contrast to this study, the suppliers are able to examine whether the mezzanine bears the greatest improvement potential and can provide recommendations accordingly. Furthermore, financial considerations can be taken directly into account, which might further narrow the alternatives.

Following, the authors aim to provide a plausible system recommendation to KN by transferring the generic findings of the system evaluation to the specific case in focus of this study. It was found that all considered systems could technically fulfil the requirements and are expected to improve the current situation. However, taking into account KN's expectations in terms of picking productivity, picking accuracy and space savings as well as the key measurement from table 6.1 some systems are more feasible than others.

Considering that KN's main goal with the implementation of an automated order picking system is to reduce the operational costs, picking productivity seems most relevant. The miniload system performs the weakest in terms of picking productivity and even though the current productivity might double or triple, the improvement does not seem significant enough to justify an implementation. Similar could be true for VLMs, but the authors expect that the more advanced VLMs with a dual tray or twin function, can provide sufficient picking productivities. In difference, the shuttle and CarryPick system can achieve extremely high picking productivities which exceed KN's requirements by far. Therefore those two systems appear too big for the specific case, as they could most likely not be scaled appropriately. All AS/RSs can be equipped with appropriate ICT applications, hence no system is found to be superior in terms of picking accuracy.

The space utilization and implementation are somewhat correlated in KNs situation, as the order picking currently takes place on the mezzanine. Even though a horizontal carousel provides the lowest space utilization, due to the limited system height, this does not necessarily has to be regarded as a disadvantage. Considering that the ceiling height is limited to 4.6 meters on the mezzanine, the horizontal carousel is the only system that could be entirely implemented on the mezzanine. However, the picking stations for the remaining AS/RSs could also be implemented on the mezzanine, whereas the construction is placed on the ground floor. E.g. a VLM placed on the ground floor can have one picking opening at the mezzanine, thus allowing to use the mezzanine for packing. If the mezzanine is disregarded, the implementation of vertical carousels, VLMs and vertical buffer modules is expected to be easy as subsystems could be well integrated into existing rows of racks. The AutoStore in contrast, requires a cohesive area which might demand a more extensive facility re-layouting.

The authors identify the scalability and flexibility of products to be highly relevant for the system selection when operating within contract logistics. The theoretical framework emphasises on the short contract durations within contract logistics, thus an AS/RS should be highly flexible in terms of product characteristics and also scalable to allow for future growth. In the current situation, all products can be classified as small or medium sized and lightweight. All considered AS/RSs would be capable to handle those products. Even though the flexibility of the AutoStore is sufficient for the current situation, the limited box dimensions might impose limitations to future product dimensions. The group 1 systems are a lot more flexible in that sense. On the other hand the AutoStore provides a much better scalability, as storage locations and picking productivity can be scaled stepwise, whereas group 1 systems are quite limited in scalability and entire new subsystems might be required to scale up.

Despite of not being in focus for KN the ergonomics and ability to react to peak demands are briefly summarized. The AutoStore and vertical buffer module provide the best ergonomics, mainly due to travelling being eliminated and not only reduced. Even though travelling is eliminated in horizontal carousels as well, those are evaluated inferior as goods are not presented at an ergonomic picking height. Lastly, the ability to cope with peak demands is not expected to impose limitations for any of the systems, as the current peak demands could be most likely balanced by relocating goods overnight or running overtime hours.

Instead of ending with a recommendation for one exact system, a variety of system types seem to be applicable in the specific case. As the considered order picking process is a small to medium-sized operation all group 1 systems are feasible. Nevertheless, the horizontal carousel should only be implemented if there is a wish to make use of the area on the mezzanine and there is no wish to further implement automation in other parts of the warehouse. Although the vertical carousel achieves a lower overall score than the VLM in table 6.2, it is likely to be the more appropriate system type in this case due to the high picking productivity. The AutoStore is the only feasible group 2 system and is seen to be highly suitable for the considered case. Even though previously disregarded, a vertical buffer module might offer the exact compromise between group 1 and group 2 systems and could be worth an investment if more information about them could be found.

This leads to the recommendation that the first decision for selecting an AS/RS should be whether to implement a group 1 or group 2 system. In general, group 2 systems are more feasible for larger operations, perform better in terms of maximum number of SKUs, scalability and ergonomics, but worse in terms of implementation and product flexibility than group 1 systems. The decision for one system group is very important as an investment now might restrict the implementation of a more suitable system in the long term. In relation to the specific case a group 1 system might be the better investment at this point, but in the long term, if the entire warehouse becomes automated, a group 2 system is likely to be more suitable.

7. Discussion

This study concludes in an analysis with reasonable argumentation and recommendations regarding the selection and design of an AS/RSs. Nevertheless, the reliability and validity of the results must be discussed. This chapter has been divided according to the structure of the report starting with the purpose. After that follows a discussion concerning the theoretical framework, empirical study, market research and the analysis. Finally, potential future work is described.

Purpose

A factor that highly influences the validity of the presented results is if the focus of this study was formulated correctly from the beginning. The task was limited to the order picking process of small goods located on the mezzanine of the warehouse in Norrköping. However, this focus was chosen before influential factors for the selection of automated order picking systems were analysed. Hallén (2016) and Sparf (2016) both emphasised that the selection of an order picking system is highly dependent on what improvements are in focus, i.e. space savings, labour savings or increased performance. Evaluating the main goal before conducting a study might have resulted in a different outcome. Additionally, findings have been made indicating that the entire warehouse should be in scope rather than only the mezzanine, as the final recommendation might vary significantly depending on the focus.

The initial purpose of this study was to create a guideline for selecting automated order picking systems, but during the course of this thesis the focus was laid on parts-to-picker systems, thus the guideline is limited to the selection of AS/RSs. The choice to focus on AS/RSs was justified as the travelling is commonly in focus of warehouse automation and a parts-to-picker system seemed the most reasonable automated order picking system category for the underlying case. Even though the resulting guideline is not applicable for all automated order picking systems, the general setup of the guideline developed in this study is expected to be applicable for other automated order picking system categories. Therefore, despite the initial purpose of this thesis not being fulfilled, the result of this study is considered very satisfactory.

In addition, it was planned to apply the developed guideline to the underlying case to result in a recommendation to KN for one exact system by one specific supplier. Even though the current situation was thoroughly analysed and the guideline was applied to the specific context, it was not possible to recommend one exact system. The authors found that factors that could not be considered in the guideline, as they were out of scope for this study or information was too limited, would highly influence the selection of an AS/RS. This is especially true for financial considerations that have been entirely excluded from this study. Nevertheless, the recommendation to KN is considered valuable, as the feasibility of different AS/RSs for the specific case was pointed out resulting in the elimination of three out of eight system types. Furthermore, other findings that are summarized in the concluding remarks are expected to greatly support the upcoming selection process of KN.

Theoretical Framework

The theoretical framework is seen to provide a good overview of the existing literature in the area. In order to increase the validity several different sources of information have been used. Although, there is always a certain risk that the included literature is slightly biased. Articles can always be found pointing towards different directions and focusing on different areas, and it is up to the authors to select which sources of information are to be included in the study. Therefore, other literature might disagree with the findings of this report. Additionally, research has shown to be quite limited in certain areas and a bit too abstract in others. Still, the authors believe that the data included has resulted in a trustworthy framework including the relevant aspects for this thesis.

Method

The authors are highly satisfied with the method in which this study was carried out. The initial warehouse visit gave the authors a good understanding of the context and the focus of this study. This proved very useful when writing the theoretical framework and gaining an understanding of the topic. Further the visits at the different suppliers also turned out to be very useful and complemented the information gathered from brochures very well. The fact that information was gathered from several different sources, i.e. literature, KN and suppliers, served as a good basis for the final analysis.

Empirical Study

There is always a certain scepticism regarding case studies whether the data collection was performed subjectively or not (Yin, 2014). The authors therefore collected as much data as possible by themselves. The findings presented in the chapter Empirical Study are all obtained through measurements and analysis performed by the authors and could thus be considered unbiased. Still, the presented data is not always completely accurate in all cases. To allow critical thinking of the reader, all inaccuracies are directly pointed out on occurrence. Only inaccuracies that are not expected to influence the final result are included in the final report, the little impact they might have is discussed in this chapter.

The warehouse layout is off by 11 meters at the most, spread on the entire warehouse this corresponds to a deviation of approximately 5%. As the measurements are only included to provide an understanding of the walking distances this deviation is not expected to affect the final result. The inaccuracies concerning the length of the warehouse are estimated to be the biggest for the longest measurements, and were most likely caused by the authors limited experience in warehouse mapping and using a laser rangefinder. This issue can easily be corrected by double checking the measurements and updating the Visio file. The other inaccuracy in the empirical study concerns the volume data for Casall. The article master file does not include product dimensions for garments, which is why a product volume of 1 dm^3 per garment, as currently used by KN, was assumed for all volume calculations. However, those product dimensions seem too big for many of the garments, as the authors measured one small sized female top to be 0.4 dm^3. Therefore, a volume between 0.4 and 1 dm^3 for all garments seems more reasonable.

The authors own calculations regarding the picking productivity also have to be discussed since the calculations are highly based on assumptions. First of all the division of the total number of working hours spent on the mezzanine versus on the ground floor is an assumption made by KN. Further, the authors have made assumptions concerning the number of workers assigned for picking or other tasks based on their perception when visiting the warehouse. The authors do acknowledge that the assumption made here is pretty low, and most likely more people are assigned for picking. Another assumption was made regarding that pickers spent a total of seven hours of effective picking time in a standard eight-hour shift. This assumption can be regarded as pretty high, but the authors believe that this can to some extent compensate for the high number of workers assumed to be doing other things than picking. Despite these inaccuracies the calculations were considered necessary for the report and were thus conducted anyway.

Market Research

This study also includes a brief market research, where most of the information is obtained through interviews with the suppliers of AS/RSs. In order to create a reliability of the findings the information was critically evaluated and cross checked with openly available marketing material. Although it should still be pointed out that the interviews were made with sales representatives who are highly biased towards their own systems, which might have affected their statements. For all findings related to the system types rather than specific systems, it was aimed to obtain similar information from several different interviews to increase the reliability.

The authors are aware that the amount of information provided in the market research differs a lot for different types of systems. The market research was considered as an ongoing process and the focus on certain system types was influenced by the supplier selection and information available. This also affected what areas have been included for different systems. Sections 5.5 to 5.9 in the market research describe entire types of systems but only consider one supplier specific system. The systems chosen are expected to be reasonable representatives and no significant differences are expected in comparison with systems of the same type from other suppliers. However, it cannot be guaranteed that all systems from other suppliers would have the same performance and limitations, thus a more thorough consideration of those could have increased the validity further. It should also be pointed out that there might be more different types of systems available on the market, but as it is impossible to cover all of them the authors chose to focus on the major suppliers as they were seen to provide a reasonably good overview of the market.

Yin (2014) states that the reliability and validity of a study are affected by both systematic misinterpretations and general misstatements. The authors realize that the different use of terms in literature and reality can result in such misinterpretations, especially within interviews. This is further complicated by the translation from English literature to Swedish terms used in the interviews and vice versa, where certain details might have been lost. In order to avoid any ambiguities from such misinterpretations, the meaning of certain terms were clarified throughout the interviews and interviews were followed up to remove ambiguity. Lastly, the work was continuously monitored and findings were frequently discussed with the supervisors from Chalmers University of Technology and KN, which is expected to increase the validity of the results (Yin, 2014).

Analysis

The table 6.2 used as a basis for the analysis is to a high degree biased by the authors perception of the different system types and their interpretations of the evaluation factors. To some extent KNs settings have probably been taken into account even when constructing the table. .Nevertheless, the table can be regarded as a useful tool to support the selection of an AS/RS. The authors also discussed a potential improvement of the table by adding multipliers to each factor dependent on the goal with an implementation. However, this specific analysis was not performed for KN, as it would require a clearer understanding of KN's goals.

Statements such as space reductions and efficiency improvements of up to X% are purposely excluded because the authors could not validate the reliability of such information. These statements are highly dependent on the pre-existing state and can therefore neither be compared nor applied in the setting of KN. In turn, this inhibits a more detailed system comparison based on performance. At last, it can be expected that the expected payback time and ROI will play a significant role in the final decision making of KN. But, since implementation and operational costs were disregarded in this study, no statement can be made regarding the financials of different system types.

Implementation Risks

There are several risks related to an implementation of any kind. An investment always bears the risk that the money is lost or the expected improvements are not reached. Multiple risks associated with the implementation of an AS/RS can be identified, the, according to the authors, three most important risks are discussed here.

It is of high importance that the investment made either has a payback time within the length of the contract times with Bosch and Casall or that the investment is flexible enough to deal with changing product characteristics. The flexibility of an automated order picking system will always be less compared to the current setup as shelves are very flexible per se. Although, the flexibility of the analyzed systems can often be seen to be enough for handling various dimensions of small and medium sized goods, which is what the current shelving is capable of as well. Although it needs to be accounted for that investments in racks rather than shelves is always cheaper compared to changing automated order picking solutions.

A factor that can be seen as both a risk and an opportunity is that KN will be an early mover in the field of automation when considering Contract Logistics operators. As of today many automated solutions are implemented within industries instead. This can either provide KN with the possibility of using this as a sales argument, claiming that they can achieve higher throughput to lower costs compared to their competitors. Although, this can also be seen as a risk in case their competitors would decide to go another direction. The authors identify this risk as fairly low as automation is seen to lower the costs of KN which can always bring a competitive advantage. The reason that the contract logistics industry has lagged is partly due to the risks imposed with flexibility, but the authors still consider this risk as possible to overcome.

A final risk that needs to be considered is that the operations might be highly interrupted during the implementation process, thus affecting their deliveries. Although as the implementation period usually only stretches over a short period of time this can be partially mitigated by communicating the implementation to the customers and thus try to steer the demand away from that period of time. It is further seen as quite a low risk as the suppliers seem to be very good at implementing the systems smoothly. The systems are delivered in modules and the operators assembling the systems are used to working in environments with running operations.

Future work

One of the outcomes of this thesis is that automation of the order picking has higher benefits if applied to the entire warehouse rather than one specific area. Hence it would be interesting to a further study including the rest of the warehouse and see what implications that has on the choice of technology. It would also be interesting to further look at what exact parts that are beneficial to store in an automated order picking system, i.e. some of the parts for Casall are extreme high runners and might therefore benefit from being stored outside of the system.

It has further been found that there is little existing literature concerning some of the more advanced systems, despite them being available on the market. Thus the authors believe that it would be interesting to analyse these systems further from a theoretical point of view to find what advantages they bring in terms of effectiveness and efficiency.

8. Conclusion

This thesis has analysed several different order picking processes and found that for warehouses with low picking volumes and small order sizes, parts-to-picker systems are the best suitable. In comparison to traditional picker-to-parts systems, a parts-to-picker system is especially useful for an increased number of SKUs. The thesis identified factors relevant for the selection of AS/RSs and compared different systems. In relation to the case study in focus of this thesis a recommendation to KN was formulated, advising to contact suppliers of VLMs, vertical buffer modules and the AutoStore system to get a better understanding of the systems and their implications.

The existing research showed an increasing interest in the implementation of automated order picking systems. The most frequently mentioned reasons for implementing automated order picking systems are related to improvements in efficiency and effectiveness. Although, there are some barriers related to automation, the most common being related to the high initial investment costs. For the case of contract logistics another common barrier is the flexibility of the systems, i.e. the adaptability to a changing context. Therefore, it is of high importance that the main goal for the implementation is known prior to the initial investigation phase so that one knows what to focus on when comparing the systems. The goal is usually related to either increased efficiency and a decreased amount of man hours required for the picking, or related to space savings.

It was found that there is a great difference in how well the systems perform in different aspects, hence it is not possible to give a general recommendation of a system. A table was therefore constructed providing an overview of how well the systems perform in the different areas in which automation brings benefits. This table can be used by any company in any different setting by focusing on the factors that are most important in their context.

When implementing an automated order picking system several things need to be considered except from what system to use. The cost of the implementation and ROI is expected to be of high importance. Further it is highly important to consider what parts are to be stored in the system. It was found that the suppliers are able to help out with these calculations if all the data regarding the products and shipping frequency are provided.

Finally, the authors would like to comment on the validity of the report and how it contributes to existing research. The report is considered to be highly valid despite some factors, such as costs and actual performance savings being disregarded. The factors were disregarded to to the biased information available and should thus not be included in an academic report. Although, the impact of them have been thoroughly discussed. The thesis therefore contributes to the existing literature in the warehouse automation stream. The topic of warehouse automation in the order picking process can be considered highly relevant as the research is often very general, whilst this report contains specific comparisons. At last, the increasing interest from companies in the area of warehouse automation leads the authors to further believe that this report is a necessary contribution to the field of literature.

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APPENDIX I - ORDER PICKING SYSTEMS TABLE

Table I Implemented order picking systems with respective number of SKUs and picking volume handled. If the picking volume is highlighted in gray, it implies that the the number of order lines is achieved per shift and not necessarily per day.

Company	Industry	number of SKUs	Picking volume (no. of order lines/day)	Picker-to-parts	Parts-to-picker	Pick-to-box	Pick-and-sort	Completely automated picking
ABC	Pharmaceuticals	20.000	378.000	x				x
Ambrovit S.r.l.	Industrial Components	10.000	1.200	x	x			
API	Pharmaceuticals	3.000	20.000	x				x
Avon products, Inc.	Cosmetics	10.000	120.000		x	x		
Boots UK	Retail/E-commerce	40.000	30.000		x			
Cef	Pharmaceuticals	40.000	65.000			x		x
Clinton	Fashion	26.700	8.000		x			
Cofaloza	Pharmaceuticals	18.000	35.000	x				x
Cofares	Pharmaceuticals	40.000	120.000		x			x
Conrad Electronics	Retail	250.000	140.000		x			
Coop	Retail	17.000	480.000	x	x			x
Decathlon	Sportswear	40.000	35.000	x			x	
Distrelec	Electronics	250.000	1.600		x			
E. Leclerc Scapest	Retail	15.000	450.000					x
EDEKA Nord	Retail	17.000	205.600	x	x			x
EDEKA Nordbayern	Retail	12.000	378.000	x	x			x
Eral S.r.l.	Industrial Components	80.000	144	x	x			
Fincoma S.r.l.	Industrial Components	15.000	640		x			
Grupo Rey	Pharmaceuticals	7.000	2.300	x	x			
Company	**Industry**	**number**	**Picking volume**	**Picker-**	**Parts-**	**Pick-to-**	**Pick-**	**Completely**

		of SKUs	(no. of order lines/day)	to-parts	to-picker	box	and-sort	automated picking
Hefagra	Pharmaceuticals	25.000	70.000	x	x			x
Künzi S.p.A.	Home and Outdoor	4.000	750	x	x			
Marks & Spencer	Retail	16.000	8.000		x			
Meijer	Retail	7.500	100.000					x
Mercadona	Retail	850	160.000					x
Migroliono	Retail	3.000	118.000		x			x
N/A	Industrial Components	700.000	60		x			
Reprico	Pharmaceuticals	2.500	6.600	x				x
REWE	Retail	24.000	551.000	x	x			
Safar Società Cooperativa Arl.	Pharmaceuticals	60.000	40.000			x		x
SGM Distribuzione S.r.l.	Consumer Electronics	5.000	8.000					
SIT S.p.A.	Industrial Components	15.000	650	x	x			
Sonepar	Retail	30.000	6.000	x	x			
Unifarm S.p.A.	Pharmaceuticals	50.000	42.000	x		x		x
Wehkamp	E-commerce	180.000	96.000		x			

APPENDIX II - LAYOUT OF THE WAREHOUSE

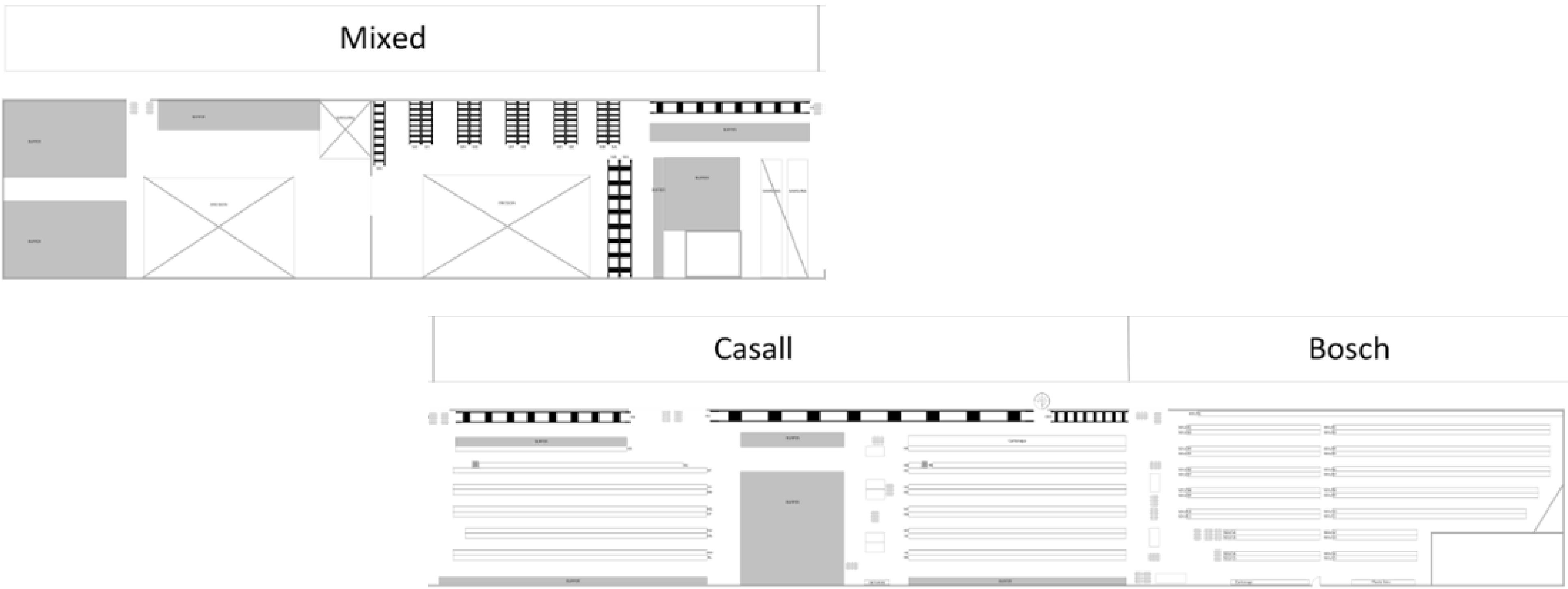

Figure A.1 Layout of the mezzanine at KN. The picture is divided into two parts as to make it more visible. The part marked as "mixed" is adjacent to the Casall area.

APPENDIX III - DAILY SHIPMENTS COMBINED, BOSCH

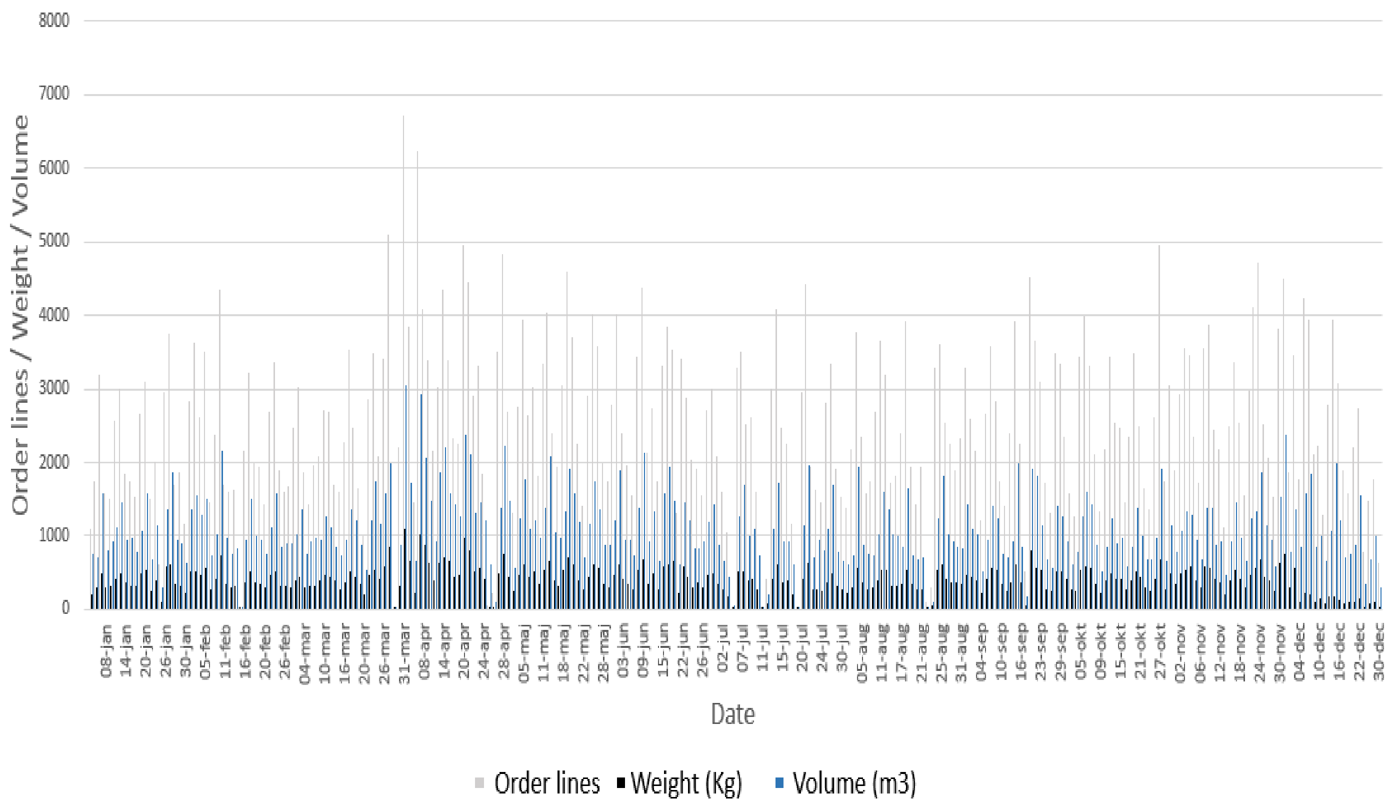

Figure A.2 Number of order lines, total volume and total weight sent out per day in 2015 for Bosch.

APPENDIX IV - DAILY SHIPMENTS, BOSCH

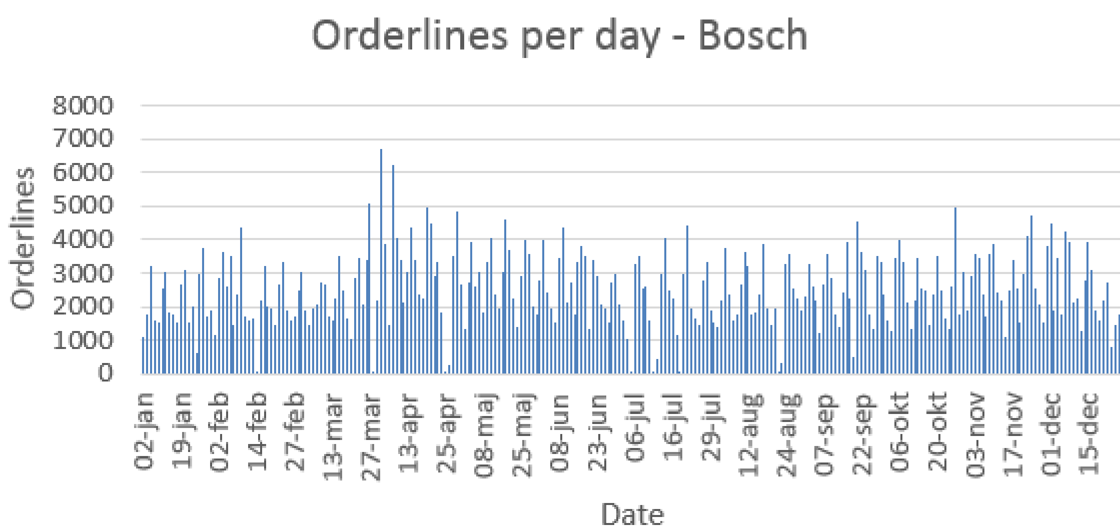

Figure A.3 Number of order lines sent out per day in 2015 for Bosch.

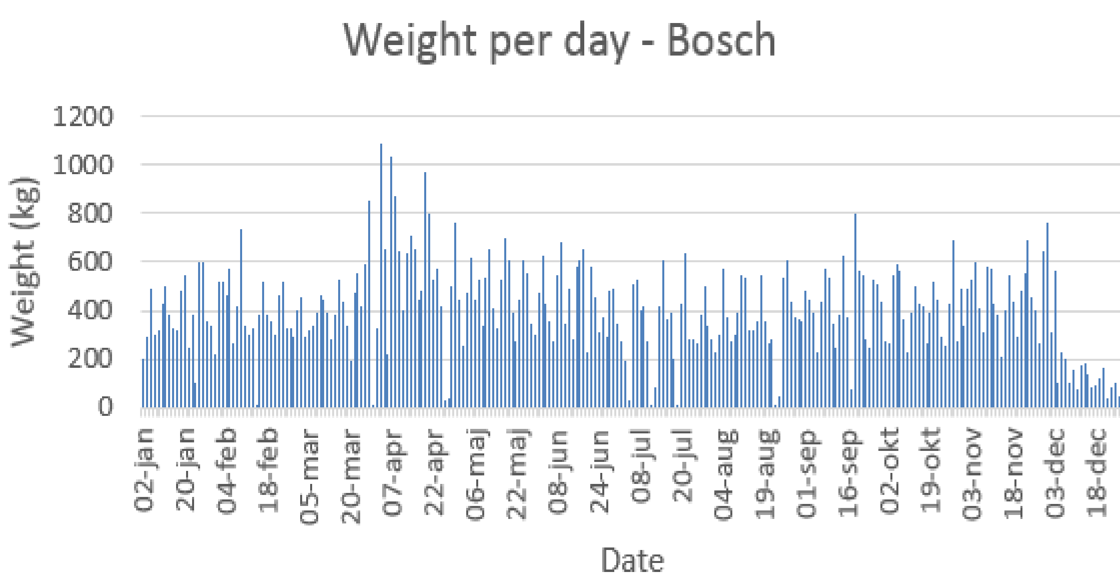

Figure A.4 Total weight sent out per day in 2015 for Bosch.

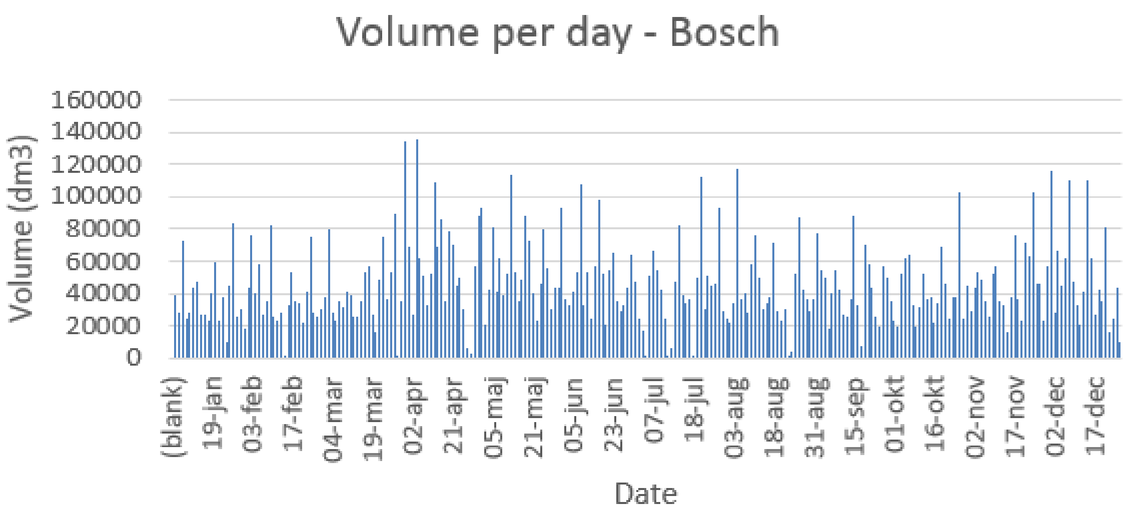

Figure A.5 Total volume sent out per day in 2015 for Bosch.

APPENDIX V - MEASUREMENT DISTRIBUTION, BOSCH

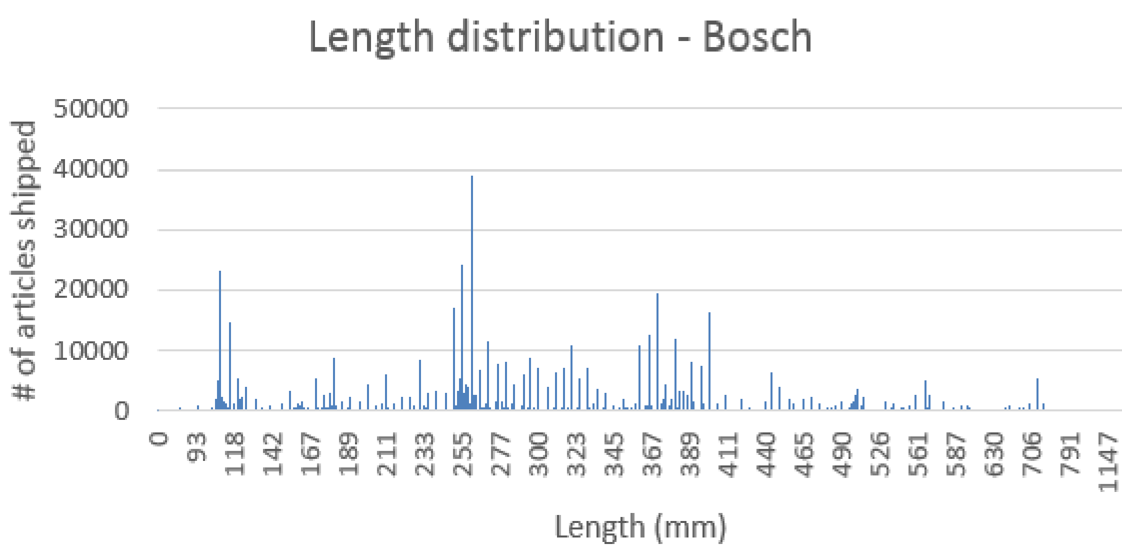

Figure A.6 Length distribution of all articles shipped from Bosch in 2015.

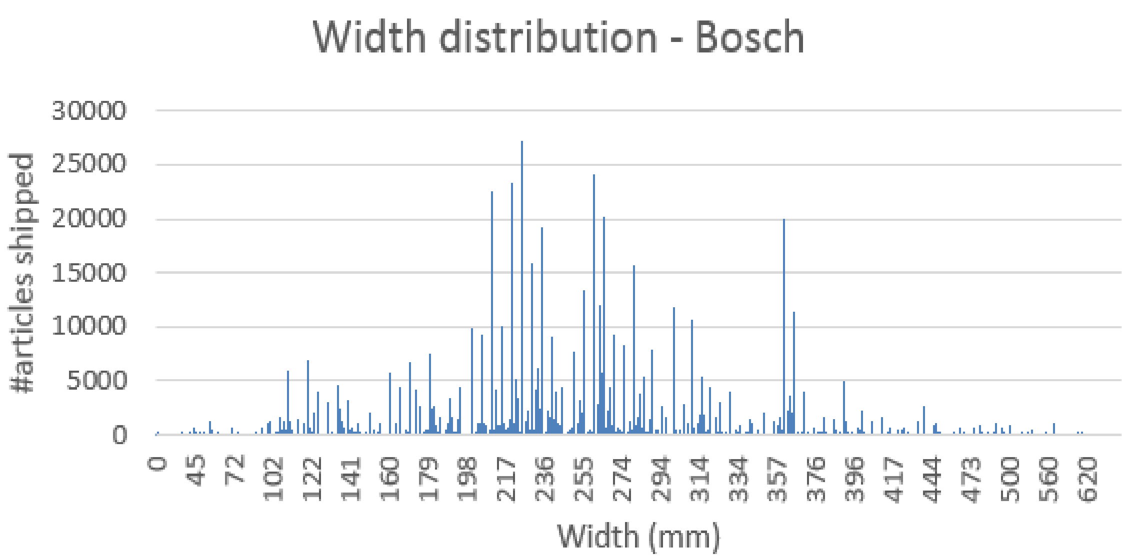

Figure A.7 Width distribution of all articles shipped from Bosch in 2015.

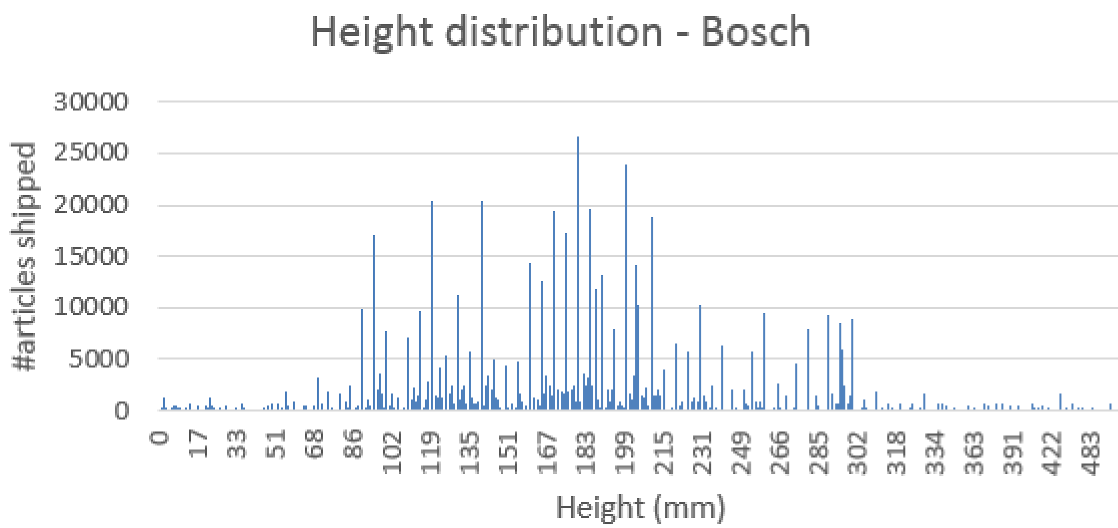

Figure A.8 Height distribution of all articles shipped from Bosch in 2015.

APPENDIX VI - DAILY SHIPMENTS COMBINED, CASALL

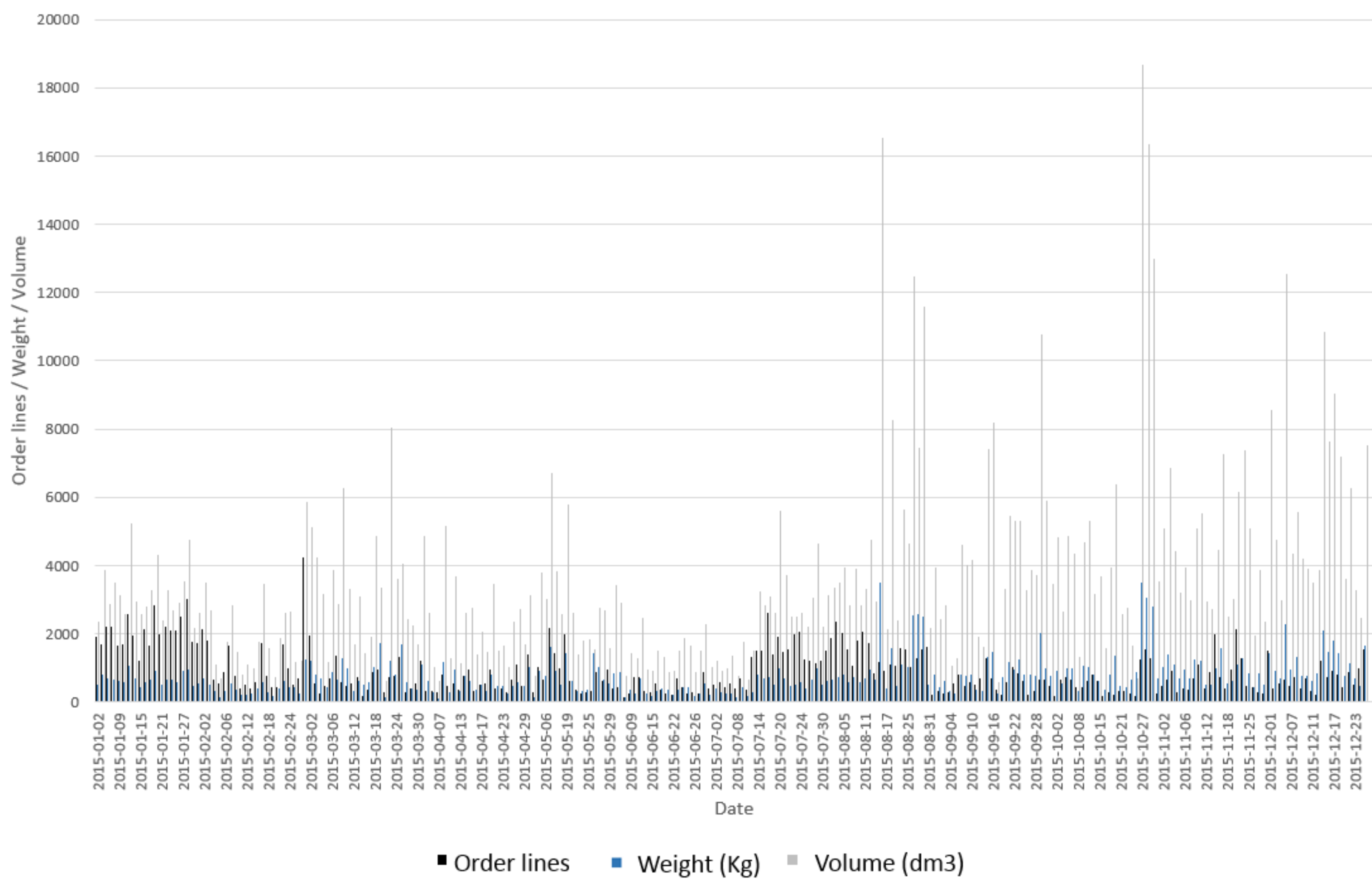

Figure A.9 Number of order lines, total volume and total weight sent out per day in 2015 for Casall. The graph disregards the values noted on 21 Aug, 24 Aug, 12 Oct and 20 Nov as those values were so high they impacted the legibility of the graph.

APPENDIX VII - DAILY SHIPMENTS COMBINED, ALL DATES INCLUDED, CASALL

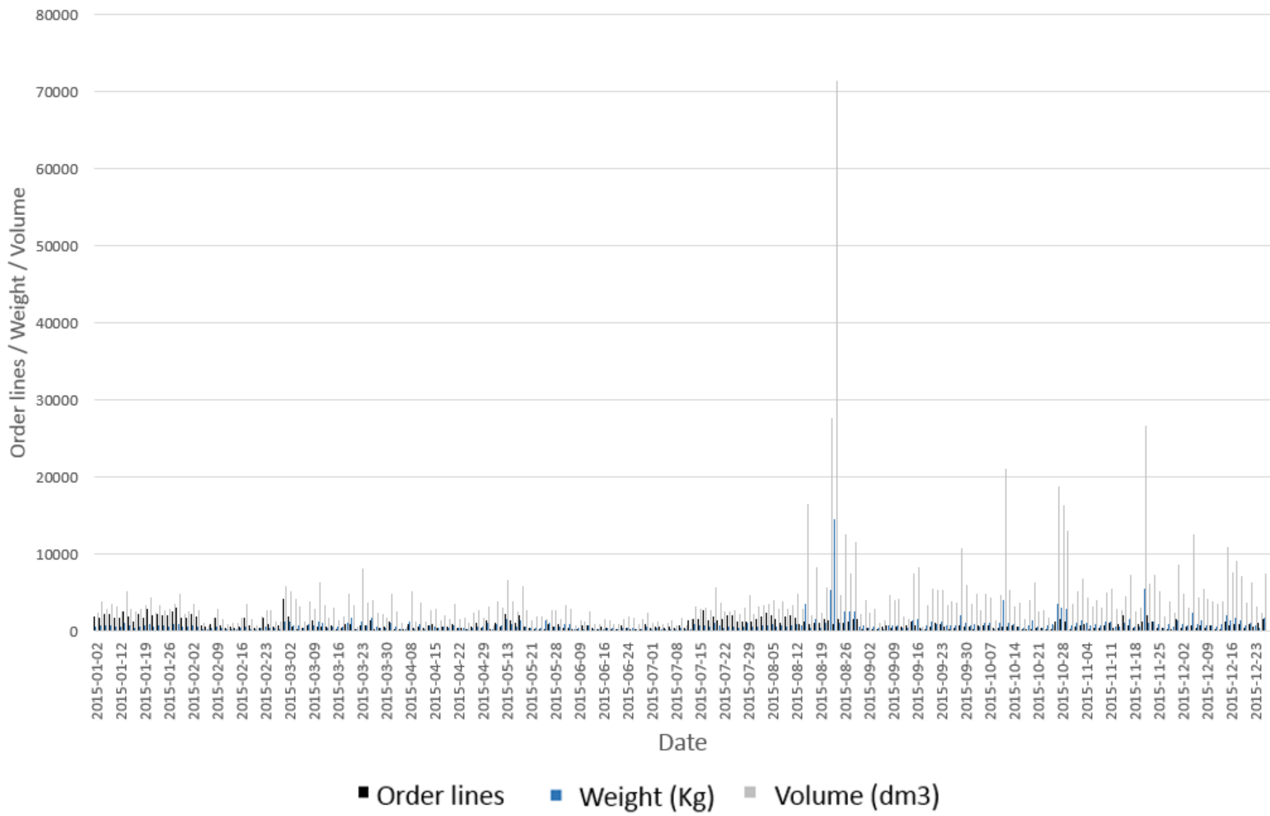

Figure A.11 Number of order lines, total volume and total weight sent out per day in 2015 for Casall

APPENDIX VIII - DAILY SHIPMENTS, CASALL

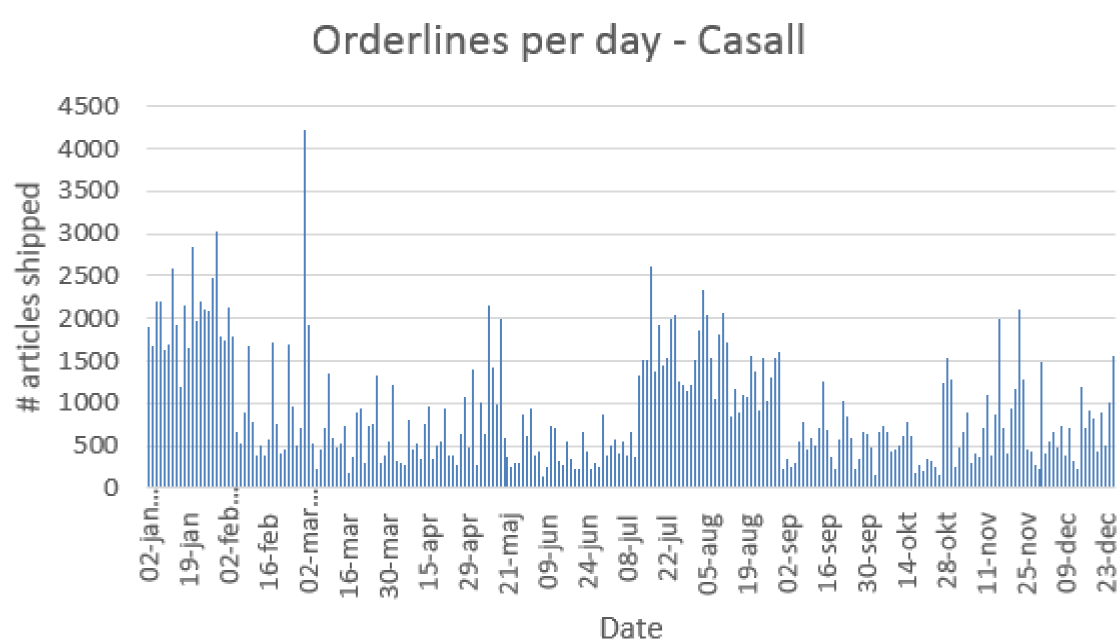

Figure A.12 Number of orderlines sent out per day in 2015 for Casall.

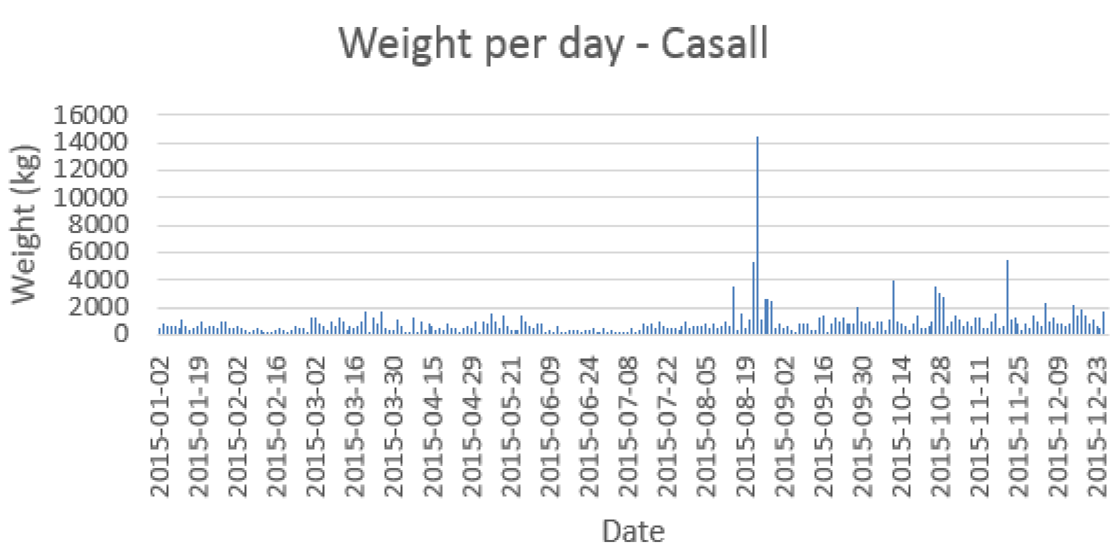

Figure A.13 Total weight of the goods sent out per day in 2015 for Casall.

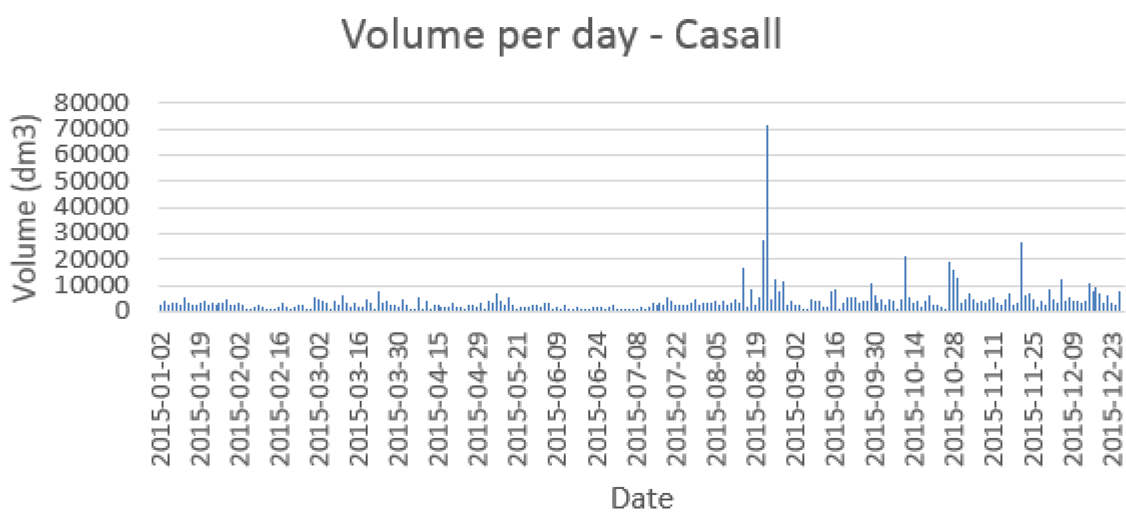

Figure A.14 Total volume of the goods sent out per day in 2015 for Casall.

APPENDIX IX - SKUS IN COMPARISON TO PICKS PER HOUR

Kardex Remstar

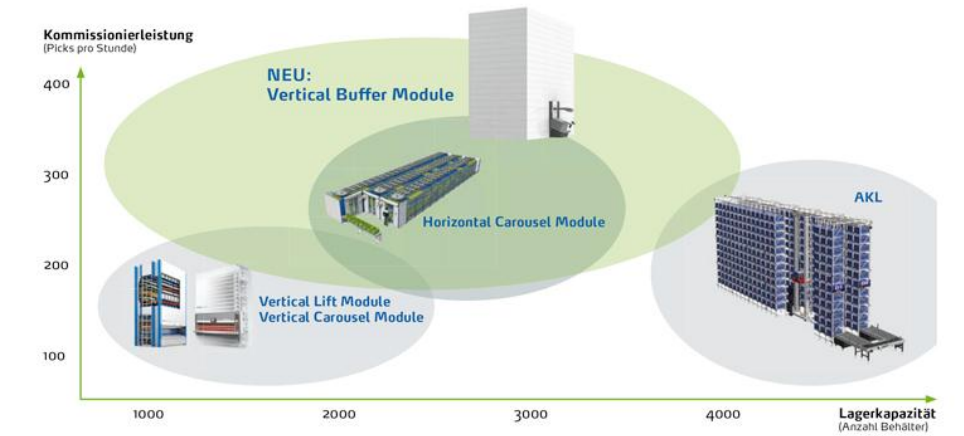

Figure A.15 Kardex Remstars systems in relation the number of SKU's and picking speed they are capable of handling (Das Einsatzfeld des Vertical Buffer Module, 2016).

Swisslog

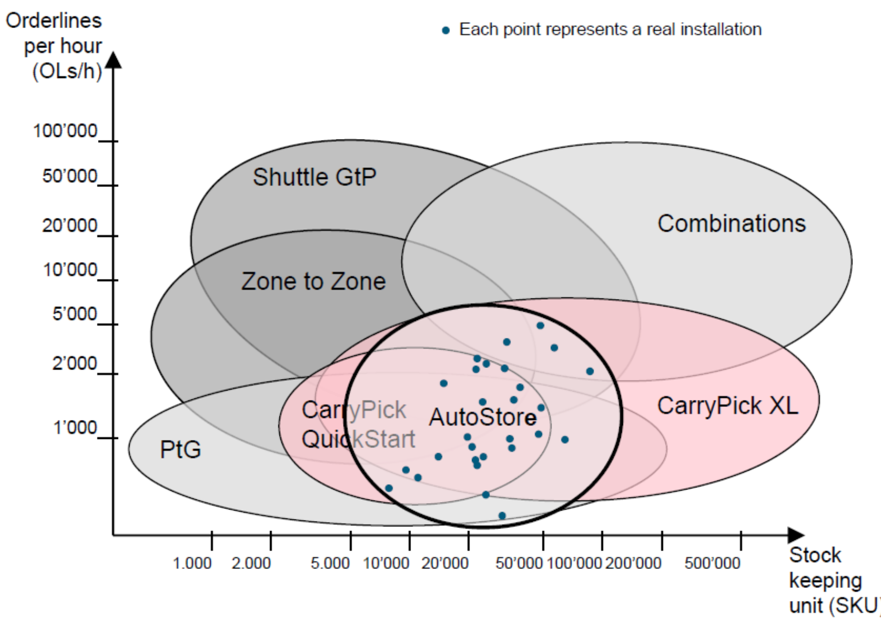

Figure A.16 Swisslogs systems in relation the number of SKU's and picking speed they are capable of handling (Sparf, 2016).

APPENDIX X - CHECKLIST STORAGE SOLUTIONS

Warehouse prerequisites

- What is the ceiling height (mm)?
  - What limits the ceiling height? E.g. ventilation or sprinklers that cannot be moved.
- Are there any width and depth restrictions?
  - In that case, what limits it?
- What load weight can the floor handle?
- What does the area proximate to the desired location for the VLM look like?
  - If possible, please attach a drawing of the facility
- Can machine parts easily be brought into the facility?
  - How big are the doors?

What shall be stored?

- How is the material stored today? Shelves, pallet racks etc.
  - Big or small parts? Is it stored in plastic boxes, containers, on pallets etc.?
- What is the weight of the material that is to be stored?
- What is the total volume (m3) of the stored goods?
- How many articles are to be stored?
- What does the demand pattern look like?
  - How many orders are handled each day?
  - How many order lines does each order consist of?
  - Is the demand pattern even or are there fluctuations?

Choice of storage solution

Choice of storage solution (VLM or vertical lift) is made based on the above questions. In general the vertical lift is better for smaller articles with a high frequency whilst the VLM is more flexible regarding the volume and weight of the goods

Control system

- Is there a need for a system that can handle the storage data (storage location, quantity, weight etc.)?
- Should picking and replenishment information be sent from a WMS to the storage solution?
  - What ERP/WMS system is currently used?
  - Should the system return information regarding the picks, replenishment to the WMS?
- Is there a need for other picking aids?
  - LED strips marking the storage location
  - Confirmation bar at the picking station
  - Label printer
  - Scanner

Why storage solutions

- What is the reason for investing in a storage solution? What do you hope to achieve?
- What is the main reason for an eventual investment?
    - Save space
    - Increased efficiency in the warehouse processes