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“Order picking system design in an ETO manufacturing firm”

A Case Study

Master’s Thesis in the master’s Program
Supply chain management

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Abstract

Warehouse order picking is the most important activity in a warehousing system since it accounts for more than half of the total cost in a warehouse. Due to this, there have been advancement and introduction of paperless picking systems which can reduce error and decrease the time spent on picking. The aim of this thesis is to examine and propose a suitable picking system in the component warehouses which feeds production at ABB capacitors in Ludvika, Sweden. This purpose led to a framework for an order picking system using ABB capacitors as a case study. The design of this framework is achieved by an extensive literature study, benchmarking at another unit of ABB group in Ludvika and observation made at ABB capacitors. The design framework which is a result of this study focuses on preconditions required prior to the design of an order picking system, design steps that should be considered and performance evaluation of the system. In addition, this thesis proposed the use of a handheld barcode scanner in ABB capacitors warehouse since it is more suitable and can be used as a paperless picking technology in the company. Some benefits of the proposed picking system at ABB capacitors includes substantial cost and time savings as well as error reduction in the picking process. The result of this work can be applicable to similar cases and can serve as a guideline in the design of a picking system in a manufacturing warehouse. Also, this thesis contributes to existing literatures in order picking system design especially in the case of an ETO manufacturing firms.

Keywords: Order picking system design; picking process; warehouse activity; picking assisting technology; paperless order picking; Storage policy; layout design; forward-reserve allocation; Pick by voice; Pick-to-light; RFID in warehouse;

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Last but not the least we would like to appreciate the support that we have received from our family and friends during this master thesis and throughout our education.

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List of Abbreviations

AC	Alternating Current
BOM	Bill of Material
DC	Direct Current
ECM	Enterprise Content Management
ERP	Enterprise Resource Planning
LED	Light-Emitting Diode
MHz	Mega Hertz
OEM	Original Equipment Manufacturer
OPS	Order Picking System
RFID	Radio-frequency identification
ROI	Return of Investment
SKU	Stock-Keeping Unit
UHF	Ultra High Frequency
WMS	Warehouse Management System

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1. Introduction

The highly competitive atmosphere of manufacturing enterprises makes many companies consider cutting costs and improving productivity of their operating systems. One way to reduce production costs is to reduce in-plant logistics associated with the operating system. Since order picking activities are considered as the source of 55% of the total expenses in warehousing systems, therefore, one way of cutting the logistics costs is improving processes in order picking systems. Any inefficiency in order picking system can also exert detrimental effects for the whole supply chain (Koster, 2007).

Hence, to improve the order picking system, we need to understand the conditions which can affect the design of a picking system.

This introductory section first provides a background to the research area. It mentions the importance of having an appropriate picking system, different effective factors in design of a picking system and available assisted picking technologies. Thereafter, it is continued by a description of the type of industry which is focused upon in this thesis, and finally, the aim and scope of the project is presented.

1.1 Background

Today, many warehousing experts focus on order picking system as the most important area to elevate productivity, since it has a direct impact on the performance of a supply chain. Order picking is the process of retaking components or products from storage area when these are requested by a specific customer. This process consists of clustering and scheduling customer orders, allocating stock on locations, picking the components or items from storage area, realizing orders to the floor and disposal of the picked items (Koster, 2007). Since most of order picking systems encompass considerable amount of manual activities performed by labor, one way to elevate the productivity of these systems can be through improving pickers' productivity in two ways; reducing the time of the process and the number of possible errors (Battini, et al, 2015).

Considering the close connection between technical facilities, information sharing system, organizational and process structure, design of an order picking system is a complicated process (Ten Hompel & Schmidt, 2007); it can be affected by several factors such as product characteristics, type of customer orders, type of functional areas, available equipment and the combination of equipment as well as operational policies for a specific functional area. Order picking systems can be categorized considering four important decisions; who is the picker (human or machine), how is the movements in the picking area performed (pickers or goods move in the picking area), how the picking areas can be connected and finally, which picking policy is implemented (pick by order or pick by item) (Dallari, et al., 2009).

Recent trends in distribution and manufacturing systems have yielded an increased complexity in the order picking process. In manufacturing systems, changes such as smaller lot sizes, more direct deliveries, shorter cycle times, higher level of product customization makes more complexities in material feeding systems (Koster, et al., 2006). This trend exerts more physical burdens on material handling. Order picking process which is a part of material feeding, is evolving since the order processing systems are now more frequent. Therefore, the configuration of picking systems in the warehouses and the content of activities related to the picking process have been changed considerably since now larger pick volumes needed to be fulfill within shorter time periods (Battini, et al., 2015).

The technological growth in pick assist technologies has introduced several paperless picking systems which can reduce the human errors and speed up the picking process. However, in choosing a paperless picking system the trade-off between costs of investment and the return of investments from reducing the number of errors and time saving should be considered. There are several new approaches in order picking systems which utilize different types of technologies such as LED or digital screens, voice-activated tools (voice picking), lighting devices (pick-to-light) and wireless instruments (Battini, et al, 2015).

It is therefore of interest to understand preconditions for efficient use of existing solutions in picking systems for different types of manufacturing system and suggest the best possible order picking option regarding to the existing limitations for a given case, which in this thesis is ABB Capacitors' warehouses. ABB Capacitors is a unit of ABB that produces capacitor units. This part of the company has its own manufacturing, warehousing, logistics and management staff and it could be considered a company within a company and warehousing activities are controlled by the logistics manager.

1.2 Purpose/Problem analysis

The purpose of this study is to examine and propose a suitable picking system in the component warehouse which feeds production at ABB Capacitors. This work will draw from the observation, a suitable picking system which can be recommended to the company, putting into consideration, the steps required to achieve the desired picking system. Therefore, this thesis will focus on the investigation of picking systems; this involves preconditions, advantages and limitations of different type of picking systems. Moreover, different type of available devices and technologies for improving the efficiency of picking systems will be assessed.

Order picking for production is an important aspect of warehouse activities in manufacturing industries. Due to this, it is important to have a functioning system, through which materials are picked for supply to the production area. Lack of an appropriate picking system can lead to significant inefficiency in material supply feeding system which might increase production costs. This entails having an efficient order picking system used for material feeding in production.

In order to design an order picking system, several preconditions and contextual factors must be taken into consideration. The demands (factors) on the system will be dependent on the company's priorities and goal for material picking. The preconditions will determine the design of the picking system based on the company's priorities. This will include design steps which are applicable to the context of the thesis and the situation at the case company. The design steps are the main part of the design and should cover the necessary factors which needed in the case company based on the available context. The choice of preconditions which is placed on the system design also reflects the level of technology (in terms of order picking assisting technologies available) to be used in the system. Based on the available picking assisting technologies, a suitable picking support technology which would be of most benefit will be recommended. This thesis will also look at the benefits which the proposed order picking design will bring to the case company both in terms of productivity in the warehouse and some economic benefit of adopting the system.

Based on these, the following research questions are proposed to understand the issues and benefits which a proposed picking system will bring to the company.

RQ1. What preconditions or contextual factors are necessary to have in place prior to the design of a picking system?

RQ2. What are the steps involved in the design of a picking system in ABB Capacitors?

RQ3. What new order picking support technologies are available?

RQ4. What is the most suitable picking support technology for ABB Capacitors?

RQ5. What benefit does a proposed picking system bring to the warehouse at ABB Capacitors?

1.3 Scope and /or limitations

This work is carried out on behalf of ABB Capacitors in Ludvika which is responsible for the development, production and sales of capacitors to power systems. Here, the work will mostly be at the warehouse where goods are received to produce wet and dry capacitors.

The production process is done in three different floors; starting from the third floor down to the first floor. The picking system to be designed is for the assembly operations (which take place in first and third floors). The warehousing system in the company is a decentralized system and items are picked from different warehouses into the final assembly section. These different zones consist of: a tent, outdoor warehouse (yard), central warehouse (in first floor). The design will focus on time efficiency and cost benefits which a new picking system will bring to the company especially for the tent and the central warehouse. Other benefits which might arise from this design are added advantage but is beyond the scope of this thesis.

The other consideration in the design of the order picking system is the manufacturing process which is based on Engineer-to-Order disciplines; therefore, there are a large variety of items in the warehouses which makes the picking system more complicated. At the case company, there is lack of structure during a picking trip, and an order can be picked several times in different trips, which makes it difficult to track and evaluate the picking process.

1.4 Report outline

This section lays out how the thesis is structured. It will enable the reader to follow the logic of the thesis easily and explain what should be expected from each chapter.

Introduction: This chapter introduces the research and the aim of the thesis with relevant research questions which the thesis will fulfill.

Theoretical framework: This shows the concepts, theories and literatures that is used as a frame of reference for the thesis.

Methodology: In this chapter, the way in which data is collected was explained, both for the literature review and the case study.

Empirical data: This gives information about the current situation at ABB Capacitors. It includes information about the OPS and how it works at ABB. It also gives the issue which the ABB Capacitors faces currently with the way materials are stored and retrieved from the warehouse.

Analysis: This chapter compares the empirical data to the literature review and as a result is aimed at choosing the right OPS for ABB Capacitors.

Discussion: It explains if the purpose of the thesis was met based on the finding made in the thesis. It also explains some issues which might have arose in the thesis but are beyond the scope of the thesis.

Recommendation: This chapter is intended for the host company and provides reasons why the selected OPS should be adopted and the right OPS which can be implemented in the company as well as cost benefits which the new system will provide.

Conclusion: Here, the summary of the research questions which are the major findings of the thesis are stated.

Figure 1: Report outline of the thesis

2. Theoretical framework

This chapter presents the theoretical framework of this project and is divided into the following sections; Section 2.1 discusses about order picking process in a warehouse. Thereafter, in section 2.2, different stages and preconditions in design of an order picking system are explained. Moreover, available order picking technologies and the suitability of each technology for different environment are presented. Finally, in section 2.3 the performance measures which can be considered in an order picking system will be discussed. The purpose of this chapter is to examine and understand available literatures and works which serves as a base of reference that will aid in achieving the aim of this thesis. Also, this chapter lays the foundation upon which the design framework was built as seen in figure 19.

2.1 Warehouse order picking system

Order picking is an activity which involves picking a small number of items from a warehousing system in order to satisfy independent orders (Melacini et al., 2010). This activity plays an increasing role in supply chain management both in production (i.e. supply of assembly stations) and distribution activities (i.e. customer order fulfillment) (Dallari et al., 2007). A manual OPS involves various activities which occur during picking. Some of these activities are conducted by warehouse personnel with the help of information systems and equipment which aids picking. Figure 2 gives an example of activities which can be found in a picking process. The inner circle shows the core activities which are done during an order picking tour while activities outside the inner circle initiates the order picking process.

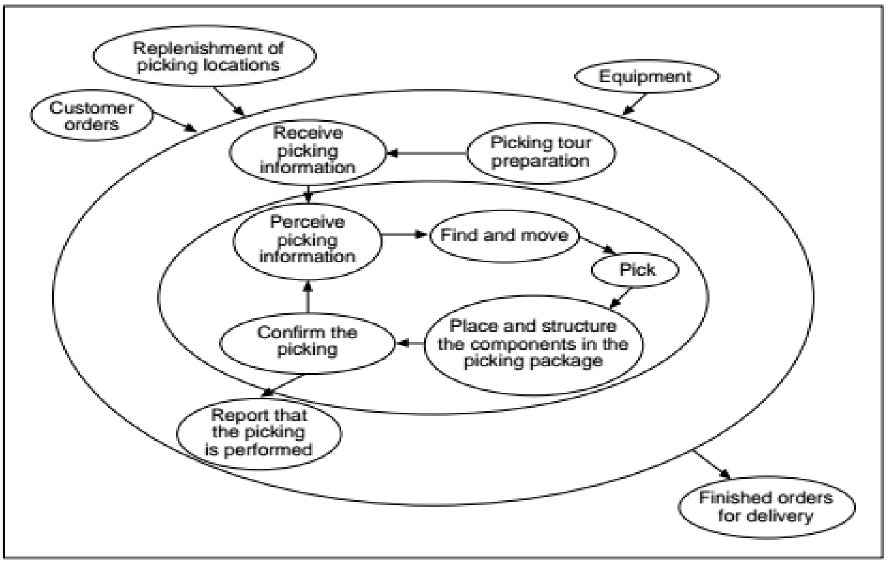

Figure 2: Activities in an OPS process, adapted from Brynzer et al., (1994).

2.2 Design of an order picking system

Order picking systems are very different in the case of complexity. These systems can vary from fully automated systems to manual ones (Goetschalckx & Ashayeri, 1989). This complexity can range from a small retail store to large distribution warehouses. Different factors such as material profile, operating strategies, system requirements, system alternatives, transaction data, and economic and environmental constraints which can affect the complexity of an order picking system (Yoon & Sharp, 1996). However, in the design of all these operating systems the trade-off between performance and the related costs should be considered (Goetschalckx & Ashayeri, 1989).

Sometimes several orders picking systems are used in a single warehouse (De Koster, et al., 2007). This design can vary according to the material flow of an order picking system which means how pickers and goods can be brought together and also the way that a single unit should be transported in different stages of a picking process (Ten Hompel & Schmidt, 2007). For example, in different zones of a warehouse, picking method can be automated in one zone and manual in another. Most warehouses utilize human resources for their order picking systems. Among these, picker to parts approach- a method in which pickers walk or drive through the aisles to pick articles- are the most prevalent ones (De Koster, et al., 2007).

2.2.1 Preconditions and contextual factors to the design of an order picking system

Contextual factors and preconditions are important parameters which can exert significant effects in the choice of an order picking system and should be available prior to the design of the system. To understand the concept of order picking, it is important to put into considerations some factors which are necessary for the system design. Here, one should think about managerial considerations, systems requirement, operational constraints and information availability as the main factors which can affect the design of an order picking system.

Managerial consideration which should be considered prior to the design of an order picking system is economic and environmental decisions. These decisions include the budget (cost), size and layout of the building (Yoon & sharp, 1996). Besides, organizational culture and training method is another managerial consideration which have significant effect on the design of a picking system. It is up to the system designer to make decisions based on the conditions which is imposed by the management. System requirement is another precondition which should be considered. This involves the storage capacity, response time for orders and number of orders, components supply, etc. Another factor is the operational requirements which are already in place at the warehouse. They include; working hours and shifts, product groups, item characteristics and order classes etc. A detailed list of these considerations is seen in (Yoon & sharp, 1996).

The information availability is another important factor in an order picking design which is mainly dependent on warehouse information technology. The warehouse information sharing system is known as warehouse management system (WMS) which can work independently or as a part of an Enterprise Resource Planning (ERP) system. However, the basic principles in all types of warehouse systems aim to control movement of goods within the warehouse the most efficient way (Karimi, 2014).

Warehouse Management System (WMS) and Enterprise Resource Planning (ERP) software can be considered alternatively as inventory management software. Although ERP can be used in the warehouse management system, however, they are not the same (Woo, 2012).

The key purpose of a Warehouse Management System is to manage the movement and storage of items in a warehousing system. It can track the items at different stages like picking, packing and receiving stages. The main advantage of WMS systems over ERP systems for warehousing system is that WMS systems sometimes can optimize inventory bases on real-time information. In this case, it can show the optimal location for each good according to statistical data and trends (ibid). The WMS systems are often supported by the company's main transaction system like an ERP system to access information regarding to customer orders and purchase orders (Kempfer, 2005).

On the other hand, Enterprise Resource Planning (ERP) is usually used in companies with several production sites in different areas as inter-location production planning and control system (Ten Hompel & Schmidt, 2007). The main purpose of this system is to facilitate information sharing between all functional areas (Woo, 2012). Implementing a specialized WMS instead of the warehouse module of an ERP system can be reasonable in the following conditions; (QSTOCK, 2017);

- If flexibility exerts great effects on the business.

- When operations are complex, ERP systems are not capable for in-depth product tracking, therefore, a specialized WMS can improve functionality.
- If a specialized WMS can add value through increasing productivity in a system.

Based on these preconditions, one can draw some design parameters which should be considered in order picking system design as stated by (Parikh, 2006); storage policy, picking strategy, material handling equipment, picking method, forward-reserve problem etc.

2.2.2 Design stages

Yoon & Sharp (1996) developed a three-stage order picking design process which consists of input, selection and evaluation steps. In the first step different issues such as managerial concerns, operational constraints and transaction data on customer order and products are considered. In this phase, the overall structures of an order picking system as well as preconditions for all subsystems are determined. At the second stage, elements of subsystems about operating policies and equipment types are specified. This step includes the physical and information transformations as well. The final step consists of quantitative and qualitative reconciliation of existing subsystems which may result changes in specifications.

Goetschalckx and Ashayeri, (1989) introduced six main steps in a classical engineering design methodology which consists of goal definition, data analysis, determination of design options, evaluation, detail design of the selected option and finally system implementation. Thereafter, they pointed out that the design of an order picking system encompasses the four first steps. They also defined a new nine-step classification of order picking design about internal and external constraints as well as the abovementioned classical design steps. These nine steps involve marketing channel selection, material characteristics classification, product demand analysis, order picking storage capacity determination, storage policy selection, mechanization level selection, layout design evaluation, design of information control system and finally batching and picking policies decision.

In this work, the first three steps are considered as the input data stage and the other six steps are considered as design selection steps in an order picking system design which are elaborated in the sections below.

2.2.3 Forward-reserve allocation

One of main considerations in an order picking system design is the determination of forward-reserve area. Forward-reserve allocation involves splitting the items into two different areas (De Koster et al, 2007; Petersen II, 1999). The reserve area is assumed to store buffer items and the forward areas stores the pick items. In other words, the forward area is used for efficient picking of items and the reserve area is used for efficient storing of the items (Petersen II, 1999). The reason behind this split is to speed up the picking process and to reduce the travel time of workers. In allocation of SKUs to the forward area, it is critical to consider the tradeoffs between order picking and replenishment frequency to maximize the efficiency of the forward area (Goetschalckx & McGinnis, 2010).

A Forward-Reserve problem involves the decisions which must be made regarding the size of the forward area and what items to place there. Here, decisions on the number of forward areas to have to made since it requires constant replenishment from the reserve area to the forward area (De Koster et.,al). Furthermore, increasing the size of the forward area reduces the number of deliveries, but in turn will increase the work done during order picking in the forward area (Petersen II, 1999).

De Koster et.al, 2007, introduced “dynamic storage” as a way in which the forward-reserve problem could be mitigated. It involves the same procedure of feeding materials to the forward area dynamically, just in time for it to be picked. Research on various forward-reserve area solutions can be seen in (Walter et al., 2013; Gu et al., 2010)

2.2.4 Storage policy selection

Storage policy selection can be seen as a way in which SKUs are allocated to a storage location in a warehouse. Here, the main aim is to determine the best approach to allocate materials to storage areas while minimizing travel time (Pakirh, 2006; Dukic & Oluic, 2007). There are various storage policies which can be used in a forward & reserve area, such as: randomized, dedicated, volume based, family based, and class based. Among these methods, volume based is considered best in terms of travel distance reduction (Pakirh, 2006; Dukic & Oluic, 2007; Petersen II, 1999).

Randomized storage policy involves items being assigned randomly at any empty storage location in the warehouse. This storage policy is appropriate when there is no statistics demand or when the goal of a company is high space utilization (De Koster et al, 2007; Dukic & Oluic, 2007), and reduced aisle congestion (Dukic & Oluic, 2007) and it works best in computer controlled warehouses (De koster et al, 2007). The drawback to this method is an increase in travel time and inefficiency (Pakirh, 2006; Dukic & Oluic, 2007; Petersen II, 1999).

In volume based policy items are assigned to storage locations based on amount or number of use, which reduces travel time of the picker/operator. Although volume based will yield a decrease in time travel, it might also result to aisle congestion and unbalanced utilization of the warehouse (Dukic & Oluic, 2007). Volume based storage policy is considered the most efficient in terms of throughput while randomized policy is considered as the least efficient (Petersen II, 1999). This is seen in (Dukic & Oluic, 2007), which compares to volume based storage policy to random based storage policies in a variety of operating conditions.

In class-based storage policy, items are divided into different groups based on specific criteria and each group is assigned to a location (Yang & Nguyen, 2016). This classification can be according to frequency of requests or similarity of SKUs (Pakirh, 2006). Within each group in a block, items can be stored randomly (Yang & Nguyen, 2016).

Further details of different storage methods can be seen in (Sharma & Shah, 2015; Pakirh, 2006; Dukic & Oluic, 2007; Petersen II, 1999).

2.2.5 Mechanization level selection

Another important decision making in an order picking design is specifying the level of automation in the warehouse. It can vary from manual to full automated systems. While choosing automated systems for different parts of a warehouse, it should be considered that how it can affect the productivity of a system. Therefore, implementation of an automated system is more reasonable while the operating costs of activities are high due to complexity in a system; as a case in point, it can be cost effective in large volume warehouses (Baker & Halim, 2007). Different warehouses have different requirements in implementation of an automated system; however, they have similar goals with this regard. The major motivations are quality assurance (considering products, processes and service consistency), costs saving and diminishing repetitive and intensive activities of personnel (Ten Hompel & Schmidt, 2007).

Dallarli, et al., (2009) classified order picking systems according to the level of automation in a warehouse. In this case four main factors are considered; who pick the goods (machines or humans); how the movement is in the picking area, if conveyors are utilized for connecting different picking zones and finally which picking policy is determined. Therefore, the level of automation can vary from picker-to-parts systems to fully automated picking systems. Although there have been attempts to fully automate order picking process, order picking system still employs human operators in a large scale and picker to parts is considered as the most important in manual order picking system (Henn & Schmid, 2013).

2.2.6 Layout design

The layout design has a significant role in the productivity of picking system, particularly when it comes to a manual picking system. Layout design determines the length of a picking tour (routing) which is part of the picking process (Caron, et al., 2000). The aim of routing is to find the shortest way in a picking trip when there are several possible routes to pick items (Ten Hompel & Schmidt, 2007). Therefore, items are sequenced to reduce the travel time. Several different heuristics algorithms are suggested in the literature for optimal routing in different situations (Roodbergen et al., 2008).

Moreover, a warehouse normally consists of different areas such as receiving areas, storage area and order picking area. A Layout design project starts with determining the required size of each area, types of racks and equipments. Thereafter, the layout structure can be arranged. In calculation of optimal number of aisles, strategic and short-term decisions should be considered (Roodbergen, et al., 2008).

2.2.7 Design of the information system

The design of the information system can be described as the way through which the picking operators can receive the information related to goods to pick for each order. Traditionally, picking information is in the form of paper picking lists which encompass identification, quantities, location, etc., of the items which should be picked (Brynzer & Johansson, 1995). By increasing the volume of items in a warehouse, human errors add up considerably and become very costly. Moreover, pickers accuracy has a direct effect on the quality of products which customers receive (Berger & Ludwig, 2007) The paperless picking systems are equipped by a set of devices which are designed to facilitate the pickers' job, mostly in terms of receiving picking information (Battini, et al., 2015). These systems can speed up the picking processes and accuracy.

2.2.7.1 Order picking-assisted technologies

Many authors agree that order picking is one of the most labour and time intensive activities in internal logistics and therefore has a high operation cost. The reason behind the high cost is due to manual picking of orders, which makes the travelling time of workers a critical factor in the efficiency of the warehouse (Grosse & Glock, 2013). Industries are aware of the financial benefits of accurate order picking (Kempfer, 2005). This has resulted to improvement in the speed and quality of order picking systems including the development of automated picking solutions (Guo et al, 2014) and paperless picking systems. Examples of available paperless picking systems include; pick-to-view, traditional pick-to-light, pick-by-voice, handheld and barcodes, handheld and RFID tags, RFID pick-to-light (Kempfer, 2005; Brattani et al., 2015).

According to (Lim et al., 2013; Azanha, et al, 2016; Poon et al., 2009; Choy et al., 2017) some of these paperless picking systems requires additional systems and middleware for proper integration into the WMS or ERP system used by the company. Today's Enterprise Resource Planning (ERP) systems are capable of handling vast amounts of data. Although they are not specifically designed to operate within the supply chain realm, these systems are generally adequate for smaller, low volume distributors. But as they grow, companies in warehousing, distributing, manufacturing and other supply chain-driven industries should replace or enhance ERP capabilities with a Warehouse Management System (WMS) (Tamburrino, 2016). Besides, different performance measures such as time, quality, ergonomics flexibility and cost can be considered in the selection of an order picking assisted technologies.

I. Handheld barcode scanner

A handheld barcode scanner is one of the most commonly used and first adopted devices which aid order picking process (Battani et al., 2015). In this method, items or locations are tagged with a barcode which are scanned by the operator during picking. When scanned, the devices communicate directly with the warehouse information system. It can also emit sounds to show that the code was read or to confirm that it is the right item that is picked. This device can be combined with a paper picking list, but also can be integrated into the handheld. By this, once an item is picked and scanned, the device shows the next item to be picked. As mentioned by Battani et al., (2015), this approach is more appropriate for low-level manual picking warehouses with a low-medium rate of picking where pickers pick items from storage shelves while moving along aisles.

Apart from handheld barcode scanners, there are modern and more advanced portable scanners which comes in different ranges, most common of them is the wearable barcode scanner which can be in form of a glove or a ring worn on the hand and finger. The advantage of this over handheld is that users can freely use their hands. In other to avoid the scanners from scanning on its own, the wearable scanners come with triggers and automatic scanning for activation (Schofield, 2017).

II. Pick-by-voice

In this system, the device allows operators to communicate with the warehouse information system via its voice-directed function. Information regarding picking is received by voice through the headset device worn by the operators, and confirmation is done verbally when the item is picked (Battani et al., 2015). This process in voice picking application is via sending order information to a picker from the source systems in the previous layer. This application can also transfer the data from pickers to the source systems for update (Azanha et al., 2016). Utilizing pick-by-voice systems is becoming a common approach to enhance productivity and reduce the number of errors in distribution centers. Wal-Mart is the first company that implemented this technology in their distribution centers (Berger et al., 2007). According to Battani et al., (2015), this solution is economically reasonable for a low-level manual picking system with a low-medium rate.

The benefit which this technology provides includes; freedom of movement and having hands and eyes free, which increases speed and flexibility of picking. A detailed explanation pick-by-voice technology is seen in (Azanha, et al, 2016), including benefits and drawbacks.

III. Traditional Pick-to-light system

In this type of system, pickers are informed by the light on which SKUs to pick and the quantity of the SKUs to be picked for an order (Xu, 2012). In a pick to light system, different colors are used to direct a picker; in this approach the lights can be on and off according to the picking list. Moreover, the lighting signal can alert pickers in the case of picking a wrong item (Alessandro, et al, 2013). A pick to light system is seen to be an efficient and accurate method, and therefore is popular in warehouses for picking, sorting and assembly. However, this system deals mostly with small sized, human friendly items with large demand (Xu, 2012).

IV. RFID handheld system

Currently, Infrared, ultrasonic and radio frequency identification (RFID) technologies are the most widespread methods for objects identification in different environments like manufacturing sites, warehouses, retail stores, etc. This technology utilizes a small tag consists of an integrated circuit chip and an antenna which can react to radio waves which are transmitted from an RFID reader (Poon, et al., 2009). RFID tags can carry considerable amount of information in compare to barcodes since barcodes can provide 12-15 information characters while most of RFID chips can carry 94 characters. RFID tags are attached into a housing device (Moattar, 2007) and information can be stored, sent and processed through these tags (Poon, et al., 2009). There are two types of RFID tags: passive and active (Moattar, 2007).

Passive tags use the radiated energy from RFID readers since these tags work without batteries and have virtually unlimited lifetime. On the other hand, an active tag equipped to a battery. This type of tags is more expensive and as a result less popular. The tag's lifetime is limited and needs to be recharged (ibid). RFID readers and tags are used in low frequency (less than 135 kHz), high frequency (3.56 MHz) and ultra-high frequency (between 850 to 960 MHz). Low frequency systems are readable in small distances and can be used close to the water and metals. High frequency systems can read larger distances with higher speed and are applicable for reading several tags at the same time. However, these tags can be affected by metals. The last option is ultra-high frequency system which is the best option for tracking goods in a warehouse (Battini, et al., 2015).

RFID technology can facilitate the use of random storage and as a result improve warehousing productivity since it can reduce the identification time. It can reduce inventory inaccuracy and incomplete orders (Lim, et al., 2013).

RFID technology is mainly utilized in picking systems in two ways: RFID tags handheld and RFID pick-to-light. RFID tags handheld function is like barcode scanner, but it can contain more characters in coding system. In this case, a paperless picking list can be integrated into the handheld and speed up the picking process (ibid). This technology is one of the best options for low-level manual picking systems with a low-medium level of picking rate (Battini, et al., 2015).

V. RFID pick-to-light system

It is good to mention that some warehouses utilize a combination of several pick-assist technologies in their order picking systems for example combination of RFID and pick to light approach. This system is smoother, in other words, does not require direct contact between the reader and the tag to get the information stored in the tag. In some cases, RFID gloves are worn by the operators, thereby freeing up the hands for picking. RFID gloves elevate picking process via reducing the process time and accuracy of the picking. In this case, pickers can use both their hands and the confirmation is done without any further action by pickers (Battini, et al, 2015). Further reading on RFID pick-to-light can be seen in (Alessandro et al., 2013; Battini et al., 2015).

Alessandro et al., (2013) suggested two different configurations of RFID pick-to-light system. First configuration consists of three main units: lights and passive tags installed on the shelves and one red light to alert wrong picking. In this system every picker follows a specific color. The second configuration uses a wireless UHF-RFID reader in the gloves which are worn by each picker. Therefore, pickers have more freedom of movement and as a result the picking process can speed up. The lights are installed on the shelves and a centralized control system manages the reader which is an active reader in this configuration. The control system sends information regarding to the picking lists as well as signals to turn on and off the right lights. In the case of wrong picking, the red-light alerts pickers like the first configuration. This technology is economically reasonable for low-level manual picking systems with a low-medium level of picking rate as well as multilevel picking (where pickers move to the picking aisles on board of forklift or crane) at all picking rates (Battini, et al., 2015).

A summary of different paperless systems used in manual picking are compared in table 1 below.

	Ease of use	Picking time	Cheapness	Flexibility	Modularity	Reading distance	Pickers simultaneity	Environment influence	Errors interception
Handheld and barcodes	High	Medium	Medium	High	High	Few centimetres	Possible	Medium	After barcode scanning
Handheld and RFID	High	Medium	Medium	High	High	Up to 20 cm	Possible	Low	After tag scanning
Pick-to-voice system	Medium	Medium	Low	High	High	Not applicable	Possible	High	After code communication
Traditional pick-to-light system	High	Medium	Medium	Medium	Medium	Not applicable	Difficult	Low	At the end of picking
Fully automated pick-to-light system	Medium	Short	Very low	Very low	Medium	Not applicable	Not possible	Low	Immediate
RFID pick-to-light system	**High**	**Short**	**High**	**High**	**High**	**Up to 2 m**	**Possible**	**Medium**	**Immediate**

Table 1: Comparison of paperless picking systems, adopted from (Alessandro et al., 2015).

2.2.8 Picking strategy/policy

There are different types of order picking strategies in warehousing systems. An order picking strategy determines the approach which a picker follows in the storage area to pick required goods (Petersen II, 1999). There are three order picking strategies according to (Parikh & Meller, 2006; Kevin et al., 2006); batch picking, zone picking and discrete picking. However, De Koster et al., 2007, argues that discrete picking is a part of batching picking and therefore have two classifications which are zone and batch picking. In discrete picking, one picker oversees picking all goods for a single order in a picking tour. In the batch strategy, a picker should pick all the items from several orders that are grouped in a batch and in the zone picking strategy, one specific area in a warehouse is allocated to one picker and that person oversees picking activities only on that area (Parikh & Meller, 2006; Kevin et al, 2006).

In batching strategy, several orders are grouped together and picked at the same time. According to Tompkins et al., (2003), two types of batch picking are; pick-and-sort and sort-while-pick.

In pick-and-sort method the pickers only pick items and do not sort while picking these items. Reasons for this might be due to the capacity of the cart used for picking. A cart with a small capacity makes it difficult to sort the while picking and therefore is moved to a downstream operator who does the sorting. One advantage of this approach is seen in form of a high pick rate of the picker. This method is different from sort-while-pick where the picker sorts the items during the picking. Here, the cart is usually big enough to enable sorting of items. This means more time during picking but also eliminates a downstream picker as seen in the former approach. This shows a tradeoff between pick-rate and sorting system. It should be noted that in both situations, pickers usually travel around the picking areas which increases the travel time (ibid).

In zoning strategy, the warehouse is split into different areas or zones, each having independent pickers in them. Tompkins et al, (2003), distinguished between two types of zoning, Viz., sequential and simultaneous zoning; this is also noted as progressive and synchronized zoning in (De Koster et al., 2007). Frazelle & Apple (1994) categorized three different types of zoning which are; sequential, batch and wave zoning.

Sequential zoning, also known as progressive zoning involves usually the use of conveyors in the movement of the carts between the zones. Each picker at each zone picks only the required SKU from that single order. Here, an order is complete when it passes through all the zones and contains all the required SKUs (Petersen, 2002). One drawback of this method is that it reduces the pick rate of pickers. This is because only one order is handled at a time. But this eliminates the presence of a downstream sorter or or sorting system (Parikh & Meller, 2008).

Synchronized zoning which sometimes called simultaneous or batch zoning; in this method, all goods related to batch orders are released simultaneously to all the zones and are picked at the same time between all the zones. Then picked orders are collected together through a sorting system. Although this approach increases the pick rate of the pickers, it requires additional downstream picker of sorting system.

In addition to sorting and pick-rate, blocking and workload imbalances are two other factors which can affect the selection of a picking system. Blocking reduces productivity in the form of waiting times. On the other hand, workload imbalance is because of unevenness in work distribution which are assigned to pickers and it is attributed mostly to zone picking (Parikh & Meller, 2008). A summary of benefits and drawbacks of different types of zone and batch picking strategies is seen in (Parikh & Meller, 2008).

The four factors (sorting, pick-rate, blocking and workload imbalances) mentioned above are recurring factors in batch and zone picking strategies and are decision problems when choosing a picking strategy. Parikh & Meller, (2008), suggested a zone and batch system cost model, which incorporates the 4.2.2effects of these fours factors, as a feasible solution to address the problem. More of this model can be seen in (Parikh & Meller, 2008).

2.4 Performance evaluation in order picking systems

There are many performance metrics used in the measure of order picking system efficiency. Chen et al., (2010), argued that most focus is on time (travel time and fulfillment time) and suggested that other objects such as, service level (flexibility, quality, ergonomics), space utilization and cost (Battini et al., 2015), should also be taken into consideration. In this section, priority is given to time efficiency and cost performance, while other performance factors mentioned here are extra factors which are beyond the scope of the thesis.

2.4.1 Time efficiency

Time is one of the most important factors in evaluating the performance of an order picking system. According to Dukic & Oluic, (2007) order picking activities (replenishing forward area, identification of items and locations, transportation of pickers in the warehouse, administration, picking items from the shelves, etc.,) are the most time-consuming activities in conventional warehouses. The mean throughput time of an order is an important measurement of the efficiency of an order picking system. The sooner an order can be picked, the faster it can be moved to the required station, which increases the service level which the warehouse provides (Yu & De Koster, 2009). In manufacturing and distribution, there has been increase in customers' demand and short lead times. Therefore, to meet these demands, companies tend to accept late orders while providing timely delivery within the tight time window (Koster et al., 2006). A work by Battini et al., (2015), showed how time spent during picking is affected by different paperless picking technologies.

2.4.2 Quality

Quality can be defined as accuracy and completeness in an order picking system. Between the times an order released to and the order picking process is finished, there is the possibility of detecting errors (Koster et al., 2006). Quality problems in an order picking system can jeopardize customer relationships or stop assembly process (Weaver et al., 2010) and faults in the products. There are several articles which studied the impact of different technologies on the amount of errors in order picking systems (Battini et al., 2015; Weaver et al., 2010; Berger & Ludwig, 2007). Battini et al., (2015) define different types of errors in a picking process, the errors are categorized in detectable errors and propagating errors. Detectable errors can be prevented by a paperless picking approach, because the wrong item confirmation can alert pickers immediately. The second types of errors are hardly recognizable, and it results more work in picking process. However, the concept of quality in order picking process has not been fully comprehended and therefore, it needs more research

(Fager, 2016).

2.4.3 Costs

Order picking contributes the major part of operational costs; it is considered as 50-75% of a warehouse expenses (Petersen & Aase, 2004). Manual picking is seen to be a critical activity and improvements made here will bring about time and cost savings in a warehouse (De Koster et al., 2007; Battini et al., 2015; Grosse et al., 2015). As seen in Battini et al., (2015), trades offs can be made between cost of investment in picking systems and investment in reduced picking error and time. Four main hourly cost were listed by Battini et al., (2015), which are; stock location cost, fixed cost, picking error cost and pickers cost. However, many researchers consider costs of time saving in design of order picking systems than other types of costs. The cost focus in this thesis will be in the form of investment cost for the proposed picking system and the pickers cost (man hour).

3. Methodology

This section focuses on the research design which involves the different frameworks through which data is collected and analyzed (Bryman & Bell, 2003). In other words, the research design includes the conditions that are used when evaluating business research. Different types of research designs include; experimental design, cross-sectional design, longitudinal design, case study and comparative design.

The main purpose of this study is to improve the picking system in ABB Capacitors; therefore, it can be considered as a case study. In this type of research design, a single case is analyzed intensively and in details. Case studies are usually done in a location, which might be an organization or a workplace. It can also involve "investigating one or a small number of social entities or situations about which data are collected using multiple sources of data and developing a holistic description through an interactive research process" (Easton, 2010, p.119). Bryman & Bell (2003) argued that there is a possibility to associate case studies with qualitative research. And that exponent of case study research often favors qualitative research, such as structured, semi-structured or unstructured interviewing and observation, because these methods are helpful in generation of intensive and detailed examination of a case.

Bryman & Bell (2003), distinguished between two different research strategies, which are qualitative and quantitative approaches. A notable difference between both approaches is quantification. In a qualitative approach, there is an absence of values while in a quantitative approach, measurement is applied. The differences between both research methods are deeper irrespective of the presence or absence of quantification; due to both have different epistemological foundations.

Therefore, quantitative research method focuses on the quantification in the collection and analysis of data that involves a deductive approach, combines the practices and standards of natural scientific model and puts the social reality view as an external, neutral reality (Bryman, & Bell, 2003). On the other hand, qualitative research mainly focuses on words rather than numbers in the collection and analysis of data. It focuses on inductive approach, how people interpret their social world rather than norms and practices of natural scientific model views social reality as a continuously shifting evolving property of individual's making (Bryman, & Bell, 2003). However, the above statement about quantitative and qualitative research is not absolute, sometimes an inductive approach can be adopted to conduct a quantitative research and vice versa.

Although there has been growth in combing both research methods, not all writers support the use (Bryman & Bell, 2003). There are different approaches to combine quantitative and qualitative; triangulation, facilitation and complementarity (Hammersley, 2002) and priority decision and sequence decision (Morgan, 1998). More details of the above-mentioned approaches can be seen in (Bryman & Bell, 2003).

In this thesis, the approaches used are facilitation and triangulation. Here, quantitative research approach is to facilitate qualitative research. In this case, warehouse operators, packing and assembly operators responsible for picking items and a logistics expert were interviewed through a semi-structured interview. In triangulation, quantitative research is used to corroborate qualitative research and vice versa. In this thesis, some aspects of triangulation are seen in the form of different research methods used and the frequency study conducted to improve the quality of the thesis.

3.1 Project plan

The plan for the thesis was constructed around the case description and goal of the work provided by ABB Capacitors. The initial scope of the task was broad but was later narrowed down and focused on the specific task which is seen in this thesis. This was achieved by several meetings with the supervisors at the ABB capacitor and Chalmers University of technology and the authors.

An initial literature review was made to gain more insight on the topic at hand which also led to the formation of the research questions seen in this thesis. On approval of the scope and research questions by all parties involved, an extensive literature review was conducted by the authors to identify relevant literatures in warehouse order picking. This was followed by the empirical study carried out at ABB Capacitors in Ludvika which lasted more than two months. This included data analysis of orders and items, observations and interviews which were all carried out at the case company and another functional unit of ABB which served as a benchmarked company. In addition to this, a frequency study was carried out to identify major activities and their share in the pricking process. The final plan of the thesis is to analyze the data gathered and propose a suitable order picking system for ABB Capacitors Ludvika.

3.2 Project research steps

This study will be carried out in four phases: theoretical framework, investigation on current situation at the warehouse, observing the way in which items are arranged and picked at the warehouse, mapping, benchmarking and recommendation. The first three steps consist of data gathering and the last stage encompass recommendation through analyzing the data gathered in previous stages as seen in figure 3 below.

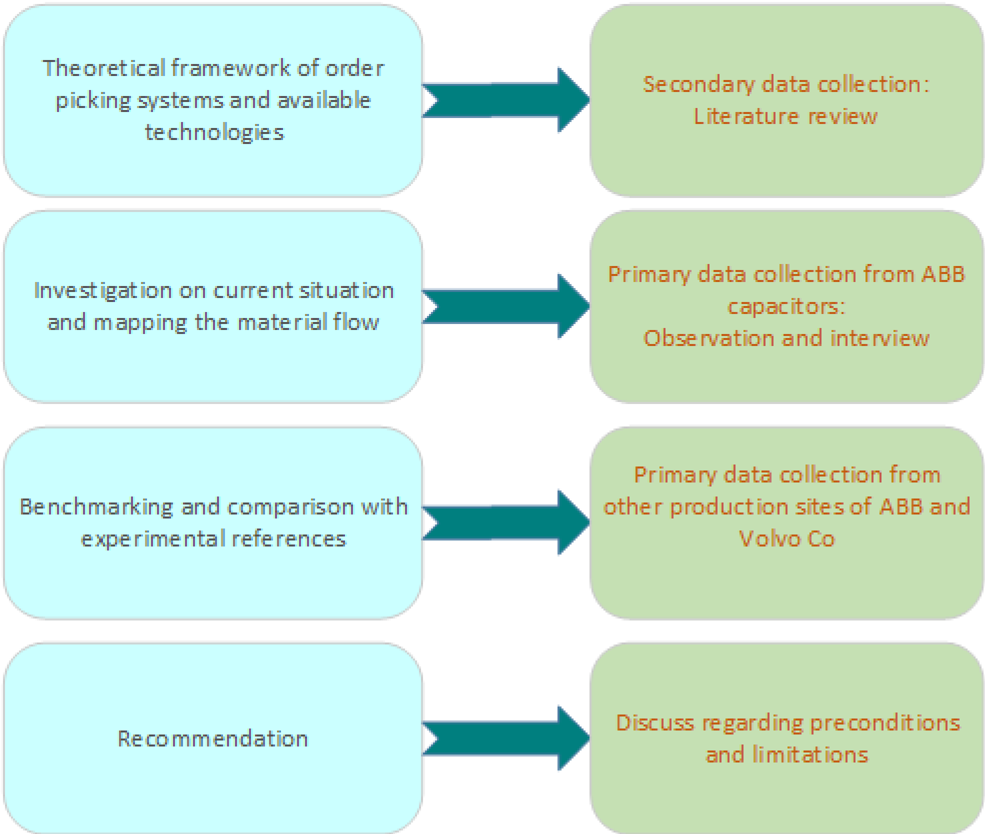

Figure 3: Project steps

3.2.1 Literature review

The master thesis will start with reviewing the scientific and practical papers about different types of order picking systems, and investigation about new tools which can facilitate this process. To carry out the researches, different search engines such as Summon (Chalmers library), Mendeley, Google Scholar, Sciencedirect, Emerald Insight and Proquest, etc. were utilized and different keywords such as order picking, material feeding, warehouse management system, pick by voice, pick to light, pick by vision, paperless picking, warehouse manual picking, RFID scanners and order picking design.

In this thesis, the focus will be on understanding the impacts of different manufacturing systems on design of an order picking system and, the preconditions under which a specific picking design can bring advantages for a manufacturing system. Besides, identifying the limitations and obstacles for these systems are crucial for more precise analyses. Regarding different picking devices and technologies, the usability and application of different types of technologies will be studies. In this case, the availability, cost effects and accuracy of different technologies will be

3.2.2 Data Collection

This step includes understanding the current situation in ABB Capacitors warehouses and mapping the material flow from receiving area to the assembly area. This part can bring a deep knowledge about the existing limitations and preconditions in the company which can help to determine a suitable order picking system for this specific situation. Besides, items characteristics in the warehouses (from different aspects such as size, demand frequency, product family, etc.) and order profiles (number of orders per day and number of items in an order) were studied to understand the complexity of the order picking system. Semi- structured interviews were the bases of data collection with the warehousing and in-plant logistics personnel and then presentation of our results to the interviewees to eliminate the possible misunderstanding in the report. Observation of activities in the warehouse was also carried out to see how the picking is done, the layout of the warehouse, how items are allocated and stored on shelves. To gain idea on the losses in form disturbances and unwanted activities in the warehouse picking process, a frequency study of activities in the warehouse was made. The frequency study was made in 40 minutes interval seven hours a day for 10 days. The reason for this is to get wide sample activities which are performed during the picking processes. The use of frequency study to back-up the qualitative literature review is an element of triangulation which is an approach of multi-research strategy. By using this method of research improves the confidence of this thesis.

3.2.3 Benchmarking

Base on theoretical framework and investigating on current situation, one appropriate solution can be determined. The suggested picking system and its relevant technology will be compared with one other existing solution in another warehouse in ABB Group. Data for these existing solutions will be collected through interview and site visit.

3.2.4 Recommendation

Finally, about the theoretical framework on the different types of picking systems as well as available technologies, the current situation can be analyzed in order to determine an applicable solution for ABB Capacitors. Thereafter, different implementation stages will be investigated and recommended. In this section, the existing pre-requisitions, capabilities and obstacles should be considered. Moreover, the suggested solutions should be compatible with existing system. This section will be ended by suggestions for future research.

3.3 Reliability and Validity

Reliability and validity are used as the basis for evaluating the quality of management and business research. Reliability deals with the question of if the results of a study are repeatable (Bryman & Bell, 2003). It also brings into light if the measures used in the research are consistent. Furthermore, validity is the most important criteria for measuring a research.

Validity entails the integrity of the conclusions, derived from a research (Bryman & bell, 2003). It also includes the credibility of the research, if it can be accepted and transferable to other related businesses.

The quality of business research demands for certain criteria to be met by the report in order that the results presented are coherent and easily identifiable by other researchers involved in similar projects (Bryman and Bell, 2003). Businesses changes and it will be naive to expect things to be the same; therefore, results might vary if this study is replicated in the future by someone else. However, to mitigate this effect mentioned, a wide range of literatures and similar case studies which applies to the context of this thesis was used to provide consistency in the report. Bryman and Bell (2003), argued that for a measure of a research to be valid, it must first be reliable.

4. Empirical data

This chapter gives general information about the current situation at ABB Capacitors. It consists of their products, manufacturing processes, warehousing and information sharing systems.

4.1 About ABB Capacitors

ABB is a pioneer technology leader in different fields such as utility, industry, transport and infrastructures with a workforce of about 100,000 people. ABB provides solutions that improve the power quality of electrical networks, develops and produces a comprehensive range of products and solutions.

ABB Capacitors products aim to eliminate fluctuations and improve power factor in line with grid requirements, which in turn leads to improvement in the power quality of electrical networks. Power quality products and solutions are available for low-voltage, medium-voltage and high-voltage systems. Range of products in ABB capacitor include, capacitors and filters, shunt reactive power compensation banks with or without reactors etc., and provides solutions for both AC and DC applications. ABB Capacitors in Ludvika produces high-voltage systems and the other products are produced in the other production sites.

For capacitor production in Ludvika, the production process is done in three different floors since it is a multi-story plant. The production activity starts from the third floor (assembly into capacitor units) to the first floor (finishing touches, final assembly and packing) as seen in the figure 4 below. More details of different activities performed in these floors are described in detail in the coming sections.

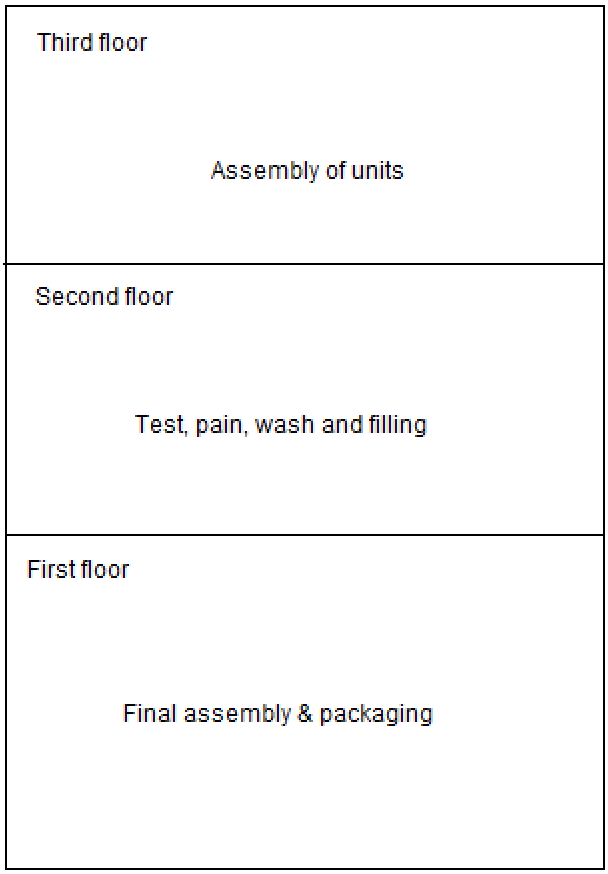

Figure 4: Plan of Capacitors production

In this work, the focus is on the order picking system in ABB Capacitors warehouses. The warehousing system is described in detail in the subsequent sections.

4.2 Warehouse system

In the information system of ABB (ERP LN) one internal and one external warehouse are defined for ABB Capacitors. The internal warehouse is a decentralized warehouse because different locations in this production site are considered as parts of the internal warehouse. These different zones consist of: a tent, outdoor warehouse (yard), central warehouse (in first floor) and warm storage. The external warehouse is located 15 kilometers from the production site. The external warehouse is used for storage of bulk materials and large items. Figure 5 below shows the layout of the focused warehousing area in the first floor. The working hours of different operators in the company are similar, but the number of shift differs. Warehouse operators have one eight hours shift per day, while assembly workers have two eight hours shifts per day. It is good to mention, in an eight-hour working shift, almost one hour is considered as the rest time (lunch time and coffee time).

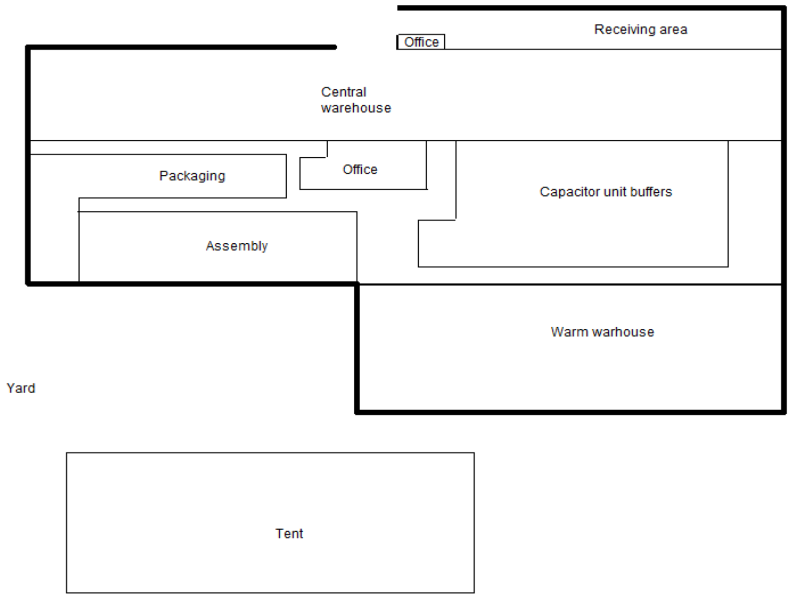

Figure 5: First floor layout (Warehouse Area)

Although there are several separated warehousing zones in ABB Capacitors, the tent is the only zone which has dedicated warehousing operators who is responsible for replenishing this zone, and other warehousing zones are handled by several operators who share the labor with each other.

There are three receiving areas in the internal warehouse: outdoor receiving area from where large items are received, dry receiving area which is utilized only for bulk materials and is in the first floor and finally the main receiving area which is located in the first floor and all other items are received from that place.

4.2.1 Types of items in the warehouses

Component parts: These items are used in the production and assembly of capacitor which is the final product.

Delivered parts: These types of items are purchased just for delivery to the customers together with capacitor units or banks. These items are only packaged and delivered to customers and are not processed or used in production. Figure 6 and 7 show sample of a capacitor unit and a capacitor bank.

Figure 6: Capacitor unit (Product)

Figure 7: Capacitor Bank (Product)

Packing parts: These items are only used for packing of final products and special orders. Items used for packing are not components of the capacitor units.

4.2.2 Central warehouse

In the central warehouse, most of the items have dedicated places according to product groups, however, in each product family, the allocation is random. One group of items is very small items like bolt and fasteners which are sent to customers and used for final assembly in the customer sites. The other groups are bulk items like films and cables. These items with dedicated positions can be said to belong to the same class.

One part of this warehousing area is allocated to the Kanban system which feeds the third floor (start of production). Kanban items are defined according to their lead time and demand pattern. In this case, items with short lead times (less than two weeks) and more stable demand pattern are replenished by Kanban system. Also in the central warehouse, there is a line of shelves where items are placed randomly. The items placed on this do not belong to any product group and the position of these items changes overtime. Also, sometimes there are capacity limitations for bulky items, since there are high stock levels for specific items in the warehouse. Therefore, making it difficult for warehouse staff to find an appropriate location for they items. Due to this space limitation, items can be placed by the shelves which block the aisles and creates extra job for staff during picking or replenishment on the shelves. This high inventory level is to avoid shortages since suppliers can stop production for a couple of weeks and due to long lead times for such items. Generally, most items in this warehouse are used in the third floor.

Figure 8: Vertical carousel

Some small items which have very low demand frequency are positioned in one pallet with several other items in the central warehouse. This positioning is due to lack of space in this place which make it difficult for pickers to identify these item as it is shown in the picture below.

Figure 9: Several items in one pallet in central warehouse

4.2.3 Warm warehouse

The warm warehouse mainly is utilized for capacitor containers and leads. Both product families have dedicated lines in the warehousing area. However, since there are a large variety of capacitor containers in this warehouse, therefore, random allocation is used for placing capacitor containers on a specific line. Here, semi-finished products are temporarily stored as a buffer before final assembly. The storage of this buffer is not organized and sometimes they are stored in the dedicated places meant for other items in the storage.

4.2.4 Tent

Three types of items are kept in the tent; Wooden items for packing which are more sensitive to the weather, big metal components and small metal components which can be stacked in pallets. They type of items in the tent are less sensitive items which is why they are placed on the tent. Here, wooden items and some oversized metal items have large volumes and occupied the main part of the tents; this issue makes some limitation for design the layout since forklifts should have space to move safely in the tent. Currently, a U-shape layout is considered for this zone. Figure 10 shows the placement of items in the tent.

The main issue with this storage zone is that there is no identification and allocation system in this area. So, when an item arrives to the tent, the location of the item is recorded in the ERP system, but the system does not show the actual position of the item in the tent. Moreover, in some cases, the position of items is shown to be in tent in the ERP system; however, due to lack of space, those items are placed in the yard. Therefore, it takes a considerable time to pick the items from this area. All the items placed here are used in the final assembly either for packing or packed for delivery to customers. It should be noted that no items from the tent is sent to the production line. Apart from the issue with identification process, there is high variability of items which can be placed in the tent. The reason for this is due to the unique products which are produced by the company.

Figure 10: Warehousing area in the tent

4.2.5 Yard area

This area is used for very large items such as racks and wooden boxes (figure 11). There is a random system for placing the items in this area, since these items are large, it is easier to identify them in comparison with other items. However, because there is no system for placing and identification of items in this area, the picking process can be a time-consuming activity. The items which are positioned in this area in wooden boxes should be fast moving items. However, some boxes have been kept in this area for a long time due to changes in production planning or customer request to postpone deliveries. Therefore, the wooden boxes may break because of humid weather and makes extra job to fix which means waste of time and material.

Figure 11: Warehousing area in the yard

4.3 Order picking process

In this section, the current order picking processes in different floors are discussed. Here, the production starts from the third floor which is the only floor with the forwarding area for almost every item which is used in this floor. On the other hand, on the first floor, most of the items are picked from storage areas and there are buffer inventories only for small number of standard bolts and fasteners which are used in assembly process as well as standard cables which are cut and packed according to orders in the packing station.

4.3.1 Picking process for the third floor

The production of units starts from the third floor. The number of components in this forwarding area is around 30 basic items. However, some of these items have several variations in their own groups E.g. there are over 400 different types of capacitor containers, but the number of capacitor containers varies over time according to the orders (i.e. the number of capacitor containers in a warehouse at a time can be any amount, e.g. 50). All items used in production of the capacitors are listed individually in the company's information system and not classified in groups as mentioned above. Some of these components (bulky items) have dedicated places and some have random locations in this forwarding area.

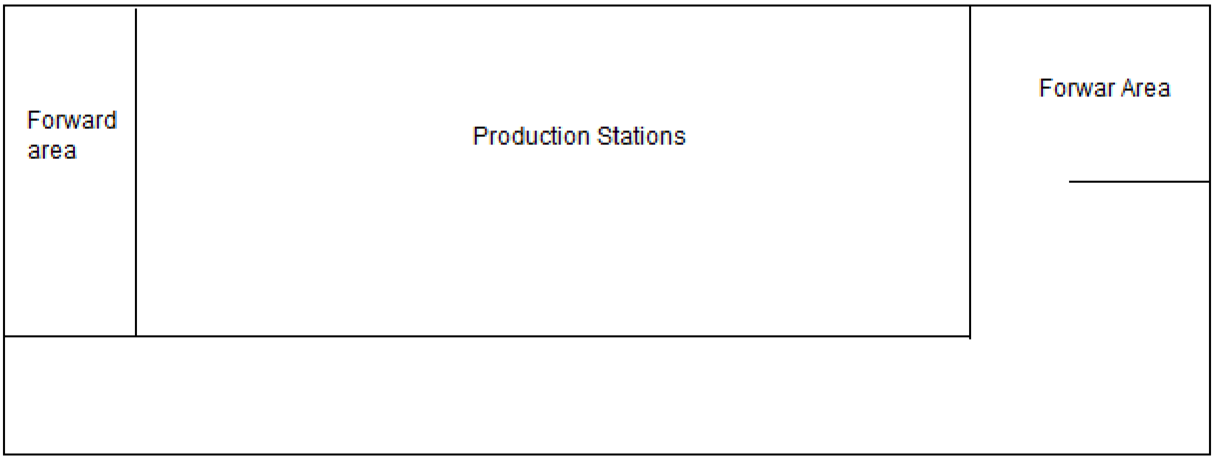

Figure 12: Third floor layout

Assemblers are mainly responsible for picking operation of their own assembly part in this floor. It is good to mention, since the production of units in the third floor is sequentially carried out in several assembly stations; therefore, the order picking process for a single unit is done by several assemblers. Assemblers refer to the bill of material (BOM) as their picking-list, but only checks for the items to pick on the system without printing an actual picking list. They have access to BOMs on the computer of their own floor. Warehousing operators are responsible for replenishment of the forwarding area. In this case, warehouse operators oversee the replenishment of items in the forward area. The inventory control for replenishment is carried out by visual check; therefore, a warehouse operator walks through the forward area, to check for used up items which require replenishment. This control normally happens twice a day (once in the morning and once in the afternoon). For more customized items like capacitor containers and different types of leads, warehouse operators receive a paper-based picking list one week in advance and refill the mentioned items according to production plan.

The replenishment at the production stations in the third floor are done individually by the assemblers (for items not in the Kanban), but the Kanban system (used for some stations in the third floor) is replenished by the warehouse operator during the daily routines. Replenishment of both the production station and the Kanban is done from the forward area on the third floor while replenishment of the forward area is done from the central warehouse located on the first floor.

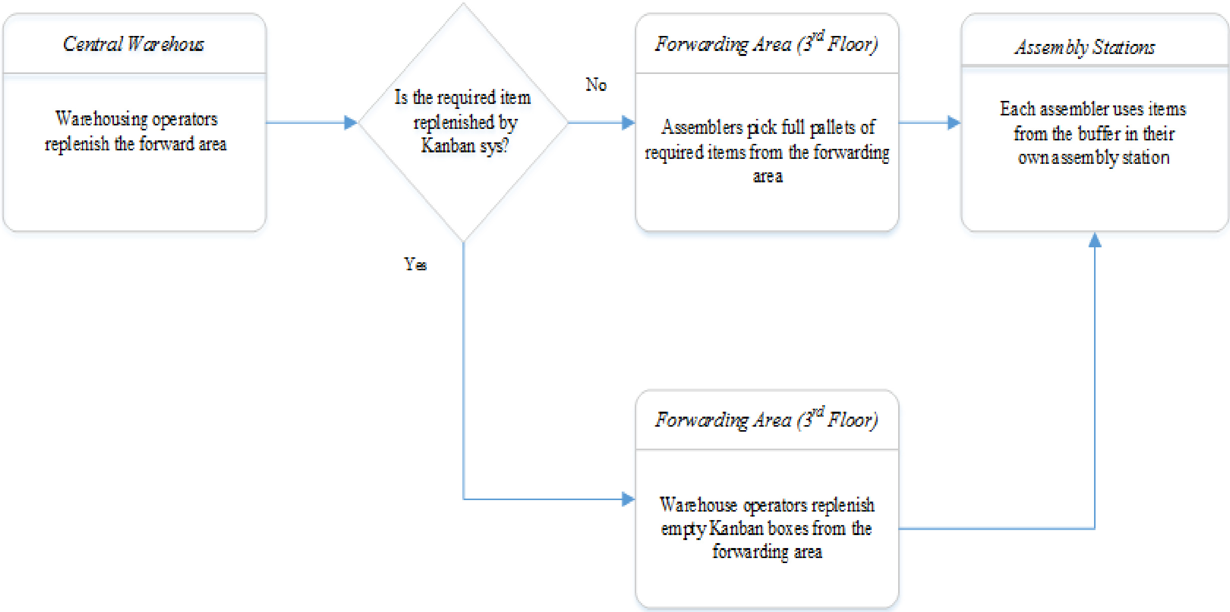

Figure 13: Picking process in the 3rd floor

In the forward area on the third floor, there are situations where there only exists one capacitor container in several pallets. These pallets might have the same item number but for different projects. In this case, the items are left in the forward area for longer period, thereby occupying space on the shelf.

In this floor, assemblers provide a buffer in their assembly station, which can be a full pallet for some items or Kanban boxes which are placed close to the production area. The picking process is illustrated in figure 13. In the current situation, there is no confirmation step in picking process while assemblers pick their required items from the forwarding area.

4.3.2 Picking process for the second floor

In the second floor, the wet capacitor units are tested, washed, painted and filled with the oil. Therefore, there are a limited number of raw materials (four or five items) in of this floor and these items are standardized. The oil is transferred from a big tank which is an outdoor area to this floor via a pipe and sand and colors are refilled by warehouse staff once a day or each other day, therefore, the material feeding system in this floor is not a big concern for the company and therefore will not be considered in this work.

4.3.3 Picking process for the first floor

In the first floor, final assembly of the products is done in modules (and sometimes in bank for small orders) which is the last stage of the assembly process. The final assembly is carried out in two stages; at the first stage, the assembly operator fixes some bolts and fasteners on the bushings of the capacitor units. This step is the final step of assembly process for capacitor units. The bolts and fasteners which are used at this step are mostly standard items. In the next step, capacitor units are assembled on banks and ready for packing to the customer. At the other station, packing of the orders is also carried out. Sometimes, an order can encompass more than one hundred packages and the final assembly is carried out in the customer's place. Assemblers are responsible for picking most of the items from reserve area. In the case of large orders, one assembler checks for the required items one or two days before the pickings, especially in the tent and yard area, by walking through these areas and observing if the required items are available. In this situation pickers may pick all the required items from the tent and yard and position them together somewhere in the yard or tent. There is no dedicated place for this purpose and each picker may choose different position/location for gathering these items. However, it does not mean that they specify the exact position of items for the picker.

Some small items, bolts and fasteners which should be packed and sent to the customers together with the semi-assembled products are picked by warehousing operators. These bolts and fasteners are standard items which have dedicated locations in the central warehouse. However, in the case of emergency, assemblers can pick items from the receiving area, before they are registered in the system. This issue creates problem for warehouse staffs since assemblers don't register the items which are picked from this area and it leads to having wrong data in the inventory system.

Besides, some bolts and fasteners which are used very frequently in the assembly station are kept at the assembly station. These items are ordered automatically through the ERP system which sends the orders to the suppliers and is replenished by the warehouse staff when the item arrives. The reason behind this issue is that the production department needs more inventory control on these items. Therefore, these items are not considered in the scope of this work. However, for large and heavy items which are placed in the tent, picking of these items can take time since sometimes pickers need to remove barriers which are in front of the required items. This is also noticed in the yard. The picking process for both assembly and packing stations is illustrated in figures 14 and 15 below.

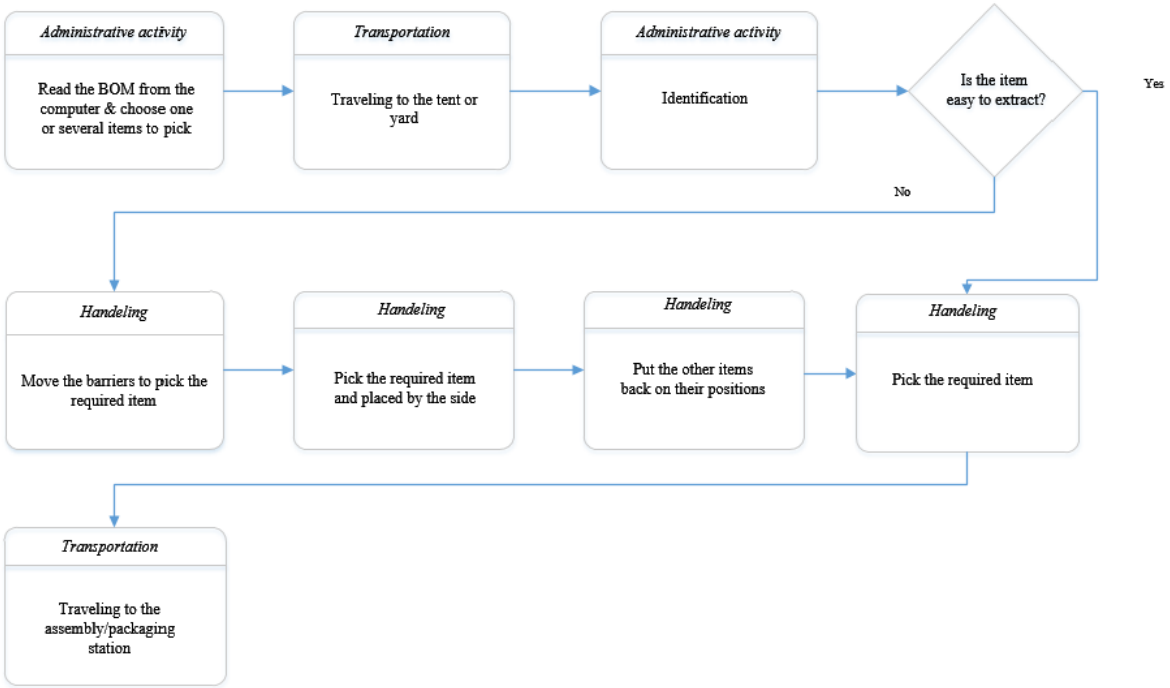

Figure 14:
Picking process from tent/yard

As seen in figure 13, it might occur that other pallets might obstruct access to the items to be picked. In this situation, the picker must move the pallet blocking the items before picking and after that, return the pallet back to its original position or in another position close by. This situation explained here is mostly for the tent storage, but also can be applicable to the yard, which is beyond the scope of this thesis.

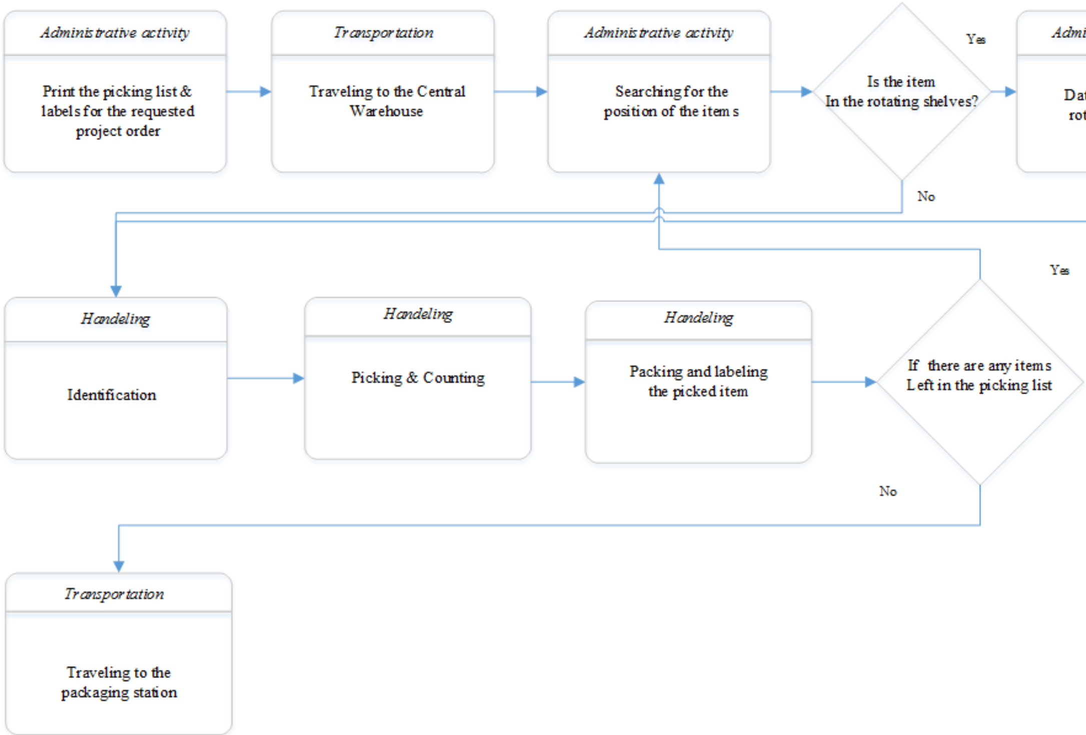

Figure 15: Picking process from central warehouse

In Figure 15, the picking process in the central warehouse is similar but done differently from the picking in the tent as shown in the previous section. The reason for this is due to the item characteristics and because the central warehouse is more organized. In the central warehouse, they have vertical carousel (vertical lift model) which houses a large variant of SKUs and therefore makes it easier to pick these items since there is little to no movement of the picker. With this, the picker can select the shelf level and pick items based on the order in the picking list.

The main consideration in this floor is about the number of items, because all products are produced through engineering to order principle; henceforth, the selection of items in the picking process should be done through a large variety of items and components which makes the tracking process a complicated activity.

There are different reasons which cause time waste in the picking system. The main reason for this time waste in ABB Capacitors warehouse is related to searching process for the materials which have arrived at the site, but the location is not registered as arrived items in the information system in the warehouse. Moreover, in some cases the production department takes the new arrival items which have not been registered in the information system, without informing the warehouse staff. The reason behind the delay for data entry can be unavailability of packing lists as well as limited resources for checking the receiving area. In some cases, the printed labels which contain information about pallet items are not fixed properly on the pallets and it may lead to loss of labels during the transportation process. In addition, misplacing of items on the shelves is another reason for time waste; in some cases, the information about position of items are registered manually in the system, and might result to keying in wrong information which is a common human error.

For some small items which are positioned on top shelves where it is hard to keep track of items visually, warehouse staff controls the number of items by manually changing the number of remaining items after each picking process. So, when assembly operator picks items directly from the warehouse without the knowledge of warehouse operators and without changing the number of items in these pallets, it leads to inaccuracy in the information available to the warehouse operators. The impact of this is seen in the form of item shortage at the warehouse.

4.4 Order characteristics

According to the statistical data, there are more than 1000 project orders per year for ABB Capacitors. It is good to mention that a customer order can encompass several project orders, or it can be only one project order. As a case in point, a project order may include one of the following items; capacitor units, capacitor banks, modules, a reactor, spare parts, etc., while a customer order can encompass a combination of the mentioned items. Moreover, some project orders such as reactor, transformer, lifting device, etc., are the items which are purchased and sent to the customer with the other items in a customer order.

Figure 16 below shows the variation in the quantity of items for each project orders for the year 2016. In this figure, some projects contain only one item, which is not clearly visible in the chart. The quantity of a project order can significantly vary, for example from more than 400 capacitor units to one capacitor unit or capacitor bank as seen in figure below. Most times, all items in a customer order are sent in one delivery for small customer orders. Henceforth, the number of items which should be picked in one customer order can also vary a lot.

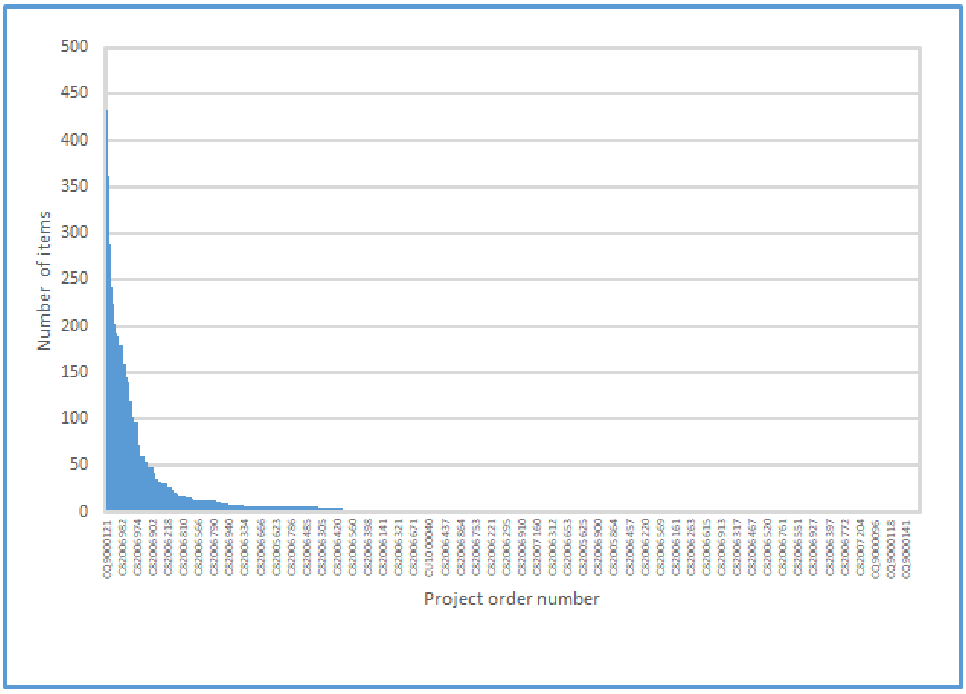

Figure 16: Produced orders in 2016

4.5 Items characteristics

In ABB Capacitors, there can be over 4500 items (component parts used in production, assembly and packing) in the warehouses, based on the design of products (based on the customer orders). However, data shows that currently, there are more than 1000 items in the system. The size of components has a large variation from very small items such as bolts and fasteners to very big items like racks and large packing pallets. Here, items characteristics in different warehousing zones and production floors are discussed. Items are placed in different storage locations based on where they are needed in the production floor, their sensitivity and the size, weight and nature of the items.

4.5.1 Items characteristics in the central warehouse

The items which are kept in the central warehouse can be divided to bulk items like films, coils, cables and wrapping papers (press pan), very small items such as different kinds of bolts and fasteners and other item which have usually small sizes. Most of the items in the first two categories are more frequent items, the third category is less frequent and sometimes there are even unique items which are packed and sent to the customers or used in the production based on specific customer orders. The main part of central warehouse is allocated to the items (component parts) which are used in the third floor.

4.5.2 Items characteristics in the tent

Components in the tent can be classified in three groups; first, wooden packaging boxes, metal components which are stackable in standard pallets or cases and oversized metal items which can't be kept on the pallets or standard cases. According to the statistical data the main part of items in the tent are unique items (The share of items based on the annual consumption is shown in figure 17 below). The items located in this storage area are mostly packaging and delivered parts used for final assembly and packing for delivery to the customers.

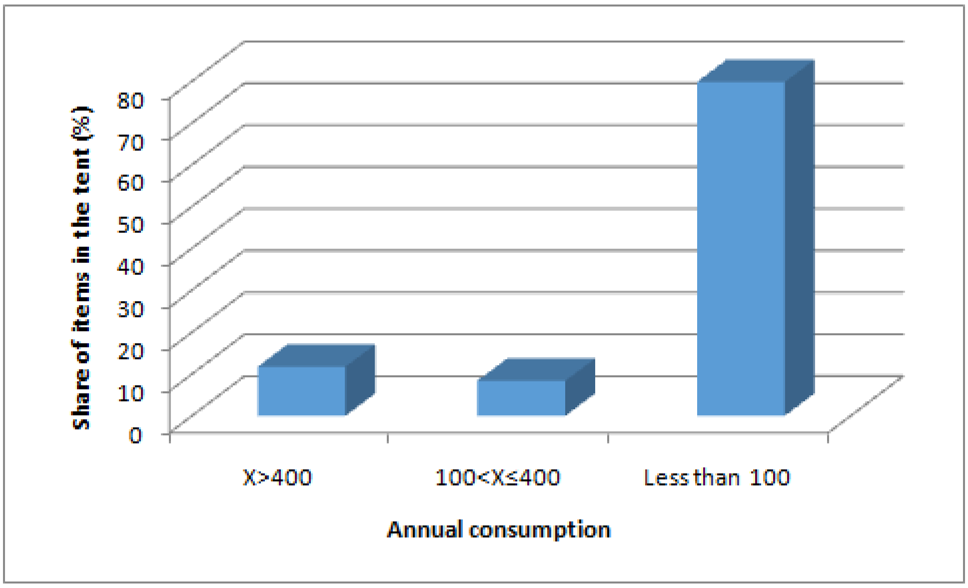

Figure 17: Share of items based on annual consumption in the tent

4.5.3 Items characteristics in the yard

The items which are located in the yard are mainly racks, wooden boxes which are less sensitive to humid weather or fast-moving items and other big items which are kept in cases and supposed to be sent to the customers in a short time. However, some items in the yard are stored for about a year; presumable from problems with the planning system or issues with the customer. The reason behind keeping items in this area is lack of space in the tent and other indoor warehousing area.

4.5.4 Items characteristics in the third floor

More than 60 percent of items in this floor are standard items which have high and medium frequency, the rest of the items which have low frequency are used based on specific orders. Figure 18 below shows the share of items according to their frequency of use. This chart is based on ABC/XYZ analysis which was done by the company seen in Appendix 2. In this case, items with high volume and medium variations in demand (AY) as well as items with medium volumes and low variation in demand (BX) are considered as more frequent items; items with medium volumes and medium variations in demand (BY) are considered as medium frequency items and finally, items with low volumes and medium volumes and high variations in demand (BZ and CZ) are considered as low frequency items.

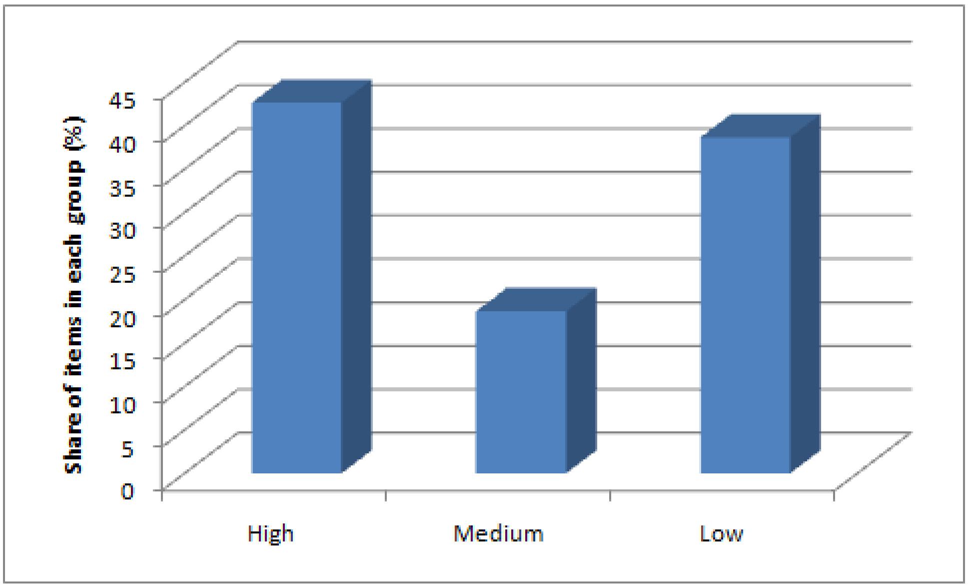

Figure 18: Share of items based on frequency in the capacitor units' production floor

4.5.5 Items characteristics in the first floor

As it is illustrated in figure 19 below, in the first floor, less than ten percent of items have high demand frequency and more than 60 percent of items have low frequency. Large variation of customer orders leads to increasing number of unique items in this floor. Figure 18 below shows the share of items according to their frequency of use which is based on ABC/XYZ analysis done by the company as seen in Appendix 2.

Most of the items in this category belong to low volume category (group C); only two items belong to high volume category (group A). However, these two items have high variations in demand (group Z). Besides, four items belong to medium volume category (group B) with medium (group Y) to high variations (group Z) in demands. Therefore, the demand frequency categorization for the items in the first floor (final assembly and packing) is different from items in the third floor. Here, items with medium volume and variations in demands (BY) as well as items with low volume and low variations in demand are considered as high frequent items. Items with low volume and medium variations in demand (CY) are considered as medium frequency items and finally items with high to low volumes and high variations in demands (AZ or BZ or CZ) as well as new items are considered as low frequency items.

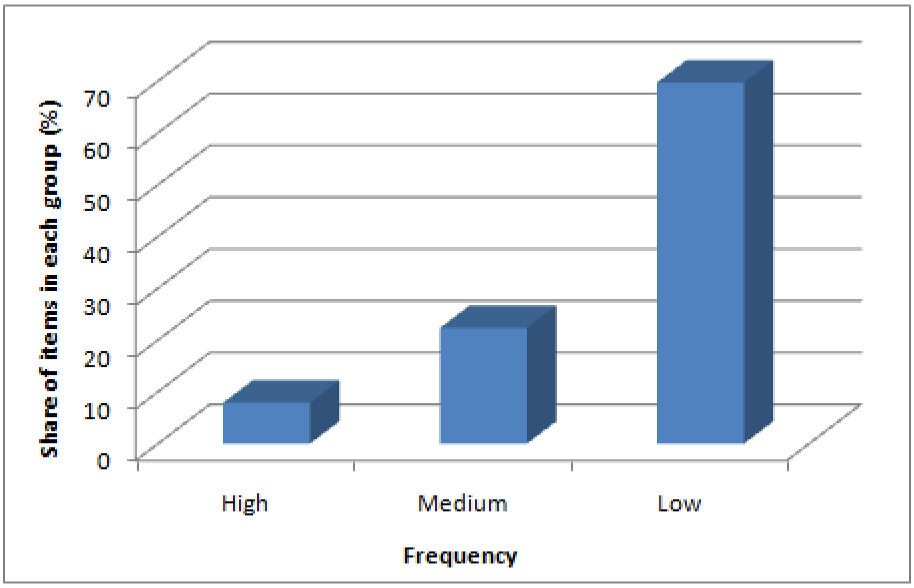

Figure 19: Share of items based on frequency in the final assembly and packing station

4.6 Information system

ABB Capacitors utilizes ERP LN, which is the company's ERP system, and it is also used as their warehouse management system. ERP LN is not a WMS, but currently serves the purpose which is used for. In ERP LN, warehouse operators look at stock point inventory which gives them information (e.g. Number of items in inventor warehouse location etc.) about what they need to know. This is also available in the hand scanner which is used by these operators. Items are stored by warehouse and then items can be sorted based on the warehouse location and not the exact location or position of the item on the shelves.

Most items in the warehouse are unique and therefore are not standard items. This situation makes it difficult to define a fixed location for items in the warehouse on ERP LN. This is one of the main issues which the warehouse is facing. And because of this, a storage list is not used by operators to store items on the warehouse. Also, BOM is used as the picking list, which in some cases is not used by operators since the printed format can be unstructured. The other consideration about ERP LN is the limitation in the number of characters which can be used in the coding system. Currently, at least eleven characters can be used in identification codes.

Although, there is a barcode scanning system in the ABB Capacitors warehouse, but, this system is not efficiently used for several reasons. The first problem is regarding the uniform approach in barcode definition. Currently, there is not a standard barcode definition in different warehousing zones; as a case in point, in the central warehouse, the location of materials is defined to the shelf level, while the location of material for warm storage is defined at row level and in the tent area there is no detail information barcode system about the exact place for items. The second issue is related to the execution of the warehousing system. The operators do not always use the barcode scanners.

In the central warehouse, the scanner is used to indicate where to pick an item for some items and gives information on the quantity of item available in the warehouse. This is different for smaller items since they currently lack barcode tags for such items. Here, operators in the warehouse can pick these items (bolts, fasteners, etc.) as of when required without the use of barcode scanners. In addition to this, the scanners used at the warehouse is just for identifying the location of products, but is not used for confirmation of the picked orders. The reason for this might be since only warehouse staff has barcode scanners, therefore, in the case when assemblers pick items from warehouse they do not have access to barcode scanners. In addition, this step is not requested from pickers in the system.

4.7 Benchmarking of picking systems

Here, the picking system in another warehousing system in ABB Group is discussed. The purpose of this section is to understand how this production system works with their order picking and warehousing system.

4.7.1 Benchmarked business unit in ABB Group

The products in that unit are highly demanded which are connected to a transformer. There are around five product variants in this production system. The number of components which are kept in the warehousing system is around 9000 items. These items are not oversize items, so, they can be placed at standard shelves. In the following subsections different steps in design of the order picking system is presented.

4.7.1.1 Storage policy

At this site, due to the nature of the items used for the product, storage locations where divided into fixed storage and random storage locations for parts. A lot of items are very small which are kept on drawer shelves which are not very depth. Therefore, they were able to efficiently utilize space by using this kind of shelves for small items. Besides, a position may contain several items at the same time; this storage position is mainly for small items.

4.7.1.2 Information system

The information sharing system used here are ERP LN and ECM which can be integrated with the hardware (barcode scanner). The ECM system has the possibility to accommodate a pick-to-light system which is still on the pilot stage at the factory. The use of handheld barcode scanners by warehouse staff aids in easy tracking of items locations, confirmation of picked items and keeps track of inventory quantity at the shelves by updating the location of items in the information system. These benefits resulted to a huge savings in time spent during picking compared to paper-based picking system as noted by logistics manager. Besides, the confirmation helps the re-ordering process, as it acts as a trigger in ERP system.

Each location in the warehousing area is determined by specific code. This code represents a specific division on each shelf. Since computerized scanning system is utilized for retrieving items, they can improve the space utilization rate through allocating one spot to several small items.

4.7.1.3 Picking process

There are two types of picking process in this system; kitting and replenishing the bins at workstations using in-plant milk run supermarkets. In the first case, pickers use a paper-based picking list for kitting which is sorted according to the location of items. Picking for kitting is done by discrete batching rules, since the number of items in a kit is large enough, which makes it impossible to carry several kits at the same time in picking area. For the other picking process, they bring empty bins which are used in in-plant milk-run supermarkets, to the warehousing area and scan the code on the bin, which contains the item information including the position of that item in the warehousing area. The size of items for replenishing bins is usually small which can be placed in small bins. Due to lack of a routing program/logic, transportation through aisles is the main part of picking activities, although the warehouse area is very close to production site. Transportation is done by both a tow train and forklifts. In both picking process, barcode scanners are used for confirmation of picking at warehouse level (not in detail like station level). Most of items in this warehouse area have standard size. Here, four dedicated pickers are used for kiting items. Other warehousing operators are responsible for replenishment of items from receiving area to central warehouse and from central warehouse to milk-run supermarkets.

4.8 Frequency study for order picking process

Here, the frequency study was done for a space of two weeks (ten working days). The time interval between each observation is about 40 minutes and a total of 100 observations during this duration. The central warehouse, the tent, the yard, the forward area in the third floor (production of capacitor units), receiving area and assembly stations have been observed in this study. The observation was not split into the different warehouse areas because picking orders can be from any part of the warehouse and the picking performance is being measured, not each single warehouse area. The main purpose of this study was to better understand the picking process at ABB Capacitors warehouses. This process consists of different activities such as receiving picking information, replenishment of warehouse locations, identification and movement, positioning items, etc. However, since the picking activities are carried out by warehouse, assembly and packing staff all other activities which are done by these individuals was also considered in this study. Warehouse staff are responsible for item replenishment in all the warehouse areas including the forward area and picking from the central warehouse. The packaging staff are responsible for packing the capacitors and responsible for picking in the tent and yard. The assembly staff mostly picks from the warm storage and sometimes from the yard and tent. These activities were chosen based on initial observation made by the authors and are the main activities which are carried out during picking. The number of pickers can vary in the system according to absenteeism and work load. Therefore, the number of operators which were observed in this time interval ranges from five to ten, with an average of eight persons. The observed activities in this system are listed as below;

1. Administrative activities which include all activities related to data registration, labeling, printing and retrieving information from system. The main part of administrative activities for assembly staff is reading the design and BOM for assembly, but for warehouse staff the main administrative job is data registration for receiving items. Writing item codes with bold letters on pallets to make them more visible from upper shelves
2. Transportation which includes moving items to warehousing area/ forwarding area/ final assembly & packing station, moving empty pallets back to the warehouse and transport with empty forklift.
3. Handling activities encompass replenishing warehousing (reserve) area and forward area, picking, moving barriers for picking required items, repositioning items in the warehouse.
4. Identification or finding of items which should be picked
5. Inventory control consists of periodical inventory control and emergency inventory control. The emergency inventory control can occur due to conflict between inventory level in the information system and available stock in the warehouse.
6. Final assembly and packaging activities take place at assembly and packing stations. These activities are only carried out by production staff. Therefore, warehousing operators are not involved in this type of activities.
7. Waiting can happen due to stop in the system or inappropriate allocation of tasks among operators.
8. Walking.
9. Other activities mainly encompass meetings, fixing tools, unloading and receiving items from receiving area, measuring, etc.
10. Rest; here, the time interval for frequency study includes two coffee times (normally fifty minutes for each coffee time) and one lunch time (between half an hour to one hour). It is good to mention that operators are not paid for resting in the lunch time. However, sometimes the rest time takes more than one and half hour.

For better understanding of the picking process and warehousing system, the results of observed activities are shown in two different diagrams. First diagram (figure 20) illustrates activities which are carried out by warehouse staff, packing operators and assemblers and the second diagram (figure 21) specifically shows the warehouse staff activities. The pie chart is coded in different colors where similar activities have identical shades of colors.

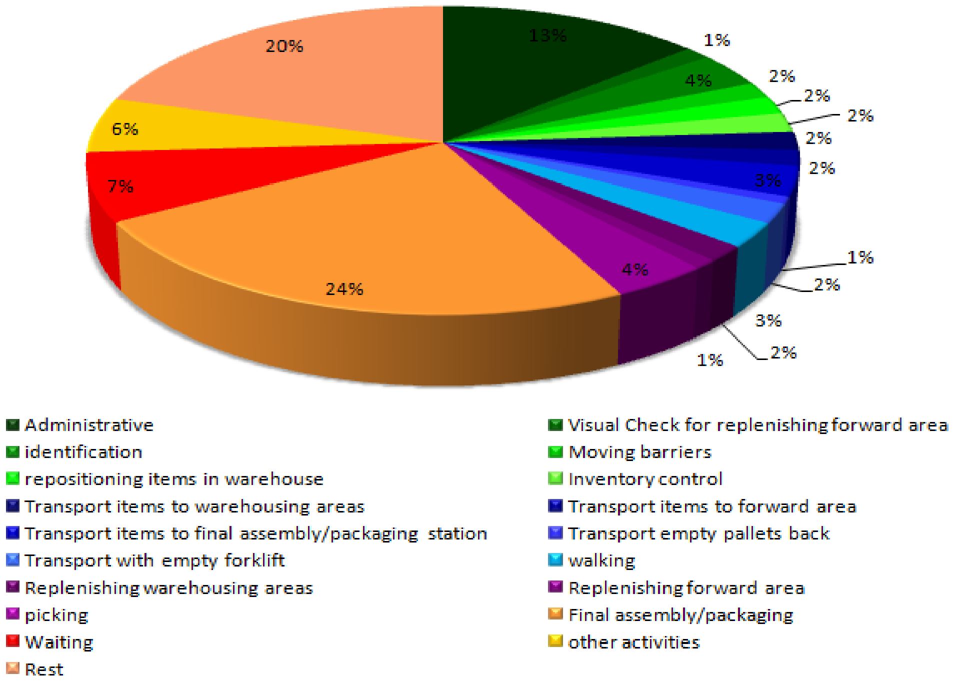

Figure 20: Activities performed by warehousing, packing and assembly staff

The above figure 20 shows the share of different activities carried out by warehousing, packing and assembly staff. Here, we can see that the main material handling activities (transportation of items, picking, repositioning items, moving barriers, item replenishment) accounts for 19% of the total activities done on the first floor.

The different percentages of these activities are as highlighted above shows that rest and final assembly accounts for more than 40 % of the time spent during each shift. These activities will not be considered since they are beyond the scope of this thesis. However, every other activity in the bar chart are related to the order picking and are therefore the focus of the frequency study. A more concise share of warehouse activities is explained and visualized in figure 21 below.

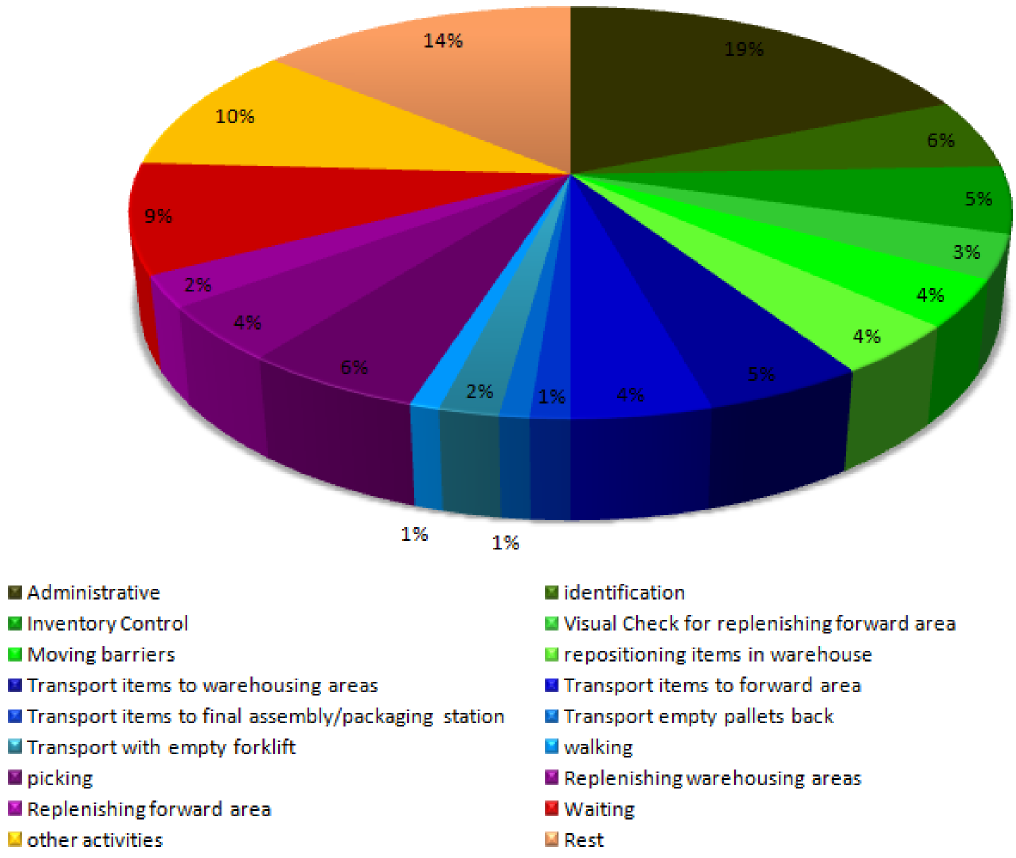

Figure 21: Activities performed by warehouse staff

The table 2 below gives the share of activities for all staff members on the first floor where the frequency study was made. It is an extrapolation of figure 20 above and it gives the average number of activities performed by warehouse staff and assembly and packaging staff. From the table below, one could see that assembly and packaging staff accounts for more of the activities performed on the first floor due to final assembly and packaging which has an average of 20.2%. The activities performed by the assembly & packaging staff accounts for over 61% of the total activities carried out on the first floor in total while warehouse staff activities accounts for less than 39%.

Involved operators / Type of activity	warehouse	assembly & packaging	Total activity
Administrative	6.1	5.1	11.2
Transport items to warehousing areas	1.6	0	1.6
Replenishing warehousing areas	1.4	0	1.4
Visual Check for replenishing forward	1.1	0	1.1
Transport items to forward area	1.4	0	1.4
Replenishing forward area	0.8	0	0.8
picking	1.8	1.5	3.3
Transport items to final	0.4	2.2	2.6
identification	1.8	1.2	3
Transport empty pallets back	0.3	0.3	0.6
Transport with empty forklift	0.6	1.1	1.7
walking	0.3	1.9	2.2
Final assembly/packaging		20.2	20.2
Moving barriers	1.2	0.2	1.4
repositioning items in warehouse	1.3	0.2	1.5
Waiting	2.8	3.2	6
Inventory control	1.7	0	1.7
other activities	3.3	1.5	4.8
Rest	4.5	12.4	16.9

Share of warehousing operators and assembly and packaging staff in different activities

5 Analysis

This section is divided according to the thesis design framework seen in figure 3. In this section, analysis of the case is made which was guided by the literature study performed in section 2. The aim of this chapter is to evaluate the current findings made in the case company, based on both the empirical data and the literature study made. This chapter also explains the design framework of the thesis and how it is applied to ABB Capacitors to answer the research questions defined in the purpose.

5.1 The design framework of the thesis

Based on the literature review done above, two different order picking system design approaches which were discussed by Yoon & Sharp (1996) and Goetschalckx and Ashayeri, (1989) were evaluated and combined (section 2.2.2) to form a suitable framework for this thesis. In addition to the two approaches mentioned above, the current situation at the case company was also considered and influenced some of the factors mentioned in the design framework. This is shown in figure 22 below.

According to these two models, the new design framework has been developed in three main phases. The first phase consists of gathering input data about the preconditions and contextual factors in the system. These contextual factors have been categorized into four main groups; managerial consideration, system requirements, operational constraints and information availability. At the selection phase, six steps in design of an order picking system are discussed. At the final phase, costs, quality and productivity are considered as different performance measurements to evaluate existing subsystems which may result to changes in specifications.

Figure 22: Design framework of the thesis

5.2 Preconditions for order picking system design

In this section contextual factors and preconditions which can exert significant effects in the choice of an order picking system or should be available prior to the design of the system in the case company are discussed below. The selection of contextual factors was based on the literatures and the current situation in ABB Capacitors. These preconditions are very important inputs which guide the design of the order picking system at ABB Capacitors and are the basis upon which other decisions are made in the selection phase of this thesis.

5.2.1 Managerial consideration

The first precondition which should be considered is managerial consideration in ABB Capacitors. The first issue with this regard is related to the size and place of the warehouse buildings which are fixed. Another consideration is the budget limitation which means the proposed picking system may not be implemented in short term because of this limitation.

Organizational culture is another important factor which has a great impact on the choice and implementation of an order picking system. Currently, the picking process and allocation of items in ABB Capacitors warehouse is done according to the perception of each operator and there is no standard process with this regard. On the other words, the picking activities and other warehousing activities in this system are mainly result oriented than process oriented.

As noticed, some of the workers at the warehouse have no much experience regarding warehouse management which might affect the way in which work is done in the warehouse. Therefore, it is necessary for the warehouse manager or logistics manager in the company to properly train warehouse staff when employed. By doing this, employees will be able to adhere to the operational process which is in place and not based on their perception. For instance, employees should always be able to use the current barcode scanners at the warehouse always during picking.

5.2.2 System requirement

The second consideration is about system requirement in the case company. First factor in this category is storage capacity which is almost fixed in the central warehouse and it is not going to be increased by for example increasing the height of each column or changing the arrangement. However, storage capacity can be improved in the tent by implementing some changes in the layout of this warehousing area.

Response time is another system requirement which can affect the design of the order picking system. Currently, picking orders are sent to warehouse staffs two weeks in advance which is the standard response time for picking of items to the assembly station on the first floor. However, this response time might change suddenly to one day due to changes in production plan and will require warehouse staffs to start picking immediately. This makes the picking intensive for the pickers and might increase the number of errors.

Component supply is another factor which can exert significant impact on the design process. At ABB Capacitors, based on the production department request, some metal items which are related to one project order and provided by one supplier should be received in one pallet. Therefore, one single item may be requested in several project orders, which means one single item number can be found in different location, but with different project order number. However, changes in the purchase order system could improve the storage efficiency and facilitate identification process for a single item.

5.2.3 Operational requirement

Operational requirement such as order characteristics, product groups, working hours and shift are other effective factors on the design of an order picking system as discussed below.

The first effective factor in this category is related to the number of picking orders per day, if this number is high, it makes the order picking process an intensive activity which increase the necessity of automation in the system (Ten Hompel & Schmidt, 2007). Another effect of this factor is in the design of reserve-forward area, by increasing the number of picking orders, the necessity and the size of the forwarding area will increase. In ABB Capacitors, the number of order picking per day is in average four picks. However, the number of items per order as well as the quantity of items in an order can vary a lot; for instance, a project order can contain a single item or more than 400 items.

Product groups, order classes and item characteristics which are part of system requirements can affect the design of an order picking system in several ways. According to the characteristics of the production system which is based on engineer to order principle, the final products can vary according to customer's' requirements. It should be noted that the products are capacitor units, which then are assembled based on customer requirement during final assembly and packing. Therefore, the number and size of items (components) used in producing the final products can vary a lot (especially during packing). This issue can have an effect the different design stages of an order picking system, such as; the storage policy, design of reserve-forward area, mechanization level and order picking and batching policies etc.

Working hours and shifts is another factor which influences man hour availability and as a result has an impact on the level of mechanization. As a case in point, when there is high level of picking and the working hours is limited, then more pickers or higher level of automation are required in the picking system.

5.2.4 Information availability

Prior to the design of a picking system, information regarding the movement and storage of items should be available which will aid in the design of the system. This information can be found in the warehousing management system or the company's ERP systems which is used in the warehouse.

The main effects of a warehouse management system on picking process are related to the speed and quality of the process. In the case company, a warehouse management module of ERP LN system is utilized as the warehouse management system. The mentioned system has some limitations such as amount of characters which it can be allocated to each code. Another problem is related to the lack of standardization in coding system. Therefore, to improve the information sharing in the warehousing system, defining standard codes for different places is crucial.

Another concern is related to the ability of WMS system (both warehouse management module of ERP and a specialized WMS) to communicate with a picking assisted technology. To implement advance picking assisted technology such as RFID handheld, RFID pick-to-light or pick by voice, an additional system/middleware is required in order to enable communication between WMS and data collection system (like RFID readers). This middleware converts the incoming data into a recognizable format (Lim et al., 2013; Azanha, et al, 2016).

Moreover, no confirmation step is defined for the picked items in the current information sharing system (ERP LN) which create some difficulties in the replenishment system. In the other word, there is no digital trigger when picking an item which makes it hard to control the inventory both in storage and forwarding areas. Therefore, confirmation of picked items should be integrated with the system and scanners should be available for production and assembly staff.

5.3 Design steps

This section evaluates the different factors that were considered in the design of an order picking system for ABB Capacitors. These factors were considered based on the context observed at ABB Capacitors warehouse, the preconditions and contextual factors and existing literatures. Therefore, about the input data different steps in order picking design have been selected. These steps are; Forward reserve allocation, storage policy selection, layout design, mechanization level selection, information system design and picking policy. These are explained in detail below and are seen in the selection stage in the design framework (fig 22).

5.3.1 Forward reserve allocation

According to Petersen, (1999) the aim of forward area is to speed of picking process while it is improving the storage efficiency for the reserve area. Therefore, in allocation of SKUs to the forward area the trade-offs between order picking and replenishment frequency should be considered (Goetschalckx & McGinnis, 2010). In this section, design of reserve-forward areas in the third and first floors is discussed.

5.3.1.1 Reserve-forward design for the third floor

Most items in the third floor are standard items which are used frequently in the production process. Therefore, considering forward area for these types of items can improve efficiency of the system. Moreover, low frequency items are usually based on orders. For example, producing a specific order may take one week and it requires some unique and low frequency components; therefore, during this week production stations may need to be fed several times a day by those items but in a short period. So, it is good to keep those items in the forwarding area when required. This is in line with the current situation at the company.

5.3.1.2 Reserve-forward design for the first floor

As it is mentioned earlier, most of the items which are used in the first floor have low frequency (more than 60% of items have low frequency) and very large size. Besides, all required items for final assembly and packing are directly retrieved from central warehouse, tent and yard warehousing area. However, some project orders have large number of items or large quantity. Currently, for these types of project orders, pickers collect items in one place in the yard or tent according to their perception, since, there is no dedicated place as a forward area for the purpose. Therefore, to eliminate the disorderliness in these warehousing area, it is reasonable to determine a forward area in the yard for collecting items which belong to large orders, one or two days before packing.

Main part of items which are in the central warehouse belongs to the third floor where there is a forwarding area for the items. However, for the items which belong to the first floor there is no forward area. One major constraint with this regard is space limitation. Therefore, pickers must pick those items directly from the central warehouse

5.3.2 Storage policy

From the review of the literature and a look at the situation at ABB warehouse, it is necessary to consider the tradeoff between travelling time and space utilization, while choosing a storage policy for a specific warehouse.

Although, in the current situation, there is a classification for assigning some SKUs according to product groups in the warehousing areas, but, generally the storage policy is completely based on the perception of warehouse staff. In this case, the quality of the assignment can differ according to their perception. In the other word, lack of standardization in storage policy leads to uncertainty in decision making about space utilization in the warehouses. Here, about the types of items in each warehousing zone, an appropriate storage policy is considered and discussed in the subsequent sections below.

5.3.2.1 Storage policy at central warehouse

The current storage strategy used in the central warehouse is based on the production area in which the items are used (E.g. first floor and third floor), but is not implemented throughout the entire warehouse. This is seen in a section of the warehouse where items are stored randomly to utilize the available space without regards to the product classification. In this section includes shelves with free spaces where warehouse staff can place items or components parts without taking into consideration if that position is the proper position to place that item. In this case, it is important to classify all items in the warehouse based on the production areas. Most of the items in the central warehouse are bulky items which belong to different product families, it is therefore reasonable to consider dedicated locations for each type of family. However, to improve the space utilization in each class of items, random allocation of items to locations with family groups should be adopted (De Koster et al, 2007). This why a forward area is necessary, since some items can be placed closer to the assembly and in specific locations for picking by assembly workers and placed randomly in the reserve are in other to utilize available space in the central warehouse. In addition to this, when selecting a storage policy for a warehouse, the size of a warehouse should be taken into consideration; which in this is not big at ABB Capacitors. Therefore, traveling time is less important and not considered in the central warehouse, which is a disadvantage of random storage. However, by classifying the items based on the area of usage and product family can reduce the identification time during picking. An illustration of the storage strategy is seen in figure 23 below.

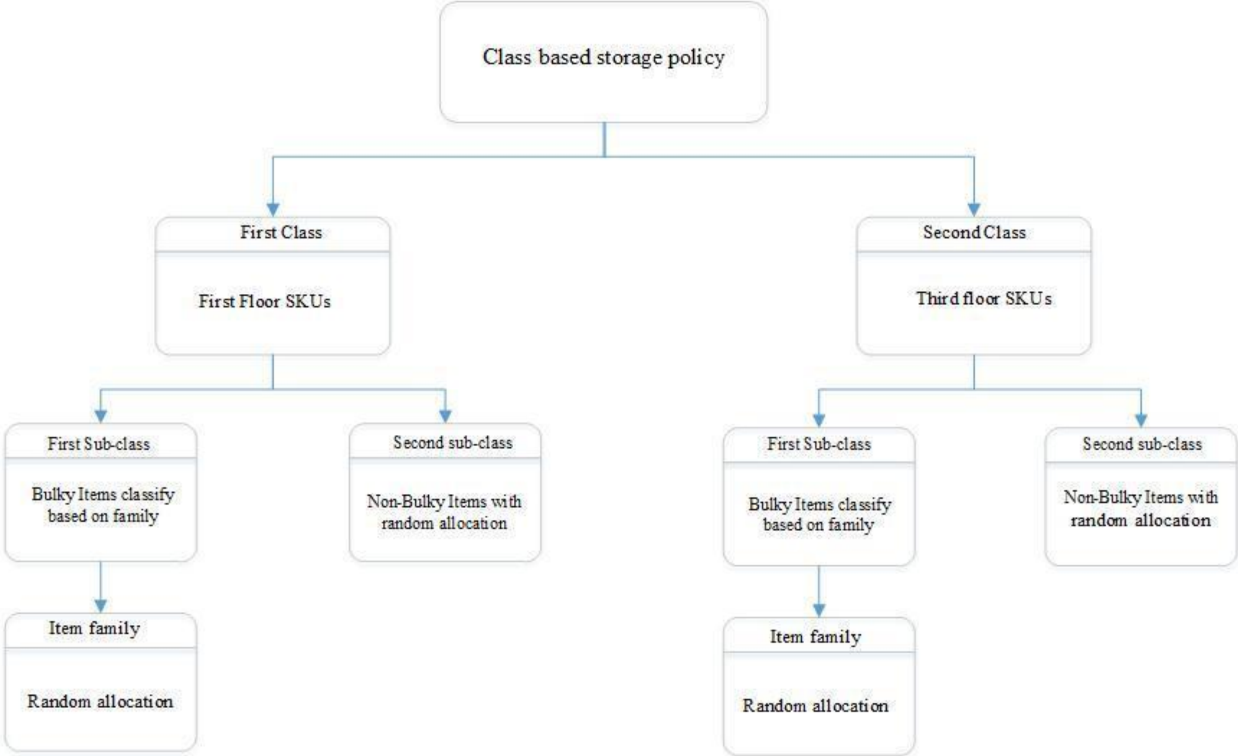

Figure 23: Storage classification in the central warehouse

Apart from high space utilization which a random storage policy will bring to this storage area, other reasoning behind adopting the random strategy within groups is because it reduces aisle congestion and works best in computer controlled warehouses. Although the warehouse is currently controlled manually, the aim of this thesis is to design a suitable picking system for the warehouse, of which will contain improvement in technology used in the warehouse.

5.3.2.2 Storage policy at tent

Currently, this storage area follows random storage policy which makes it very difficult to track items since they don't use any computerized system for identification and allocation of items in the tent. There is lack of organized structure in the tent; this is seen in the way in which pallets are arranged. Items which are contained in pallets are placed in front of each other which make it hard to access and identify. This increases the identification and handling time since material must be moved to access the desired item or component to be picked by the operator. This unnecessary work which is done by the operators results to inefficiency in the process and can result to picking error. As it is mentioned before, currently there are three groups of items which are kept in this storage area; wooden pallets and boxes, big metal components and small metal components which can be fitted in pallets. Therefore, the storage classification in this area can be based on SKUs similarities, and three groups of products can have dedicated place and placed randomly in each class location. This storage policy presents a logical way/sequence of placing and identifying items in the tent. The structure of this allocation will be discussed in section 5.3.4 (layout design).

5.3.3 Mechanization level selection

At ABB capacitor warehouses, picking is mostly done manually by warehouse operators or assemblers with the help of forklifts and reach trucks. This is ideal for the current situation due to the nature of the items, orders and warehouse locations. With regards to the nature of the items to be picked, it varies in size, weight, shapes and quantity and therefore makes it difficult be moved or picked by automated system. These items characteristics vary all the time and therefore cannot be standardized, which is not suitable for automation. Besides, automated system is reasonable when it elevates the productivity, eliminates repetitive activities or reduces intensive jobs (Ten Hompel & Schmidt, 2007). However, in ABB capacitor, the number of picking per day is very low; therefore, automation does not help the system in none of aspects. Another factor which should be taken into consideration is the location of the warehouses. A decentralized warehouse structure as seen at ABB Capacitors can affect the level of automation. This is because the warehouses are not integrated with the production area therefore cannot enable fully automation of the process. Partial automation can be made at each individual warehouse but in this case, is not cost efficient due to the size of the warehouses and the number of picks per day as mentioned above.

In addition to this, in the central warehouse, a semi-automated rotating shelf (vertical carousel) is utilized for the small items such as bolts, screws and fasteners etc. Although this system doesn’t speed up the picking process, it helps to overcome space limitation and ergonomic issues in the central warehouse. If space is not a limitation, it is better to put those items in small boxes on normal shelves, which increase the picking pace. The reason behind this suggestion is that the vertical carousel moves slowly, and it has about 30 rows, that is time consuming. So, sometimes, it is time taking for the picker to change the shelve levels to pick different items related to a single order. In addition to this, there are modern models of the vertical carousel (vertical lift model) which could replace the current one used at the central warehouse. This will still aid in space utilization and will reduce the time spent picking from the machine since it can be integrated with other picking support technology such as pick-to-light or RFID for easy picking.

5.3.4 Layout design

The first step in the layout design is related to determining the required size of different warehousing areas such as receiving areas, storage area and order picking area (Roodbergen, et al., 2008). These areas are where warehousing activities are carried out. At ABB Capacitors, the storage and the receiving areas are specified with fixed locations but do not have a specified picking area due to the nature of the warehouse and the industry. As seen in this case study, the company is an OEM (Original Equipment Manufacturer) and the warehouses areas can differ from traditional warehouses used for distribution and by retailers. Therefore, the nature of the business affects the layout of the business and determines if a warehouse should have a separate order picking area or carried out in the storage area. In this thesis, the layout design of the tent will be considered only since this is where considerable changes can be made. The reason why the central warehouse will not be discussed is due to the size of the warehouse and the current layout works and therefore a new layout design might have little or no impact on the performance of the warehouse.

In the case company, there can be a considerable improvement in capacity utilization of tent. Currently, the tent has U shape arrangement as a layout which is not ideal for this area. The first reason behind this idea is that it doesn’t help visibility of items for pickers, since pallets are placed in front of each other due to lack of space. Besides, the items are kept in this area are usually heavy items which are needed to be picked in several picking tours (usually at each picking tour one or two pallets are transferred to the packing area). However, the reason behind this arrangement is the size of wooden boxes and pallets which requires more space for free movement in the tent. Therefore, by rearranging the internal structure of this warehouse, a higher space utilization rate can be achieved. The capacity of this area can be improved by utilizing some shelves and adding several lines at the back area of the tent (more detail is discussed the recommendation seen in figure 24).

Another factor which can be affected by the layout design is picking tour (routing). The aim of routing is to find the shortest way in a picking trip when there are several possible routes to pick items (Ten Hompel & Schmidt, 2007). However, route problem is not considered and not applicable in this case, since each picking tour is not very long due to the following reasons;

- The size of the warehouses is not large.
- Most of the items in the tent are heavy items, therefore are picked one at a time in each picking trip.
- Small items in the central warehouse are positioned close to each other which mean less movement during picking.
- Bulky items in central warehouse are picked one at a time in each picking trip which are usually of higher frequency.

5.3.5 Design of information system

Today's Enterprise Resource Planning (ERP) systems are capable of handling vast amounts of data. This is seen at ABB capacitor which has a warehouse management module that can be used as a WMS in their ERP system (ERP LN). Although ERP is not specially designed fully in a supply chain context, it is adequate for smaller, low volume distributors. But as they grow, firms in warehousing, manufacturing and distribution together with other supply chain-driven industries should replace their ERP with WMS (Tamburrino, 2016). This shows that the size of the business or warehouse determines the level sophistication of the system to be used. Since the warehouse at ABB Capacitors are not large, i.e. are used for feeding production, adopting a new WMS for the warehouse might not be a good investment in terms of ROI and utilization of the system.

Apart from the size of the warehouse, WMS is most beneficial to situations where flexibility is crucial to the business, operations are complex and where a specialized WMS can add value in terms of increase in productivity (QSTOCK, 2017). These above-mentioned situations are not applicable to ABB Capacitors due to the nature of the warehouse. Currently picking is not done often at the warehouses at ABB Capacitors and having a specialized WMS does not bring about flexibility or increase in productivity since the number of items picks are not large and will not bring any benefit to the company if implemented. Besides, there are potential functions in the warehouse management module in ERP LN which have not been applied yet. Therefore, to elevate the efficiency of warehousing system, these potential capabilities should be identified and applied in a standard way. Currently, ABB Capacitors is working on improving the usage of the WMS function of ERP LN and therefore does not require a special system for their warehouse. All recommendation and suggestion made in this thesis about the information system and the adoption of a paperless picking system can be integrated and implemented in ERP LN and the system can also be used for item placement and retrieval in the storage location.

5.3.5.1 Order picking-assisting technology selection

In the selection of an order picking assisting technology several factors such as costs, quality, items characteristics, picking order characteristics, capacity limitation, information system requirement and ease of use would be considered based on the context at ABB Capacitors. These factors mentioned earlier will be discussed prior to the selection of an order picking support technology since they determine the choice of technology to be used.

Cost is the first effective factor in this selection. Here, the trade-off between costs of investment and costs saving (ROI) due to reduction in man-hour would be considered. The time reduction can result by facilitating tasks such as identification, confirmation and replenishment processes as well as reducing the number of errors. In the case company, the main error in the system is due to misplacing of items on the shelves, since the information about position of items are registered manually in the system, and might result to keying in wrong information which is a common human error.

Another factor with this regard is item characteristics; these features encompass number, size and value of items. In the case company the number of available items in warehouses can vary considerably according to customer orders. Currently, the average number of items in the warehousing system is more than 1000 items, but, this number can reach to 4500 according to the available item design in the system. The variation in size of items is large, which makes it difficult to consider standard packages for considerable number of the items. Some items are very valuable or sensitive for the production process which requires more accuracy during picking. However, in the case company this factor is not applicable.

Order characteristics (project orders) plays an important role is the technology selection. This involves the frequency of picking in the warehouses, number of orders picked per day and the volume of picking for each order. These factors determine the usage level of the technology. At ABB capacitor, the average number of project orders per day is four and the picking of items in these orders can be done at the different warehousing zones in the company. Therefore, the number of picks per day is around four at different warehousing areas. A part of a specific project order can be picked from the tent and yard area as a single picking order and another part of it which contains small items are picked from central warehouse as a different picking order.

Capacity limitation can increase the necessity of implementing high level of technology for tracking items. At ABB Capacitors warehouses, sometimes there are unique small items which are used for specific orders. Due to this, it is not efficient to use one pallet for each single item; therefore, these items are usually merged together in one pallet. The merging of items in pallets is to properly utilize the available spaces in the warehouses, which ABB Capacitors are currently lacking.

Information system requirement can influence the decision on the type of technology to adopt in several ways; need for extra investment on middleware; duration of installation; compatibility of the middleware with the available interface of the Company. Some technologies do not require additional middleware or systems which makes it easier to adopt them in warehouses e.g., barcode scanners. However, some technologies require additional interfaces for proper integration into available system in the company e.g. RFID. Also, systems which require additional interfaces might take time to install or implement and therefore should be taken into consideration. Therefore, here the trade-off between time and costs of installation and the amount of productivity which an order assisted technology can bring for the system should be considered.

Another factor is related to the level of availability and maturity of the technology in the market, since more widespread technologies are proven and usually easier to use and implement. For example, barcode scanner is the most available technology and comes in various forms, shapes and sizes and RFID pick-to light is relatively new technology in the market. However, today many big distribution centers and large warehouses are inclined to use more new technologies and as a result, these types of technologies are going to be widespread, too. The availability of a technology can influence the investment costs. Henceforth, if the picking process in a very intensive activity with high picking frequency, a new technology such as RFID pick-to-light could be more suitable in comparison to a more available technology like handheld barcode scanner.

In addition, some technologies are more flexible than the others and can be easily adapted to special cases where storage locations are not fixed or when there is lack of dedicated picker. For instance, pick to light is more rigid in terms of usage and item characteristics, which makes it less flexible to adopt in different scenarios. Although, pick-by-voice system has more flexibility in comparison to pick-to-light system, it still requires pickers' voice to be recorded in the system; therefore, in the absence of a picker in might be an issue for other staff to use this technology. It should also be noted that pick-by-voice is mostly suitable to low margin, high volume with long distance between locations and labor-intensive case picking warehouse operations, which is not the situation at ABB Capacitors.

According to Battani et al., (2015), for low-level manual picking warehouses (where pickers pick items from storage shelves while moving along aisles) with a low-medium rate of picking, like the case company, barcode handheld scanners, RFID handheld scanners and pick-by-voice are the most appropriate technologies regarding costs of errors, pickers costs, the stock locations cost and fixed costs. However, among the technologies, barcode handheld scanning system is recommended for ABB Capacitors for several reasons. First, ABB Capacitors currently have handheld barcode scanners in their warehousing system, and only needs some adjustments in the system for it to be possible to utilize paperless picking lists in the warehouses. This technology is mature and tested and can easily be improved in the warehouse since it is already in use. It also has an average initial cost of investment as seen in table 1. The second issue is regarding the large variation in size of items in the warehouse which makes it difficult to implement RFID scanners. The nature of products plays a role in technology selection and use of handheld barcode scanners will be easier to implement where codes can easily be placed on pallets and items. Finally, the operational limitation related to shifting hours for warehouse staff and assembly and packing staff results to the use of assemblers in picking. Therefore, when the workload is high or during the summer period, part time operators work for assembly department which makes it difficult to implement pick by voice technology in the system. Handheld scanners are easier to use and therefore does not require special training, with this any picker can easily scan and register items during picking.

Handheld can be used as a short-term solution since it is currently in available at ABB capacitors, but in the future, it is recommended to adopt a finger barcode scanner which is easier to use and frees up both hands so that the picker can be more efficient during picking.

5.3.6 Picking policy

In ABB Capacitors, two studied warehousing areas are assigned to the items with different characteristics. Therefore, it is reasonable to consider the tent and yard area as one warehousing zone and the central warehouse as the other warehousing zone. The zoning policy in this case can be a synchronized zoning which means all goods related to batch orders are released simultaneously to all the zones. For the case company, simultaneous order release means releasing orders to different zones in a specific period not exact hour (according to the low picking frequency). The picking policy in each zone is discussed in below sections.

5.3.6.1 Picking policy for the tent

This area of the warehouse at ABB Capacitors is unique in the sense that it contains many unique items and components that comes in all shapes and sizes. In relation to the item characteristics (which are mostly heavy/big items) in this warehousing area, the most suitable picking policy would be a discrete policy. In many cases, picking process for a single project order requires several picking tours, therefore, items cannot be picked all at once due to the size and weight of the items. For instance, a single item like a big box or a pallet of heavy metal plates can be picked and transferred individually to the stations where they are required.

Currently, order picking in this zone is carried out by assembly or packing staff. All assemblers can do the picking and there is no dedicated person for this job at each working shift. However, if a dedicated picker is responsible for picking from this area, it can reduce the picking time due to improving learning curve. Since there are two shifts in final assembly and packing stations, there should be two dedicated pickers for both shifts in the process.

5.3.6.2 Picking policy for the central warehouse

This warehousing area is used for storing items which are picked for the final assembly, packing stations and forward area replenishment in the third floor. Currently, small items, bolts and fasteners which should be packed and sent to the customers together with the semi-assembled products, are picked by warehousing operators using discrete picking policy. Main part of these items is stored and picked from the vertical carousel. Picking on this machine is long due to the time spent while waiting for the machine to access the desired shelf. This includes the time spent searching for the shelf level (number) of the items, operating time of the machine (keying in the shelf number and starting the machine) and rotating time of the machine. To reduce this long waiting time, a batching policy can be used during picking of items from the machine. Here, items used in different project orders but in the same shelf level can be picked at once, instead of picking discreetly for an order and repeating the process for subsequent orders. For project orders which belong to the same customer order, items in these project orders can be similar but may vary in quantity. Furthermore, this policy can be improved through system integration to automate the movement of the shelves and identification of items in the shelves. Therefore, with system support, time will be saved during identification and waiting time will be reduced. The type of system to be used depends on the company's budget, maybe investment in a new machine that incorporates all the functions or investment in a support system which can be installed in the already existing vertical carousel.

In batching strategy, several orders are grouped together and picked at the same time. According to Tompkins et al., (2003), two types of batch picking are; pick-and-sort and sort-while-pick. Pick and sort policy is not suitable in this situation, because, in many cases the number of items are large for each project order, and there might be a capacity limitation of the pallet used for picking all batch of orders. Therefore, it is not possible to fit items from several project orders in a pallet. This can be resolved by fitting these items in special boxes or bins which shows that sort-while-pick is a suitable batching policy in this situation. Boxes are smaller and are easier to handle than pallets which are currently used in the warehouse for these items. With boxes or bins, the space which the pallets take up in the picking area reduces and it gives access for easier movement. It is good to mention that, the picker movement for picking those items is very limited, since these items are stored close to each other (mainly in vertical carousel). Therefore, the boxes can be placed very close to the vertical carousel and reduces the movement made by the picker. This solution is better in terms of pickers productivity, time reduction and ergonomically. The current situation is shown in figure 24 below.

Figure 24: Picking pallets with fixed position in the central warehouse

The remaining items in the central warehouse are reserved items for replenishing forward area at the third floor where capacitor units are assembled. Since picking from this forward area is out of the project scope, the picking policy from this area is not analyzed here.

5.3.7 Frequency study analysis for the tent and central warehouse storage areas

As seen in figure 20, some activities (such as; moving barriers, waiting, identification etc.) carried out by warehouse, assembly and packing staff are unnecessary and therefore can be reduced. Reducing some of or all these unnecessary activities will increase the productivity of the workers since more time will be spent on core and necessary activities in the plant. Figure 21 gives the percentage of activities carried out by the warehouse staffs. These are core activities which are in line with order picking and determine its performance in the warehouse with material handling take up 31% of the total activities done by the warehouse staff. As it is shown in figure 21, administrative activities are the most frequent activities in the warehousing system. Warehouse staff must register packing lists data into the system manually. If there is possibility to register this information through defining a barcode, for a picking list and scanning that barcode for receiving items, a considerable time saving could happen in the warehousing system.

Another activity is identification of items in the warehouse which accounts for six percent of warehouse staff activities. Since the location of items is not defined in the information sharing system, sometimes it makes it difficult to locate required items in the warehouse, especially in the tent. In some cases, an assembler who is responsible for picking, walks around in the tent or yard with a warehouse staff (who is responsible for these areas) to find required items. Therefore, in the absence of experienced pickers, it will be a very time taking activity for other operators to find items from warehousing areas. There would be a considerable time saving in the identification process by defining a code for the location of items in different warehousing areas.

Activities such as; visual check, repositioning, moving barriers, and inventory level control etc. are waste activities which reduces the efficiency of the picking system. These activities accounts for 22% of the time spent during picking. The reason behind this is due to how items are stored in the warehouses and lack of visibility in the information system. The need for visual check can be eliminated if picked items are confirmed in the information system in the forward area. By doing this, the warehouse staff avoids making a scheduled trip to the third floor to check for used up items. The storage policy which is currently used in the warehouses brings about increased need for repositioning. Repositioning happens due to two reasons; first, when a picker moves barriers (pallets in front of required items) to pick required items, and therefore should reposition the barrier. Secondly, when one pallet of a specific item which is in lower shelves in the warehousing area is used, warehouse staff may replace it with another pallet of that item which is located on upper shelves. Therefore, having a logical way of storing and retrieval of items in the warehouses will reduce and/or eliminate some of these activities. Also, having a suitable information system, which shows location of items and the quantity of items currently in inventory will eliminate the need for emergency inventory level control/check (when there is a conflict between inventory level in the information system and available stock level) and reduce the time spent searching for items in the warehouses.

No transport related activities will be considered here since it has no considerable impact in the performance of the order picking system at ABB Capacitors. The reason for this is due to the size of the warehouses, where routing has no effect on time spent during transportation. Also, the location of the warehouses is fixed and cannot be moved; therefore the same distance is always covered during each picking or replenishment trip.

Waiting, other activities and unscheduled rest can be an unnecessary activity which should be reduced or eliminated in the system but will always be present due to unforeseen events which might occur in the warehouse and can be because of low workload in the warehouse. At ABB Capacitors, waiting is caused by inappropriate allocation of task to warehouse staff and stops in the production and assembly of products (for example, when a specific item is unavailable). Although waiting cannot be fully eliminated, it can be reduced by proper work organization in other to improve the productivity of workers. So, it is the duty of the management to build work culture which will trickle down to the shop floor. Doing this will reduce the percentage share of this activity by a substantial amount in the process. The higher share of rest and waiting can be attributed to the workplace culture in at ABB capacitors and therefore requires top management involvement in stressing out the need for worker productivity during their shifts.

It should be noted that the main picking activity accounts for only six percent of the total work done by warehouse staff and assembly and packing operators at ABB Capacitors. The reason for this low percentage is due to low picking frequency in the warehouse as explained section 4.4 & 4.5 respectively. This shows that major improvement can be achieved by reducing the effect of activities like (administration, identification, inventory control, repositioning etc.) in the order picking system.

5.3.8 Performance evaluation of the order picking system

This section is the last stage of the design frame work and explains the performance of the order picking system putting into consideration several metrics used in measuring the performance of the system at hand.

There are several performance-metrics used in measuring the efficiency of an order picking system as mentioned in section 2.4 above. In accordance with the scope of this thesis, time, cost and quality are considered here and other performance metrics such as flexibility, ergonomics and space utilization will not be discussed here. To understand how the system is performing, it is necessary to identify key activities which are carried out during the picking process and their impact in order picking system performance. This requires having a good visualization of different activities in the picking process, hence the frequency study. The purpose of this study is to evaluate the frequency of different activities in a picking process to identify various losses in the form of disturbances and inefficiency in the system.

5.3.8.1 Time performance

As mentioned earlier, time is an important factor in assessing the performance of an order picking system. At ABB Capacitors, implementation of the recommended order picking system can bring costs saving through reducing or eliminating the required time for activities such as administrative activities, identification of items, visual check for replenishing forward area, emergency inventory control, moving barriers and repositioning items. Improvement in information sharing system, layout rearrangement in the tent and introducing batching policy for some items can bring about increase in time efficiency in the order picking system. The ability to track items in the system can help the purchasing department to do a better order planning and reduce inventory level in the system. The extra inventory level in the system can create barriers in the warehousing area due to lack of space and as a result bring about unnecessary work like removing barriers and repositioning items in the warehouse. Table 2 below shows the share of different activities which can be improved by implementation of the suggested order picking system.

Activities \ Considerations	Involved operators	Share of Act among whole pickers	Share of Act warehouse staff	Improvement
Administrative activities	all pickers	13%	19%	In the main part of warehouse staff activities
Visual check for replenishing forward area	warehouse staff	1%	3%	It can be eliminated entirely
identification	all pickers	4%	6%	Significant time reduction
Inventory control	warehouse staff	2%	5%	Emergency cases which are the main part of this activity can be eliminated
moving barriers	all pickers	2%	4%	It can be eliminated entirely
repositioning items in the warehouse	all pickers	2%	4%	Significant reduction
Total share		24%	41%	

Table 2: Potential areas of improvement

Here, share of each activity is according to the average number of involved operators to the number of operators which are involved in all determined activities. The formulas for calculations are illustrated in appendix 1.

Besides, if the time saving achieved by implementing handheld barcode scanners in the other business unit in ABB is considered, it implies that there could be a significant time reduction in the picking process at ABB capacitors by improving information sharing system in the order picking process. However, the exact time savings was not measured.

5.3.8.2 Quality

Quality problems in an order picking system can stop the assembly process and creates faults in the products. Quality problems can also result by having the wrong information in the system which creates difference between actual inventory at hand and system inventory. In the case company one of the most frequent error is misplacing items in the warehouse. Currently, warehouse staff registers the location of items manually, therefore, in some situation they key in the wrong location in the system. Another error is because of unavailability of a digital confirmation step in picking process. In this case, the items which are placed at the top shelves are not visible for warehouse staff to be replenished on time. Currently, warehouse staff changes the quantity of items on these pallets whenever they pick an item. However, when a picker forgets to change the quantity of the picked items, false information of the inventory is reflected in the system. Finally, picking items by production staff from receiving area before registering items in the system leads to create conflict in the warehousing system. The main reason behind this issue could be the time which is needed to register receiving orders information into the system. By defining a barcode for packing lists this process can be shortened considerably and as a result the possibility of this error will also reduce. Therefore, by eliminating the errors in the picking process and reducing time spent on unnecessary activities by implementing the suggested picking system, the full productivity of the picking and warehouse operations can be realized. These savings in time and error prevention can bring about huge cost benefits both in the short and long run as explained in the subsequent section.

5.3.8.3 Cost performance

The improvement in order picking process can bring about time saving by reducing the required man hours in the system. Besides, improvement in information sharing system of the warehouse can facilitate tracking of items in the system which can lead to better order planning. By reducing the inventory level, tied-up capital and location costs can be reduced, too. Here, investment costs (such as software and hardware costs, cost of new shelves and installation and restructuring costs) and costs saving which is can be achieved by reducing man-hours is considered. The time reduction can be achieved through the reduction or elimination of unnecessary activities in the warehouse and during the picking process. These unnecessary activities seen in figures 20 and 21 increase the total cost of the warehouse and picking operation and therefore are sources of cost savings if reduced or eliminated.

Also, the order picking system designed can bring about cost savings through reduction in the number of errors made during picking or replenishing items at ABB Capacitors. The order picking system designed does not require huge investment in facilities, man power, mechanization or picking support technologies. Therefore, ABB Capacitor is expected to see their ROI within few months if implemented. Also with the new order picking design, a building block for continuous improvement in the warehouse is laid and changes can easily be made in the system in the future.

5.4 Summary of the analysis

In this section different contextual factors and preconditions which can exert significant impacts on the different design steps have been discussed at the input phase. At the next phase, six design steps have been elaborated and selected for the case company and finally, the effect of suggested design on the costs, quality and time performance have been analyzed in the evaluation phase.

In the first phase, several factors such as fixed size and location of the warehousing buildings, budget limitation, organizational culture which is mainly result oriented and educational approach have been considered as managerial considerations in the case company. Moreover, different system requirements such as fixed storage capacity in the central warehouse, response time and components supply which is sometimes based on project orders have been considered in the design steps. Here, the important point is that one single item may be requested in several project orders should be supplied according to the project orders in several purchasing orders rather than one single order for that specific item. Finally, operational requirement is another concern in the design process. In ABB Capacitors, low number of orders per day, high level of customization in products and working hours and shifts are known as the main operational requirement.

In the second phase, six steps of order picking system design have been elaborate as below;

1. Forward reserve allocation
    - It is recommended to consider a forward area for the tent and yard warehousing area
    - There is already a forward area for Central warehouse in third floor.
    - No forwarding area has been considered for the small items which belong to the first floor in the central warehouse, because of the space limitation and low picking frequency and order volume.
2. Storage policy
    - class base storage policy for both warehousing areas is recommended all stored at random within each class
3. Mechanization level
    - Low mechanization level because of low picking rate, decentralized warehousing structure and large variation in size of items

- For a long-term improvement, it is recommended to use a modern vertical carousel instead of current vertical carousel to reduce the waiting time of shelves rotation.

4. Layout design

   - The size of different warehousing areas is fixed which is a system constraint.
   - It is recommended to rearrange the tent area layout, to improve space utilization rate.
   - Routing problem is not discussed because of the size of warehousing areas which is not large, and low picking frequency.

5. Design of information system

   - Warehousing module in ERP system is recommended.
   - Different picking assisted technologies have been discussed and barcode scanner has been suggested for ABB Capacitors.
   - Handheld barcode scanner is recommended as a short-term solution and finger barcode scanner as a long-term solution.

6. Picking policy

   - sort-while-pick batch policy for small items in the central warehouse which belongs to final assembly
   - Utilizing small boxes or bins for picking items in central warehouse instead of pallets since those are easier to handle in comparison with pallets and facilitate movements for the pickers.
   - discrete policy for items in the tent and yard warehousing area

6 Discussion

This chapter is interesting in the sense that the authors' opinions and findings are examined and stated here. It tries to explain the reasoning behind the design of the order picking system at ABB capacitors which are split into the purpose, theoretical framework, empirical data, benchmarking and analysis. In addition to this, the reliability and validity are further discussed here although clearly explained in the methodology section.

6.1 Purpose

The scope of this thesis is limited to the order picking process for a part of warehousing system (central warehouse and tent) at ABB Capacitors; however, the results of this work is applicable for the whole warehousing system within the case company. The validity of a research depends on the genuinely of the findings. The findings presented in this thesis were because of the design framework which is the basis of the thesis. It falls within the scope and purpose of the thesis and are partly based on the observation made at ABB capacitors warehouse. Therefore, it can be said that procedures used in this thesis captures the purpose established initially in the beginning of this thesis which in other words validates the findings made in this thesis. In addition, the findings made here, other departments in ABB group in Ludvika can benefit from the results of this thesis to improve their order picking systems, since, they almost have similar situation to ABB capacitors. Currently, most departments at ABB Ludvika use barcode scanners for picking components; therefore, by making some adjustments in the ERP system, it is possible for all ABB business units in Ludvika to use the paperless picking system. Henceforth, the time and cost saving which can be realized at ABB group in Ludvika could be much larger than the expected savings discussed in this thesis.

Based on the goal of this thesis, selection of the order picking system for the case company aims to bring time and costs saving as well as improving the quality performance of the system. Deductions from the literatures and the empirical data shows that improving the information sharing system and following a process oriented system in the warehouse activities can lead to quality improvement in that area. However, there are no exact numbers for improvements made which is beyond the scope of this thesis.

Furthermore, the discoveries and results of this thesis can be said to meet the aim proposed in the introduction. The design framework proposed in this thesis can serve as a guideline in the design of an order picking system at the case company and other firms which operates under similar condition. Therefore, this thesis can be duplicated under similar conditions and the findings made will be like that presented in this thesis. Since this is a case study, the findings are specifically designed for ABB capacitors warehouse based on the conditions which currently exists. The work seen in this thesis, further stresses out the importance of order picking in a warehouse and why it is necessary to having a functioning order picking system in the warehouse. Although the purpose of this thesis was achieved, there is a shortcoming which they authors did not address in this thesis. One of the shortcomings is related to cost performance since figures are not given on the cost savings that will result from implementation of the design proposed in this thesis. Based on the literatures, it can be said that there are a significant cost saving and quality improvements in implementation of a paperless picking system such as the suggested barcode scanning system in warehouse operations. However, the actual cost savings which this system will bring to the case company cannot be explicitly stated here since it requires following up of the order picking design after implementation.

6.2 Theoretical framework

In this part a good survey in the literature about the design steps and available picking assisted technologies was accomplished. The authors try to reduce the risk of bias conclusions by use of several different sources of information.

Sometimes different authors may have different views on a single subject; however, in the selection of sources authors try to use more credible papers from well-known researchers which improve the credibility of the literatures used.

Most of the literatures in this field are mostly done in retail and automotive industries which are characterized by high volume picking and standard items or products with little customization. As a case in point, in automobile industries a lot of products are produced base on Engineer-to-Order rules, however, these products are not as customized as the studied products in ABB Capacitors, since the main part of these products are assembled at module level. Therefore, the design framework seen in this thesis is because of the context at ABB capacitors and current practices seen in other order picking design studies.

Products in the case company are specified by high level of customization. Most case studies in the literatures related to order picking systems, focus on systems with lower level of customization than the case company; therefore, this thesis looks at the design of an order picking system for highly customized products which is a new subject in this field and a contribution to list of available literatures in order picking.

6.3 Empirical Study

To reduce the possibility of subjective data collection, the authors tried to use several different sources during the interviews and reasonable period of observation for different picking and warehousing activities. Besides, the empirical data has been studied by the logistics expert of the company to avoid misunderstanding and report the accurate current state of the warehouse. Also, conducting the frequency study provided the authors with a better understanding of the interviewees' statements. As a matter of fact, the collected data is not always accurate in all case studies. In this thesis, one of the inaccuracies which have been considered is related to administrative activities for assembly and packing staff that participates in the picking process. The authors do not have enough information about these kinds of activities for the mentioned operators, but the main focus of this thesis is on the administrative activities of the warehouse staff. For this reason, the results of frequency study are discussed in two different parts. The first part considered all operators which are involved in the picking process and the second part, only warehouse staff were considered specifically. This method helped the authors to figure out how the suggested order picking system can shorten the administrative activities related to warehouse staff, since the main part of administrative activities for assemblers and packing operators are related to reading design maps. However, if there was more accurate information, the judgment could have been more accurate.

6.3.1 Benchmarking

One of the difficulties with this part was finding an appropriate production system with close features to the case company production system and good order picking process in Sweden. The authors could not find an external sample to study and compare. Although the chosen business unit at ABB has some similarities to ABB Capacitors as an internal case for benchmarking, their warehouse does not have the limitations present at ABB capacitors, such as; Type and size of items/components, level of product customization and decentralized warehouse areas. Therefore, the complexity of picking process at ABB Capacitors is greater than what was noticed at the other ABB business unit. However, the modification on the studied business unit's information sharing system shows that there can be significant time savings during identification.

6.4 Analysis

With regard to the research questions posed in the purpose of this thesis, the five questions were met and explained in detail. The first research question on the preconditions or contextual factors are quite unique to the case company but could be generalized since those conditions can be similar and applicable in another context related to the design of an order picking system. For the second research question, the design framework in section 2 is the backbone of this thesis which is because of the extensive data collected from previous research and what is currently done at ABB Capacitors and therefore covers all aspects of the question. The reason behind the framework is to precisely guide the system design and achieve the aim proposed in the thesis. As seen in the empirical data, ABB Capacitors is a unique case and therefore requires a specialized approach due to the constraints present in the system. Although this is a unique case, the approach, framework and result of this thesis may be applicable to other companies with similar situation as ABB Capacitors Ludvika and as a starting point in warehouse order picking design for engineer to order manufacturing firms.

The third research question was proposed since it is important to know the current trend and support technologies used in industries to facilitate picking. Here, different picking support technologies in the market and upcoming technologies were evaluated. There is quite extensive information regarding these support technologies since most of them has been in used for decades and some of the technologies are quite mature. The challenge which was encountered here was related to the applicability of the most recent technology and their practical benefits and drawbacks in the long run. The second research question is connected to the fourth question regarding the choice of technology which is suitable for the case company. The choice of a support technology was based on comparison of the available support technologies and was related to the context at ABB capacitors in other to select a suitable solution for their situation. Although barcode finger scanner was chosen, an RFID system would be more optimal, but due to cost restrictions, the authors continued with a barcode system since it already exists at ABB capacitors and does not require any system change or modification. Lastly, in other to make sense of the work done in this thesis, the last research question was posed in other to show the benefit of an order picking system in a warehouse especially with regards to ABB Capacitors. This question stresses out the need for an organized and functioning picking system and will serve as a proof to motivate why an order picking system is needed in the warehouse.

For the performance measurements, the exact amount of improvements was excluded because the authors could not accurately determine them for several reasons. Currently, there is no evaluation on the number of errors in the picking process for the case company, therefore, it is not possible to mention the amount of improvements (X%) related to this performance measure. However, by conducting the frequency study, the share of each activity in the warehousing system and picking process has been determined. This study helps us to understand which types of activities can be shortened or eliminated; however, the authors could not give an exact amount of time saving for most of the activities, since, some activities cannot be eliminated completely in the system. Also, administrative activities can be significantly shortened by defining barcodes for packing lists and utilizing barcode scanner to register their information in the system; however, there are still some other administrative activities which cannot be eliminated such as labeling and sending or reading emails.

As seen in the analysis in section 5, several factors play a role in the design of an order picking system and focusing on the picking activity itself cannot bring about significant improvement in an order picking system. Due to this, focus was laid on improving the processes and defining procedures for the picking process by the authors. In other words, a holistic approach should always be considered in order to have a better design of an order picking system and not just the picking activity itself especially in an ETO manufacturing firms with low level picking per day.

6.6 Future work

This thesis looks at design of an order picking system for highly customized products which is a new subject in this field. It brings to light the importance of having a holistic view in the design of an order picking system putting into consideration the effects the constraints will have in the picking system design. The scope of this thesis is limited to a part of the warehouse system at ABB capacitors, however, it is recommended to investigate on the picking policy for other warehousing areas such as forwarding area in the third floor and warm warehouse to optimize the picking process in the whole warehousing system. Another problem which can bring significant improvements in the system is defining an approach to integrate the information sharing system with suppliers to reduce the administrative activities and improve item/component ordering. Besides, by better track of inventory at different warehousing areas as well as assembly stations, there would be higher level of information availability in the system. This issue can help the purchasing department to reconsider their supply planning according to the closeness of suppliers and other effective factors; since, currently there is high level of inventory for some components in the warehousing system. Therefore, at the next step, it is recommended to investigate on supply planning considering higher level of information availability.

As noticed from previous literatures, little research has been made in order picking system design in an ETO situation where there is low level picking with high product customization and high variation in item/component characteristics. Therefore, this thesis contributes to existing literatures in order picking system in an ETO firm. However, it is necessary to have further research in similar cases to identify and adopt best practices in order picking system design in an ETO manufacturing firm.

7 Recommendation

Designing an order picking system for an ETO manufacturing company is a tedious task which requires the fulfillment of several parameters and working with the constraints especially for an already existing warehouse. As seen in the current situation, the warehouses face some challenges and several changes must be made to have a logical way of storing and retrieval of items in the warehouses of ABB Capacitors. Some of the changes which are required in the warehouses are explained in subsequent paragraphs.

An important recommendation which the ABB Capacitors should consider is the need for standardization and laid out processes which warehouse and picking staffs should always adhere to. It is important to identify key activities which should always be performed and how it to carry out those activities during storage and retrieval of items in the warehouse. This will enable proper tracking of items in the warehouse and brings about time savings during picking. For instance, warehouse operators should and always use their scanners during picking and storage of items. This makes it possible to locate items, control inventory and identify free storage positions in the warehouse. This solves the problem of using heuristics by warehouse and assembly workers since a well-defined procedure is followed. Also, it will be easier to measure the performance of the order picking system which lays a foundation for continuous improvement in the warehouse.

For short term improvement prior to the implementation of paperless picking system, item barcodes can be printed in the picking lists. In this case, pickers do not need to register items codes manually in barcode scanner to search the location of goods. By scanning the item barcodes in the picking list, they can speed up the identification process. However, this is a short-term improvement. And for long term improvement, it is recommended to make some adjustment in the system to utilize a paperless picking system. Also, by adding two more handheld barcode scanners for assembly and packing staff, there would be a considerable time saving due to better tracking of items in the system. Apart from identification, barcode scanners can allocate empty position to items in the different storage locations in the warehouse. With this, it will be easy to track and retrieve items during picking and the time spent in identification will be reduced substantially.

In the tent, a way to improve capacity utilization is to place these wooden items close to the entrance. In this case, there is a possibility to add some more lines in the remaining part of the tent which can also improve the visibility of items. The other suggestion for improving capacity utilization is by placing shelves in the lines. The figure 25 below compares the suggested layout with the current layout in the tent. As noticed from the two months observation made at the site, it seems that wooden items occupy 50% of the tent space most of the time; therefore, the remaining space can be rearranged by additional lines and shelves. In this case, the gross weight of each pallet should be available on the pallet to facilitate the decision making around placement of items. By showing the gross weight information, the warehouse operator can easily find if the weight of pallet allows him to position it on top shelves or the pallet should be placed on the floor.

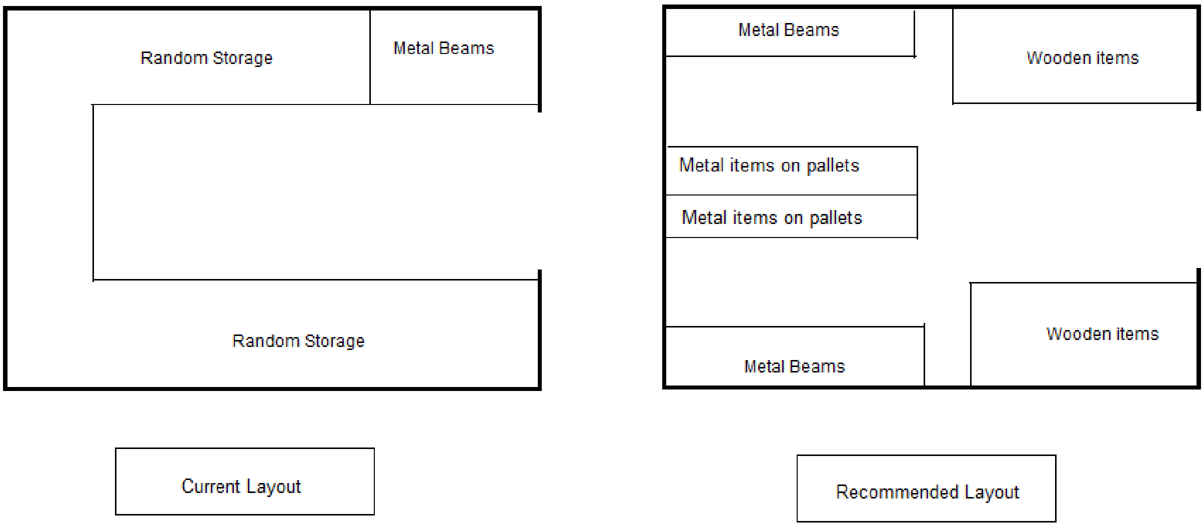

Figure 25: Current layout vs. recommended layout for the tent

The picking from the yard and tent is done by all assembly and packing staff; however, it is better to determine a dedicated picker in each working shift from assembly and production staff to improve the learning curve and speed up the picking process. Since the number of picking per day is very low in the warehouse, dedicated pickers in the first floor can carry out other tasks when they are free from picking tasks.

Avoid disturbance between picking; currently, while a picker picks items from central warehouse for instance, they may be interrupted by some other emergency tasks which reduce the efficiency of picking by distracting the pickers from their duty; especially, when the picked items are very small. Although this is recommended, it might not always be the case since disturbances during picking cannot be predetermined or controlled. In addition, by using different colors for labeling items which belongs to different orders, the sorting process can be facilitated for items which can be picked by sort while pick policy.

To finalize this recommendation, the picking assisted technology proposed for ABB Capacitors is only but a part of the changes which should be made. The solution lies within incremental changes and improvement which could be made in storage policy, picking policy, layout and work organizations. Since without these factors, the recommended handheld barcode paperless system cannot be fully utilized. In addition to this, having standard work procedures, adequate training and good managerial skills will help a long way in bring about positive improvement in the warehouse system. Figure 26 below shows the recommended action plan for implementation of the suggested order picking design.

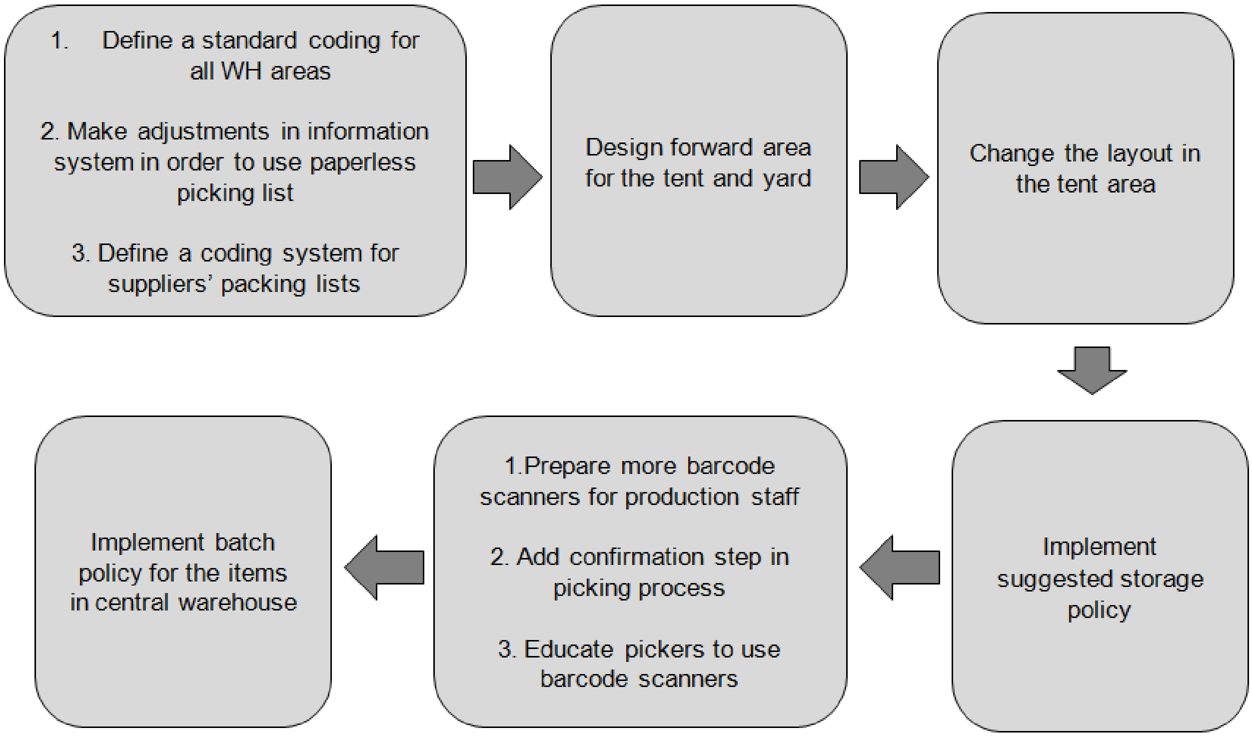

Figure 26: The recommended action plan

As seen in figure 26, there are six main stages towards adopting the recommended order picking system design for ABB capacitors. Following these steps will bring about the required improvements which will elevate the picking performance of the warehouse.

The first step involves the information system development and improvement and it involves coding available warehouse areas, shelve locations and positions. This will enable easy tracking of items in the warehouse through the system and makes it possible for adoption of a paperless picking system since locations can easily be identified by looking at the barcode scanners. In addition to this, by defining a coding system which enables warehouse operators to scan the receiving packing lists instead of manual registration, the administrative time can be reduced significantly.

It is also important to have a forward area in the yard where items which will be used for a order will be placed prior to the picking. In other words, a preliminary can be done and these items will be placed there so when the assembly operator wants to pick, it becomes easier and faster to access these items.

Currently, the area in the tent is not well organized as explained in previous sections, it is therefore important to change the layout of this area to enable easy access and create more space in the tent. This is related to the next step which is storage policy implementation. With a paperless picking system and a well coded storage location, items can be grouped and positioned in the warehouse based on the recommended storage policy. The grouping in figure can easily be implemented once the layout of the warehouse is changed and the positions are coded. This will enable easy placement and retrieval of items in the warehouse since their exact location will be available and visible in the information system.

The fifth step involves top floor managerial decision and communication with the warehouse and assembly operators. This includes purchasing additional barcode scanners which should be used for retrieval and confirmation of items in the warehouse. It is important for management to communicate the need for the use of the barcode scanners during picking and should have a standard picking procedure which every picker follows. This should be done in the form of training so that warehouse and assembly staff can familiarize themselves with the equipment and the order in which picking should be done.

Lastly, picking in the vertical carousel should be done in batches for customer orders with more than one project orders which have similar items and component parts. Here, the picking policy is sort while pick and as discussed earlier, should be differentiated with different colors which will reduce errors made during picking and sorting. In this case, the spent waiting time for the machine to rotate will reduce tremendously.

The suggested order picking system can be implemented in short term. However, for a long term solution it is recommended to use vertical lit model instead of the current carousel in order to reduce waiting time resulted by shelves rotation.

8 Conclusion

This thesis analyzed the different steps in the design of an order picking system as well as the contextual factors which are to be considered prior to the design of a picking system. The findings show that different contextual factors or precondition like managerial considerations, organizational culture, systems requirements, information sharing system and operational requirements has an effect on the design process, and therefore should be investigated before design the order picking system. During the design of an order picking system, several design steps have to be addressed and followed. Based on the context of this thesis, the steps identified and deemed suitable at ABB warehouse are; reserve forward design, storage policy selection, layout design, level of mechanization, information system design and picking policy selection. The results show that for warehouses with low number of picking per day and large variations in size of items, high mechanization level cannot be useful. In addition, when there is a space limitation in the warehousing system, randomized storage policy can increase the space efficiency. However, this storage policy requires a good information sharing system in order to facilitate item/component identification in the storage areas. Since the case company has a decentralized warehousing system, a simultaneous zoning policy is recommended for it. The picking policy in each zone can be different from others according to the product characteristics. The picking policy for the small items in the central warehouse is a batching policy while it is discrete for the tent and yard.

Moreover, in order to improve the time and quality of the picking process different picking assisted technologies has been analyzed and found that for low-level manual picking warehouses with a low-medium rate of picking, like the case company, handheld barcode scanners, RFID handheld scanners and pick-by-voice are the most suitable options. However, considering the costs and other considerations such as large size variations and unavailability of dedicated pickers in the system make handheld barcode scanners an appropriate picking assisted technology.

The design suggested in this thesis will bring about huge benefits at ABB capacitors warehouse in Ludvika, some of which includes; more visibility in the system since position and location can be easily tracked, better storage capacity utilization in the warehouse areas from improved layout and storage policy, significant time reduction in unnecessary activities seen in the picking process which in turn will lead to cost savings in the warehouse, improved picking quality and item registration and lastly, having laid out procedures for picking which can measured and where areas of potential improvement can easily be identified.

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Appendix

Appendix I. Frequency study

	04-Sep	05-Sep	06-Sep	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	Average
Administrative	10	8	10	13	11	18	15	11	9	7	11.2
Transport items to warehousing areas	2	2	1	1	1	3	3	0	0	3	1.6
Replenishing warehousing areas	2	2	2	1	0	0	1	1	3	2	1.4
Visual Check for replenishing forward area	2	2	1	0	1	2	0	1	2	0	1.1
Transport items to forward area	2	2	0	2	2	1	2	0	1	2	1.4
Replenishing forward area	1	2	2	1	1	0	0	0	1	0	0.8
picking	2	3	4	2	3	1	3	6	6	3	3.3
Transport items to final assembly/packaging station	2	2	1	4	4	0	2	4	4	3	2.6
identification	2	2	3	2	3	2	4	6	4	2	3
Transport empty pallets back	2	1	0	0	0	0	1	1	1	0	0.6
Transport with empty forklift	1	2	1	2	1	2	3	1	3	1	1.7
walking	2	3	3	2	3	1	0	1	5	2	2.2
Final assembly/packaging	18	19	23	14	11	21	24	23	28	21	20.2
Moving barriers	2	1	1	0	2	2	2	1	0	3	1.4
repositioning items in warehouse	0	1	1	3	1	2	0	2	2	3	1.5
Waiting	7	9	8	3	9	5	6	5	4	4	6
Inventory control	1	2	1	0	0	2	6	2	1	2	1.7
other activities	3	0	8	7	0	4	4	5	6	11	4.8
Rest	19	17	19	13	9	24	14	20	14	20	16.9

The detail information for frequency study of the whole pickers in ten days

	04-Sep	05-Sep	06-Sep	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	Average
Administrative	4	4	5	5	7	5	11	8	5	7	6.1
Transport items to warehousing areas	2	2	1	1	1	3	3	0	0	3	1.6
Replenishing warehousing areas	2	2	2	1	0	0	1	1	3	2	1.4
Visual Check for replenishing forward area	2	2	1	0	1	2	0	1	2	0	1.1
Transport items to forward area	2	2	0	2	2	1	2	0	1	2	1.4
Replenishing forward area	1	2	2	1	1	0	0	0	1	0	0.8
picking	1	2	3	0	0	1	1	5	4	1	1.8
Transport items to final assembly/packaging station	0	0	0	1	1	0	0	2	0	0	0.4
identification	1	2	3	1	2	2	1	4	2	0	1.8
Transport empty pallets back	1	0	0	0	0	0	0	1	1	0	0.3
Transport with empty forklift	1	0	1	1	0	2	0	0	0	1	0.6
walking	0	0	1	0	0	0	0	0	2	0	0.3
Final assembly/packaging											
Moving barriers	1	1	1	0	2	2	2	1	0	2	1.2
repositioning items in warehouse	0	1	1	3	1	2	0	2	2	1	1.3
Waiting	4	3	2	0	1	5	5	2	2	4	2.8
Inventory Control	1	2	1	0	0	2	6	2	1	2	1.7
other activities	3	0	3	2	0	1	4	4	5	11	3.3
Rest	4	5	3	2	1	12	4	7	3	4	4.5

The detail information for frequency study of warehouse staff in ten days

	04-Sep	05-Sep	06-Sep	07-Sep	08-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	Average
Administrative	6	4	5	8	4	13	4	3	4	0	5.1
Transport items to warehousing areas	0	0	0	0	0	0	0	0	0	0	0
Replenishing warehousing areas	0	0	0	0	0	0	0	0	0	0	0
Visual Check for replenishing forward area	0	0	0	0	0	0	0	0	0	0	0
Transport items to forward area	0	0	0	0	0	0	0	0	0	0	0
Replenishing forward area	0	0	0	0	0	0	0	0	0	0	0
picking	1	1	1	2	3	0	2	1	2	2	1.5
Transport items to final assembly/packaging station	2	2	1	3	3	0	2	2	4	3	2.2
identification	1	0	0	1	1	0	3	2	2	2	1.2
Transport empty pallets back	1	1	0	0	0	0	1	0	0	0	0.3
Transport with empty forklift	0	2	0	1	1	0	3	1	3	0	1.1
walking	2	3	2	2	3	1	0	1	3	2	1.9
Final assembly/packaging	18	19	23	14	11	21	24	23	28	21	20.2
Moving barriers	1	0	0	0	0	0	0	0	0	1	0.2
repositioning items in warehouse	0	0	0	0	0	0	0	0	0	2	0.2
Waiting	3	6	6	3	8	0	1	3	2	0	3.2
Inventory control	0	0	0	0	0	0	0	0	0	0	0
other activities	0	0	5	5	0	3	0	1	1	0	1.5
Rest	15	12	16	11	8	12	10	13	11	16	12.4

The detail information for frequency study of the assembly & packing staff in ten days

Formulation for frequency study

$$\text{Av number of involved operators in Act}_{\mathbf{A}} = \frac{\sum_{i=1}^{10} \text{number of involved operators in Act}_{\mathbf{A}} \text{ at Day}_{\mathrm{i}}}{10}$$

$$\text{Share of activity A} = \frac{\text{Av number of involved operators in Act}_{\mathbf{A}}}{\sum_{n=1}^{19} \text{Av number of involved operators in Act}_{\mathbf{n}}} \times 100$$

i= observation day

n= number of activity

Appendix II ABC Analysis for items in the third floor

Artikel	ABC	XYZ	
DK5101005-021	A	Y	third
DK5901318-018	A	Y	third
DK5502841-B	A	Y	third
DK5502841-C	A	Y	third
DK5101358-002	A	Y	third
DK5101358-003	A	Y	third
DK5101358-004	A	Y	third
DK5101358-005	A	Y	third
DK5101034-009	A	Y	third
DK5101034-010	A	Y	third
DK5101123-016	B	Y	third
DK5301547-003	B	X	third
DK5301579-003	B	Y	third
DK5101147-009	B	Y	third
DK5101147-010	B	Y	third
DK5301546-001	B	X	third
DK5301499-002	B	Y	third
DK5301499-001	B	Y	third
DK5101284-002	B	Z	third
DK5101284-003	B	Z	third
DK5101284-004	B	Z	third
DK5101284-005	B	Y	third
DK5301094-006	B	X	third
DK5301545-001	C	X	third
DK5301549-001	C	X	third
DK5101147-008	C	Y	third
DK5101627-001	C	Y	third
1HSN000102-892	C	Y	third
12330021-7	C	Y	third
DK5101034-003	C	Y	third
DK5101034-007	C	Y	third
DK5101034-013	C	Y	third

Appendix III. ABC Analysis for items in the third floor

Artikel	ABC	XYZ
1HSD100909-724	A	Z
1HSN000275-010	A	Z
1HSN000018-001	B	Y
1HSN000018-002	B	Y
DK5101405-004	B	Z
1HSN000275-018	B	Z
9ADA313-3	C	Y
9ADA316-6	C	Y
9ADA313-5	C	Y
DK5301427-090	C	Y
9ADA268-3	C	Y
9ADA121-27	C	Y
9ADA123-61	C	Y
9ADJ452198P2025	C	X
9ADA268-5	C	Z
9ADA121-58	C	Y
9ADA271-6	C	Y
1HSN000001-603	C	Y
9ADA316-1	C	Z
9ADA334-6	C	X
9ADA316-5	C	Z
21512069-4	C	X
9ADJ335464P3211	C	Y
9ADA316-7	C	Z
9ADA313-4	C	Y
21662055-4	C	Z
1HSN000018-035	C	Y
DK5101068-003	C	Z
DK5301427-089	C	Y
CAP-ISO1	C	Y
CAP-ISO2	C	Y
9ADA568-16	C	Y
9ADA568-20	C	Z
1HSN000018-003	C	X
1HSN000018-004	C	Y
1HSN000018-006	C	Y
9ADA271-1	C	Z
9ADA123-22	C	X
9ADJ400146P8017	C	Z

BC analysis for first floor- part 1

Artikel	ABC	XYZ
9ADA121-29	C	X
9ADA268-4	C	Y
9ADA121-411	C	Y
9ADA121-39	C	Y
9ADA121-40	C	Z
9ADA121-41	C	Y
9ADA123-62	C	Y
9ADA121-414	C	Y
9ADA121-55	C	Y
9ADA121-56	C	Y
9ADA271-5	C	Z
9ADA271-7	C	Z
21512068-2	C	X
DK5101355-001	C	Z
K2940176-002	C	Z
9ADA334-8	C	X
1HSN000231D0196	C	X
DK5101400-002	C	Z
1HSN000018-011	C	Y
9ADA620-84	C	X
K49772781-001	C	Y
1HSN000324-276	C	NEW
DK5101124-009	C	NEW
9ADA123-74	C	Z
9ADA313-2	C	Z
9ADA327-6	C	Z
1HSN000324-348	C	NEW
9ADJ335464P3811	C	Z
1HSN000102-736	C	Z
DK5502777-201	C	Z
1HSN000275-013	C	Z
1HSN000324-246	C	NEW
9ADA316-2	C	Z
1HSN000001-027	C	Z
1HSN000275-005	C	Z
CAP-CTE1	C	Z
CAP-CTE2	C	Z
1HSN000018-030	C	Y
1HSN000018-031	C	Z
1HSN000018-032	C	Z
1HSN000018-033	C	Y

ABC analysis for first floor- part 2

Artikel	ABC	XYZ
1HSN000018-034	C	Z
1HSN000324-411	C	NEW
1HSN000018-036	C	Z
1HSN000018-037	C	Z
1HSN000018-012	C	Z
1HSN000570-A	C	NEW
DK5301427-091	C	Z
1HSN000275-003	C	Z
9ABA450071P4306	C	Z
CAP-ISO3	C	Z
CAP-ISO4	C	Z
1HSN000102-315	C	Z
1HSN000102-319	C	Z
9ABA405019P1303	C	NEW
1HSN000102-768	C	Z
9ADA121-16	C	NEW
9ADA121-22	C	NEW
DK5101120-022	C	Z
1HSN000001-905	C	Z
DK5301627-002	C	Z
1HSN000102-498	C	Z
1HSN000102-499	C	Z
9ADA121-410	C	NEW
1HSN000018-005	C	Z
1HSN000018-007	C	Y
1HSN000018-008	C	Z
1HSN000001-784	C	Z
9ADA123-4	C	Z
9ADA123-12	C	Z
9ADA59-53	C	NEW
9ADA268-2	C	Z
9ADA120-44	C	Z
9ADA121-28	C	Z
9ADA123-417	C	Z
9ADA123-59	C	Z
9ADA59-54	C	NEW
9ADA59-446	C	NEW
9ADA121-42	C	Z
9ADA121-43	C	Z
9ADA123-63	C	Z
9ADA123-420	C	Z

ABC analysis for first floor- part 3

Artikel	ABC	XYZ
9ADA121-54	C	Y
1HSN000324-247	C	NEW
9ADA123-75	C	Z
9ADA121-57	C	Z
9ADA123-77	C	Z
9ADA121-59	C	Z
9ADA121-60	C	Z
9ADA121-61	C	Z
9ADA121-62	C	Z
9ADA121-63	C	Z
9ADA57-39	C	Z
1HSN000275-015	C	Z
1HSN000102-497	C	Z
1HSN000102-710	C	Y
CAP-CRT1	C	Z
1HSN000001-785	C	Z
CAP-CSA1	C	Z
9ADA123-81	C	Z
1HSN000102-581	C	Z
DK5301474-071	C	Z
9ADA121-14	C	Z
1HSN000324-694	C	Z
DK5101406-002	C	Z
DK5101405-009	C	Z
DK5901276-001	C	Z
1HSN000324-385	C	Z
1HSN000001-706	C	Z
1HSN000324-160	C	Z
DK5301434-002	C	Z
1HSN000324-215	C	Z
1HSN000324-283	C	Z

ABC analysis for first floor- part 4