

## Picking Station Design Considerations for Improved Sequence Picking

A Case Study at Volvo Cars Torslanda

*Master of Science Thesis*

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CHALMERS UNIVERSITY OF TECHNOLOGY

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*Supply Chain Management*

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Cover:

Sequence picking station used at Volvo Cars Torslanda, refer to section 4.2 at page 29 for details.

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# Picking Station Design Considerations for Improved Sequence Picking: A Case Study at Volvo Cars Torslanda

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## Abstract

The automotive industry continuously becomes more competitive. New brands grow stronger and there is a constant pressure to come up with new models with an increasing frequency. In addition, safety requirements on the cars, together with customers demanding a wide range of both models and variants of the models, makes the number of components for each car model larger than ever. The many models and variants, and the fact that these are assembled on the same assembly line, put demanding requirements on the material feeding process. One way of feeding the line with material is to send items to the assembly line pre-picked according to the building sequence of the cars. This requires facilities for sequence picking and the picking operations of course have to be carried out as effectively and efficiently as possible. As the amount of models and variants increases, also the extent of the picking activities increases and area efficiency in the sequence picking facilities becomes a concern. Hence, the purpose of this thesis is to contribute to increased knowledge about how an area problem in sequence picking facilities can be addressed.

The thesis suggests a number of different ways in which the area efficiency of a sequence picking station can be improved. The improvement suggestions vary in effectiveness as well as in the physical changes, and the level of investment, necessary for an implementation. In addition, an item classification system is introduced. The system is thought to be used when looking for picking stations with the greatest improvement potential or when looking for picking stations suitable for a specific design change. At last, three of the improvement suggestions are evaluated through a virtual implementation at Volvo. The focus is on area savings but also operational differences are addressed. The operational differences are addressed through a comparison of mappings of the activities performed at the evaluated picking stations before and after the change.

Major contributions of the thesis are the identification of design considerations for improved area efficiency of sequence picking stations and the item classification system developed as a support for identifying picking stations suitable for specific design changes. In addition, the thesis serves as a compilation of theory with focus on picking operations and also as a source of practical picking solutions as the picking operations at six reference companies are presented.

**Keywords:** Picking, picking station design, sequence picking, materials supply, materials handling



## **Preface**

The work presented in this thesis was carried out in collaboration with Volvo Car Corporation at Torslanda in Gothenburg, from June 2011 to October 2011, in order to fulfill the requirements for the degree of Master of Science in Supply Chain Management at Chalmers University of Technology in Gothenburg, Sweden.

During the work with the thesis, we worked in close collaboration with our supervisors at Volvo, Bengt-Göran Larsson and Henrik Brynzér, as well as with our supervisor at Chalmers, Christian Finnsgård. We are very thankful for their help and support and would like to express our gratitude for giving us the opportunity to work with an interesting topic in an interesting company. In addition, we would like to thank all the nice and helpful employees at Volvo in general and in TB1 in particular for giving us a great time and providing us with valuable knowledge and insights. At last we would like to thank our families and friends for love and support, and we wish all readers of this thesis 63 pages of pleasant reading.

Emma Lundgren  
Mattias Stenberg

Gothenburg  
September 2011

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## **Word List**

*Area/Space* – Area, in this thesis, refers to a two dimensional surface while space, in this thesis, refers to a three dimensional volume.

*Downsizing* – Re-packing of material delivered in a big package, e.g. a pallet, to a smaller unit load, e.g. a plastic box.

*Elevating forklift* – Forklift on which the picker self stands on the elevating part. Can be thought of as a forklift with a platform, from which the machine is controlled, mounted onto the forks.

*Item class* – Class of articles according to the proposed classification system.

*Item group* – A group of similar items, e.g. different handles or different steering wheels.

*Lifting equipment* – Equipment helping the picker lift items too heavy to be manually lifted.

*Pallet storage rack* – Rack in which pallets with products are stored.

*Rack* – see Sequence rack

*Sequence rack* – Rack with numbered pigeonholes for each and one the picked items. Used for delivery of items from the sequence picking station to the assembly line, in the correct sequence.

*Sequence picking station* – Picking station for picking and positioning of items according to the building sequence of the cars assembled at the assembly line.



# 1 Introduction

This very first chapter presents the background to the problem addressed throughout this thesis. A short introduction is also given to the case company Volvo Cars Torslanda (for simplicity referred to as Volvo throughout the thesis) and its relation to the thesis. This is followed by a purpose statement and an analysis of the actual problem. The problem analysis results in four research questions which will serve as a backbone for the report. The chapter is concluded with a statement of the scope of the work and an illustration of the thesis's outline.

## 1.1 Problem Background

As with many products in the world of today, customers can choose from a large number of variants of the different car models on the market. Everything from external features such as color, wheels and level of styling to more internal gadgets such as different stereo packages, luxury level of interior and safety equipment can be combined in a close to endless range of combinations. The many variants that a car producer needs to offer in order to stay competitive put high demands on the production systems in use as they must be able to satisfy the scattered customer demands, yet still be cost effective. The characteristics of the automotive industry have changed from those of mass production to those of mass customization (Michalos et al., 2010).

Generally no car is built without an assigned customer, something which means that the factory has to build cars with different specifications on the same assembly line, more or less randomly alternated (Gunasekaran & Ngai, 2005; Howard, Miemczyk, & Graves, 2006). Further, as it would be quite uneconomical to have one line for each car model, several models are usually built on the same line. The product variety and the assembly of multiple models at the same line calls for advanced logistics operations, in this case meaning a timely supply of a very large number of items to a limited area around the line. All items need to reach the production line in the planned building sequence in order to end up on the car they are specifically assigned to. Baudin (2002) argues that the two main factors in assembly performance are part supply and the design of the assembly work.

Actually, the car industry has for a long time been characterized by a continuous search for more effective and efficient operations. This is shown not at least by the fact that lean production as a companywide philosophy was developed and first used by the automotive company Toyota (Ohno, 1988). The constant strive for more efficient operations, in combination with the above mentioned importance of logistics, makes it interesting to investigate possibilities for improvements in the material supply supporting assembly operations in the automotive industry.

As the cars are assembled in a predetermined sequence, the material supply involves storage, or availability, of all items that can possibly be required as well as some way of delivering these to the line in the correct sequence. However, if all items were to be presented along the line, the line would be very long. So, the space along the line is in practice limited, which calls for different kinds of preparation for different items. This preparation requires extra handling, and with the extra handling comes extra transportation, storage and administration, activities which usually are related to extra costs. In order to keep these extra costs as low as possible the following three options for supplying the line with material are at hand. The preferable option, in terms of cost, is when the items can be delivered directly to the line without any additional picking or handling operations. The secondly preferred option is when only downsizing is required, i.e. re-pack items into smaller batches before

delivery to the line. The last option, which is the most expensive due to fairly substantial logistical activities, is to deliver the items pre-picked in racks according to the building sequence. All these options constitute opportunities to make improvements. However, in this thesis the focus is on the last one.

In order to increase the efficiency of a sequencing warehouse one can either look at improving the warehouse operations in some way or to change the picking operations. The improvements can be made with focus on for example costs, throughput time or space utilization (Gu, Goetschalckx, & McGinnis, 2010; Malmberg, 1996). In general, designing a warehouse is a very complex task as there are many interrelated factors to consider (Baker & Canessa, 2009). For example the placement of the products in the warehouse will affect the picker's route, as will the composition of orders and the amount of different products ordered. This complexity calls for a focus on sub-processes in order to manage the big picture and build up a well functioning whole. As for designing a warehouse according to picking route, product placement, order composition etcetera there are a lot of literature available. Meanwhile, the research on the kind of picking station in question here is very limited, whereby a focus on this sub-process seems suitable.

At last, in a distribution center, or a warehouse, order picking is very labor-intensive when using a manual system and very capital-intensive when using an automated system (de Koster, Le-Duc, & Roodbergen, 2007). Hence, regardless of using a manual or an automated system, order picking operations constitute an area where productivity improvements can make a big difference for the operating company. In addition, Dukic and Cedomir (2007) say that warehousing, besides transportation, is one of the largest cost drivers within supply chains. The supply chain costs, in turn, constitute about 10-15 % of GDP in western countries (Dukic & Cedomir, 2007). Combined with the fact that the order-picking process is the most costly activity in a typical warehouse, with up to 55 % of the total operating costs, this further supports the importance of improvements within the order picking area (Tompkins et al., 2003).

To sum up, the fact that the sequence-picking is the most expensive of the material supply alternatives for automotive companies, together with the lack of literature around sequence picking stations in the automotive industry and the overall high cost of order picking activities, makes the picking operations an interesting area of research and a promising target for improvements. Hence, this thesis will add to the theory some ideas on how to attack the problem of designing picking stations in a sequencing warehouse in a favorable way.

### **1.1.1 Case Company Background**

Volvo has a very strong brand, promising to include their four core values - environment, quality, design and security - into their products (Volvo Cars, n.d. b). In 2010 the company produced 387 802 cars out of which they sold 373 525 (Volvo Cars, 2011). Volvo cars have dealership stores in several parts of the world, with the greatest sales numbers in USA, Sweden, UK, China and Germany. There are currently 12 models produced in five factories located in Sweden, Belgium, China and South-East Asia with Gothenburg in Sweden and Gent in Belgium being the largest production facilities in terms of production volume (Volvo Cars, n.d. a). The Torslanda plant in Gothenburg produces five models – S80, V60, V70, XC70, XC90, with potentially adding S60 to the production. Volvo has been awarded several times during the years for their cars, both in Sweden and internationally (Volvo Cars, 2011).

Volvo Cars Torslanda consists of several buildings, among which there is one body shop, one assembly plant, one sequencing warehouse and a paint shop (Figure 1). In the A factory, TA, all sheets are pressed, later constructing the chassis of the cars. In the C factory, TC, the cars are assembled. The painting is located in the building behind the present warehouse. The warehouse, called TB1, provides the C factory with kitted and sequenced items for direct delivery to the assembly line.

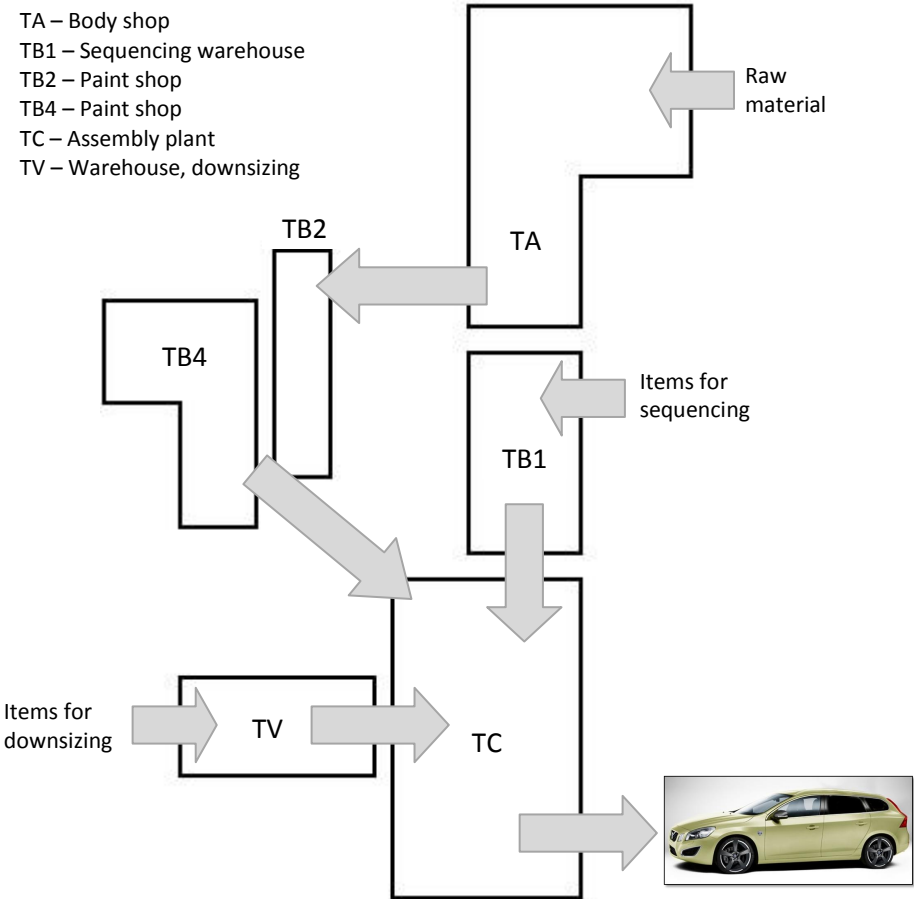


Figure 1. Illustration of the Torslanda facilities, including material flows.

In terms of material supply, Volvo has a couple of sequencing operations feeding components to the assembly line; see Figure 2 for schematic illustration of material flow to the assembly plant and Figure 1 for material flows between the Torslanda facilities. The practical starting point of this thesis is in TB1, where around 3000 items are stored and delivered to the assembly line as demand arises. The production start of the new Volvo V60 and the introduction of a range of new items, partly due to face lifts on previous models, together with an increased production have made the operations in TB1 to start to grow too big for the facilities. In addition, there are limited possibilities to expand the warehouse physically. These facts call for a performance improvement of the operations in TB1 in order to make better use of the space.

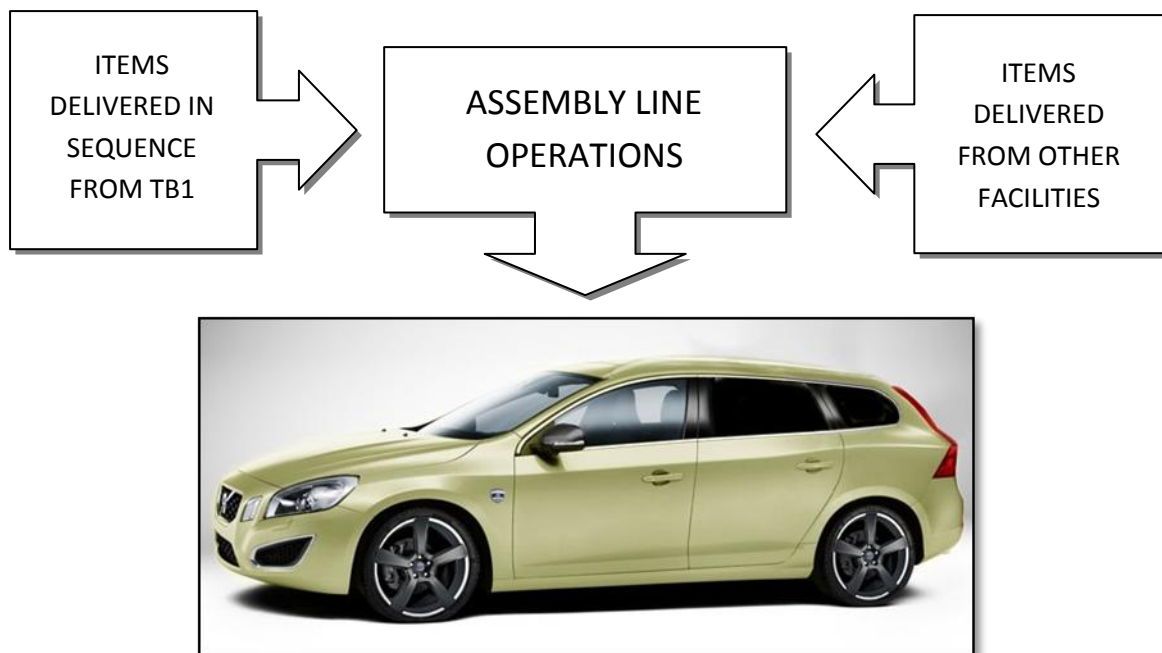


Figure 2. Schematic picture of the material flow to the assembly plant at Volvo Cars Torslanda

The operations in TB1 comprises foremost of storage and picking activities, hence these are the areas for possible improvements. The space problem is further enhanced by the fact that even though there is room for more picking stations, there is no room for inventory supporting any new stations. Because of this, Volvo is considering outsourcing of the warehouse operations in TB1 and to rather focus on the picking and sequencing operations. Hence, the main problem faced is that of how to design picking stations in a space/area efficient way.

This is very much in line with what is stated in more general terms above, with the addition of the outspoken focus on space/area. So, the main focus of the ideas on how to attack picking station design presented in this thesis is put on space/area efficient solutions.

## 1.2 Purpose and Problem Analysis

The purpose of this thesis is to develop suggestions for how the design of sequence picking stations in the automotive industry can be changed in order to facilitate better utilization of the warehouse space. More precise, the purpose is to contribute to the theory on the subject and to provide Volvo with ideas of, and insights to, how they can make their picking operations more area efficient.

The starting point of the problem is the pressure for effectiveness and efficiency in today's car industry. As mentioned in the background Volvo is considering outsourcing of inventory operations, which makes picking stations the main focus of this thesis. Since the operations in the factory are constantly evolving and the main focus is to make the daily operations work as smooth as possible rather than to develop sustainable solutions to new problems, the main question for the thesis is: *How to design sequence picking stations in a better way than today?* Due to Volvo's space limitation, the major approach to the problem is to find space/area efficient solutions and thereby the question



presented above becomes: *How to design sequence picking stations in a more space/area efficient way?* Even though space/area utilization is given a central role here, other variables as cost, time and ergonomics will also be considered.

In order to answer the main question and fulfill the purpose of the thesis, three main areas were identified; a classification system, design suggestions for the picking stations and an evaluation of the suggestions. These areas are presented closer in the following sections. At last, the research questions that will be used to solve the problem are presented.

### **1.2.1 Item Classification**

To start with, it is important to know what kind of items that are picked at the different stations. When this is known, the main sub-problem is: how can these items be classified in relation to picking station characteristics which will affect the area utilization? A further sub-problem becomes: with respect to what characteristics is it suitable to classify car components picked and sequenced before the assembly line?

The purpose of these sub-problems is to facilitate the development of a classification system which can serve as a base for what picking station can be a target for a specific design change, when there is a will to evaluate picking stations used for old items, or in order to set up the best possible picking station when a new item is going to be introduced.

### **1.2.2 Picking Station Design**

In order to change the design of a picking station it is of great importance to know what determines the picking station design and what implications a change might have; both of which are connected to how a picking station's performance is evaluated. With this in mind, the first sub-problem here becomes: with respect to what variables is it possible to design a picking station? And, as mentioned above, of great value when looking to answer this question would be to first address this sub-problem: what key performance indicators are used to evaluate order picking operations? In relation to the item classification, picking station designs especially suitable for specific classes are desirable to identify. At last, and as mentioned before, the focus when developing the layouts was on space/area efficiency.

### **1.2.3 Design Changes' Affect on Picking Stations**

The last bit of the overall problem is to evaluate if the proposed picking station design changes make any difference compared to the picking stations used today. The last sub-problem thereby becomes: do the proposed design changes make any difference in a real life setting? As the purpose of this thesis is focused on area, the main difference sought is a change in the area occupied by a picking station. However, it is also interesting to address the impact of the design changes on the operations performed at the picking station. The question itself is a question of high relevance to the main problem of the thesis as it will provide both academics and the case company with valuable information about the proposed design changes; whether they are positive or negative in terms of improvement potential. However, it is an evaluation of the answers to the previously presented questions and hence this problem does not justify a research question of its own.

### **1.2.4 Research Questions**

In this section, the sub-problems, or questions, presented in the three sections above are recapitulated in condensed form as research questions. First, as stated above, the major question

sought to be answered with this thesis is: *How to design sequence picking stations in a more space/area efficient way?* In order to answer this question, the following research questions were developed.

**RQ1:** *With respect to what variables is it possible to segment items picked in sequence?*

Classifying the items is supposed to give valuable hints of where improvements can be made. In addition, the classification system is thought to be of help when looking to implement the picking station design improvements at new stations in the future. In order to know, or evaluate, which is the most appropriate way, it is important to know what classification alternatives are available.

**RQ2:** *On what key performance indicators could a picking station be evaluated?*

To know what to look for when evaluating picking stations in the search for improvements, it is important to know on what parameters a picking station can be evaluated. Also when assessing the validity of the proposed design changes this knowledge is perceived very valuable.

**RQ3:** *With what measures can a picking station design be improved?*

Similar to the question about different classification options above is the question of how to improve the picking station design. The interesting thing to start with is how a picking station design can be changed. After answering this question, it is possible to evaluate which of the design changes are realizable in the context of Volvo Cars.

In order to answer this research question, an important sub-question to look into is: how do other companies address the picking problem related to sequencing?

**RQ4:** *Are some picking station design changes especially suitable for specific items?*

After having segmented the items into appropriate categories and developed suggestions for picking station improvement, the next step is to evaluate if some of the suggestions are more suitable for some items or items classes than for other. A valuable outcome would be if it is possible to connect some of the ideas to some of the item classes.

### **1.3 Scope**

This thesis examines improvement possibilities for picking stations used when sequencing components to a car assembly line. The focus is on area efficiency as the case company Volvo is facing area constraints in their facilities when the number of items handled in-house is expected to increase. However, also other efficiency measures are taken into account when possible solutions are presented.

In order to look at the problem in a structured way, a classification system for the items handled in picking stations was developed. This classification system was developed for the type of items present in an automotive sequencing warehouse and segments the products according to properties that are likely to affect the picking stations' designs. The classification system was thereafter used as a foundation in the search for picking station improvements.

## 1.4 Thesis Outline

The flow of the thesis is illustrated in Figure 3 followed by a brief text description below.

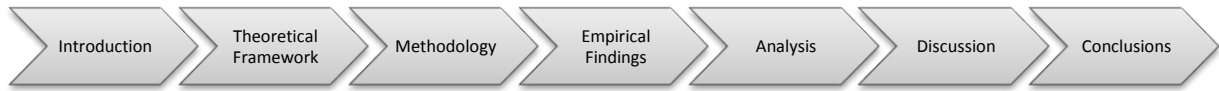


Figure 3. Visualization of the content of this thesis.

The thesis starts with an *introduction* which sets the stage for the whole work. A background to the topic is given, as is the purpose of the research, a problem definition and the research questions that will be addressed throughout the thesis. In this chapter also a brief introduction to the case company is given.

The second chapter covers *theory* in areas relevant to understand the rest of the thesis. It gives basic information in areas like work analysis and ergonomics and more detailed descriptions of picking operations.

The third chapter presents the *methodology* used for carrying out the research and analysis required to answer the research questions stated in the introduction chapter.

The fourth chapter reports the *empirical findings* made during the work with the case company and during site visits at a number of other companies. This is followed by an *analysis* of, and *discussion* around, the findings in chapter 5 and 6 respectively. In chapter 5, also answers to the research questions are explicitly provided.

At last, the report is concluded with some *general conclusions* and some more specific *recommendations to Volvo*. These are presented separately in chapter 7 and 8.



## **2 Theoretical Framework**

In this chapter, theory relevant to the topic of this thesis is presented. According to what is described in section 3.2.1, a literature review has been carried out and the information retrieved is presented in the different sub-sections below. The idea with the literature review is to create a theoretical framework upon which the rest of the thesis is built, as well as to provide the reader with background information necessary to understand the rest of the work. The chapter starts off with some theory around classification of items. This is followed by the backbone of the theory section addressing picking related issues such as ergonomics, picking operations and SAM-analysis. The chapter is concluded with a short presentation of lean principles and some relevant lean concepts together with a method for assessing material flow performance.

### **2.1 Item Classification**

When managing a large warehouse with a wide range of items it is important with inventory management in place (Min-Chun, 2011). One part of this can be a well thought through classification of the items kept in stock, in order to achieve goals such as less tied up capital and/or higher service level. A classification of items can be made with reference to one, two or more parameters. A commonly known, and often used, method is referred to as ABC-classification in which the items are divided into different classes, A, B, C etc. The division is often carried out by making use of the Pareto principle, also known as the 80/20 rule. The Pareto rule means that 80% of for example the revenue/value/area is covered by 20% of the items. However, also other classification criteria can be used, such as the ABC-classification. A drawback with the latter, as it is presented here, is that it only refers to one dimension; the importance of the item. Aspects of importance could be the frequency of consumption or financially most valuable items. The most important items are classified as A, meaning it needs the attention of the manager, while the other items are classified as either B – important, or C – not so important (Braglia, Grassi, & Montanari, 2004).

As mentioned earlier the automotive industry is characterized by many variants of the different car models. In addition, due to more cars assembled on the same line, more customized cars, higher safety requirements etc., there is an increasing trend in the number of items connected to the assembly process. Considering each item separately would not be realistic, hence the importance of the efficiency of a classification system. Above mentioned, there are different dimensions to consider when classifying items in a warehouse (Braglia, Grassi & Montanari, 2004). Criteria to use for evaluation could be constraints, safety, logistic aspects, size, weight, supplier and/or part number (Brynzér & Johansson, 1996; Braglia, Grassi, & Montanari, 2004). Other could be lead-time, obsolescence, commonality, inventory cost and order size requirements (Min-Chun, 2011). Using a multi dimensional classification system prevents over-looking important and potential control parameters. It is however important to notice the difficulty in quantifying some parameters.

### **2.2 Ergonomics**

The science of ergonomics is concerned about the impact of different parts of a job, or the design of a job, on the human-being performing it. The International Ergonomics Association defines ergonomics as follows: “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance” (International Ergonomics Association, 2010). As can be seen in the definition, ergonomics is not just about physically demanding work, such as heavy lifts. It can refer to

other interactions in a system as well, for example how working with a computer for many hours a day might affect a worker, physically as well as psychologically. However, the ergonomic aspects of interest for this work are those concerned with the health effect repetitive physical work will have on the worker if no preventive measures are taken.

Rowan and Wright (1994) claims that not only heavy lifts, but also smaller loads frequently repeated over time, will have an impact on the person performing them. If no attention is paid to the ergonomic conditions of the work, it will eventually lead to worker injuries. According to Prevent (2007), in Sweden, injuries of this kind make up a big part of absence and rehabilitation costs which have to be paid by the society. The same organization mentions that, within the European Union, work related repetitive strain injuries is one of the major problems for the European public health.

According to the Swedish governmental organization for work environment, there are rules and regulations every employer need to fulfill in order to have a work place as safe as possible (Arbetsmiljöverket, 2011). The work environment subject to the regulations contains technological, physical, organizational, social, and work-content related factors. In line with above, for this thesis the most interesting part is regulations concerning the technological and physical parts of the work as these are closely connected to the designs possible for picking stations. Important to notice is that the regulations are more of guidelines than pure rules (Arbetsmiljöverket, 1998; Arbetsmiljöverket, 2000). It is thus very much the companies' own responsibilities to judge what actions that have to be taken in order to assure a healthy work environment which also meets the legal requirements.

## **2.3 Picking Systems**

According to de Koster, Le-Duc and Roodbergen (2007) order picking can be defined as “the process of retrieving products from storage (or buffer areas) in response to a specific customer request”. This definition builds on a definition given by Goetschalckx and Ashayeri (1989): “order picking is the activity by which a small number of goods is extracted from a warehousing system to satisfy a number of independent customer orders”. Both definitions, as well as other, can be seen as equally valid. The point of bringing more than one up here is to illustrate the fact that there is no one and only definition of order picking, and that order picking can be carried out in many different ways but still fit in with definitions found in the literature.

### **2.3.1 Picking Operations**

As shown in Figure 4, order picking operations can be divided into two categories, namely picking carried out by human workers and picking carried out by machines. The classification shown in the figure was presented by de Koster, Le-Duc and Roodbergen (2007) in their comprehensive literature review on order picking. The different picking methods are explained one by one in the following sub-sections.

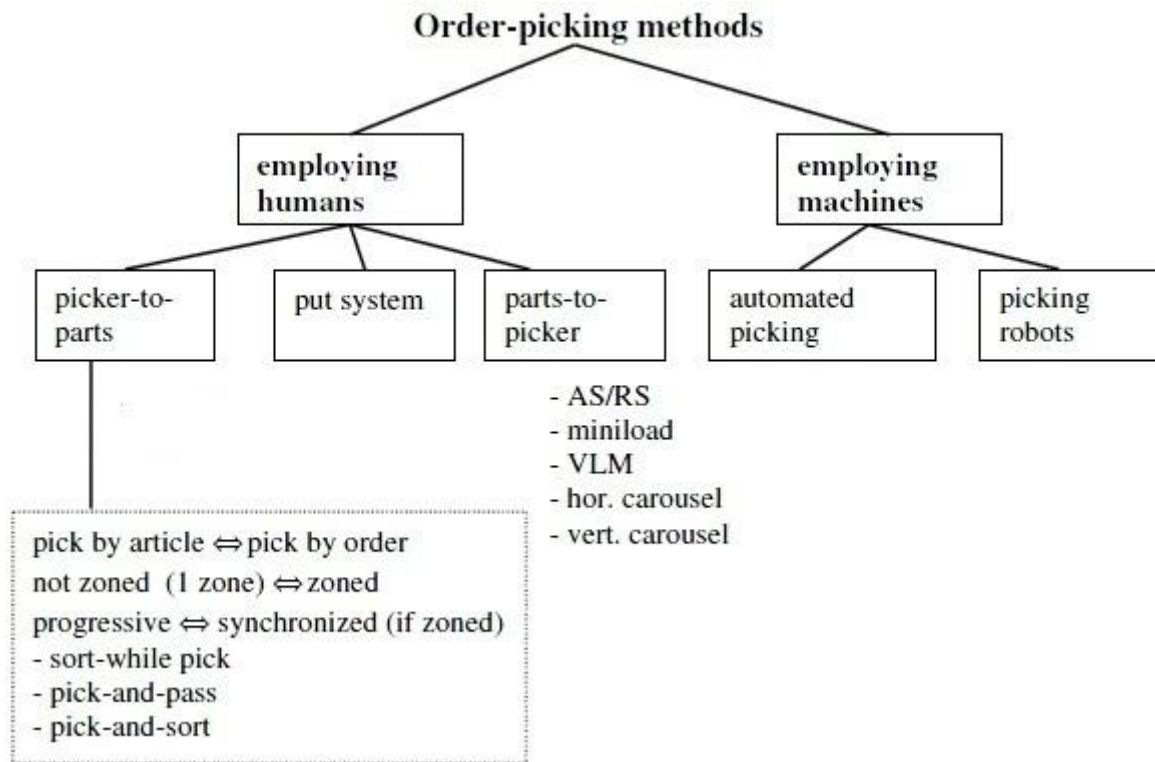


Figure 4. Different classes of order picking systems (de Koster, Le-Duc, & Roodbergen, 2007).

### 2.3.1.1 Human Pickers

When employing a human picker there are mainly three picking methods to use; picker-to-parts, parts-to-picker or a put system.

#### Picker-to-Parts

In a picker-to-parts system the picker walks, or drives, around in the warehouse facilities to pick the ordered items. The picking, in turn, can be done in many ways, as indicated in Figure 4.

First, the picker can pick specific items (pick by article), i.e. pick batches of items which are later combined with items from other batches in order to fill orders. As opposed to this, the picker can pick specific orders (pick by order), i.e. the picker completes an order by combining individual items while picking them.

Second, the picking can be performed in zones or the whole warehouse can make up just one zone which means effectively to pick without zones. To use zones means to have different articles placed in different pre-determined zones. The picking is then carried out zone by zone, either in sequence or simultaneously by different pickers. These alternatives are referred to as progressive- (in sequence) and synchronized (simultaneously) picking by de Koster, Le-Duc and Roodbergen (2007) and both can be used whether one single order consists of items from different zones or not. Since different items are assigned to different zones, the zone configuration is closely related to the storage location assignment, i.e. where in the warehouse to locate different items as well as how to assign the locations. To further dig into the issue of zone configuration and storage design is outside the scope of this report, however there are some reading available on the topic from for example Brynzér and Johansson (1996), Petersen (2002) and Speaker (1975).

Third there are three ways to perform the sorting of the picked orders available in sort-while-pick, pick-and-sort and pick-and-pass. All of these are variants of the above explained picker-to-parts methods. Sort-while-pick implies picking of multiple orders simultaneously, immediately followed by sorting by the picker. If the sorting instead is carried out after the picking is done, the method is called pick-and-sort. The last method, pick-and-pass, is related to progressive zone picking, i.e. one part of an order is picked in one zone before the order is passed on to the next zone where the picking is continued.

At last, there is an important special case of zone picking, combined with pick-and-pass, which is worth mentioning, namely pick-to-belt (de Koster, 1994). This is a system in which a moving belt is passing by different picking stations where items are picked and placed on the belt. In the end of the belt the orders are completed. According to de Koster (1994) there are mainly two types of pick-to-belt order picking systems. In the first type, the items are picked and placed directly on the belt. A bar code may be attached to each item in order to facilitate the sorting taking place at the end of the conveyor. This type can also be seen as a put system, which is presented further down. In the second type of pick-to-belt system, bins are placed on the belt in the beginning of the track. Each bin is assigned to one or more orders and information on what items should be put in the bin is attached in form of a picking list and/or a bar code containing the information. The conveyor system then automatically transports the bin to each picking station that has to be visited in order to fulfill the orders assigned to the bin. A pick-to-belt system of the second type is illustrated in Figure 5, where three picking stations can be seen. Here, items are presented in shelf racks positioned perpendicular to the belt. However, other alternatives are also available such as presenting the material above and below, and thereby parallel to, the belt. The material can even be presented using more automated solutions, such as the ones presented in the next section, and in that case the system would classify as a parts-to-picker system rather than a picker-to-parts system. The first type of system looks similar to the one illustrated in Figure 5, with the exception of the “side tracks” as the items here are placed directly onto the moving belt.

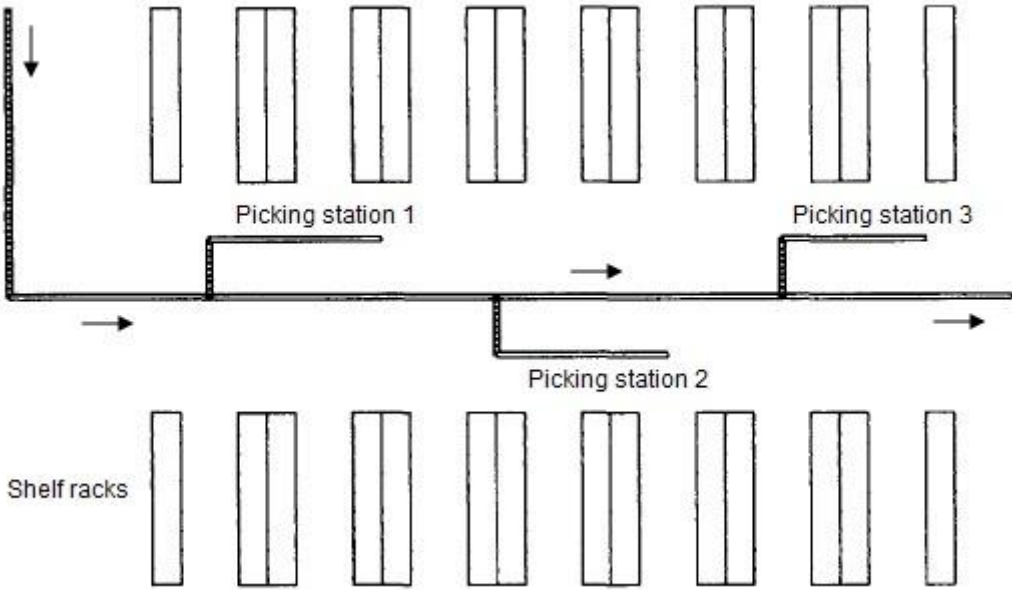


Figure 5. Pick-to-belt system using bins.



### **Parts-to-Picker**

In a parts-to-picker system the picker is stationary while the products are retrieved from the storage and presented to the picker at the picking location, thus the fairly substantial time a picker spend walking in a picker-to-parts system is eliminated (Anon, 1986). As indicated in Figure 4, there are a number of ways in which the items to be picked can be retrieved from the storage. However, these different options can be divided into just two classes.

First, an automated storage/retrieval system (AS/RS), also referred to as a unit-load or end-of-aisle order picking system, can be used. Usually this system is aisle bound and consists of a crane which travels along the aisle retrieving, or leaving, one or more unit loads to, or from, their respective inventory locations. The unit load can be a pallet or a smaller unit like a box or a bin, in the latter case the load is called a miniload. The picker is responsible for picking the right amount of items from the unit load when presented to him/her and thereafter compose the orders at the fixed picking station. A drawback with this kind of system is the high investment costs that comes with all the automation and thus the solution is usually only justifiable when inventory volumes are extremely high (Sarker & Babu, 1995).

The second alternative consists of a couple of different variants, namely vertical lift modules (VLM), horizontal carousels and vertical carousels. All these systems are usually smaller and more compact than an AS/RS-system and they also build on the same principle of a number of storage locations more or less inside a box. However, even though they often are smaller than an AS/RS system, they still can be fairly big, especially the horizontal carousel system. Like in the case with the AS/RS-system, the picker is responsible for picking the right amount of items from a unit load. Figure 6 to Figure 8 below shows the principle of vertical lift modules, horizontal carousels and vertical carousels.



Figure 6. Vertical lift module.



Figure 7. Horizontal carousel.

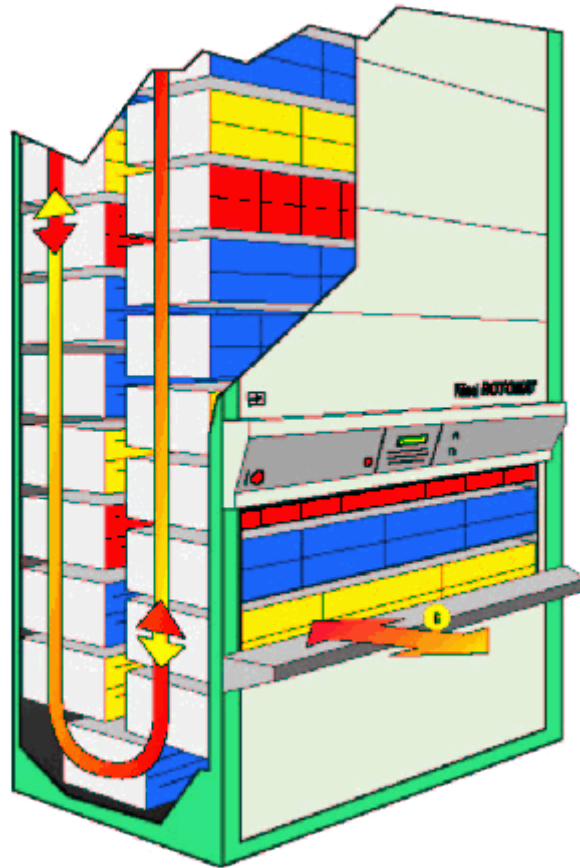


Figure 8. Vertical carousel.

### **Put System**

A put system, also referred to as an order distribution system, consists of two processes; one retrieval process and one distribution process.

In the retrieval process the items are retrieved from the storage and transported to an order picker. The retrieval process can be carried out according to either of the picker-to-parts or parts-to-picker principles presented above. In the distribution process the items presented to the order picker are distributed over customer orders, i.e. the picker puts the items on each order in customer cartons which then are to be sent out to the buyers who placed the orders.

This kind of system is especially good when many order lines have to be picked in short time. This might be the case in mail order companies like Amazon, companies which receive a very large amount of small orders from many different customers.

#### **2.3.1.2 Machine Picking**

In machine picking the picking operations are fully automated by the use of robots or other automated sorting. Other automated sorting can for example imply that items automatically are retrieved from different storage locations and thereafter added to their specific orders at different sections along a moving belt (SSI Schäfer, 2009). However, according to de Koster, Le-Duc and Roodbergen (2007), this kind of fully automated system is only used in special cases, e.g. when dealing with “valuable, small and delicate items”. In addition, and like the earlier presented AS/RS-

system, a fully automated picking system comes with substantial investment costs. Thereby this alternative is most likely not something to use in the automotive industry and when dealing with a sequencing warehouse. This, in combination with the fact that the literature base on the subject showed to be fairly thin, makes it justifiable to go no further than this with fully automated machine picking systems.

### **2.3.2 Picking Support**

The most common support and guidance for order pickers in their picking work is still paper pick tickets, which show what and how much should be picked (Vitasek, 2007). With very manual systems like this, however, the risk for human errors is relatively high. In addition, these systems tend to be less efficient than their more technologically based complements. There are a couple of alternatives when it comes to more sophisticated systems and the following are covered here:

- Combined shipping label/pick documents
- Hand-held radio-frequency terminals or mobile data terminals
- Pick-to-light
- Bar code scanners
- Pick-to-voice
- Pick-by-vision

Vitasek (2007) mentions combined shipping label/pick documents, hand-held radio-frequency terminals and portable label printers, pick-to-light technology and voice recognition technology (pick-to-voice). Combined shipping label/pick documents means that an order is placed in its shipping package immediately when it is picked, at the same time the packing label is attached.

Hand-held radio-frequency terminals are more or less small hand-held computers which receives picking information. The process in this case is similar to the use of paper based picking lists except for the paper. When labels for the picked orders are needed, further time saving may be achieved if the radio-frequency device is combined with a portable label printer.

Pick-to-light, together with pick-to-voice and classical bar code scanners, are presented in more detail by Reif et al. (2010), see Figure 10 for illustrations. In a pick-to-light system a light shows what product to pick. When the product is picked the system has to be told to show the item to be picked next. This can be done either manually, e.g. by pushing a button, or automatically, e.g. by sensors, which sense when a product is picked, at each storage location (Figure 9). The visual aid requires that a small lamp is installed at each storage location, something that makes this solution rather expensive and even unflexible when it comes to changing the warehouse- or picking station layout (Figure 10 (2)). In additions, frequent functional tests need to be performed to make sure that the lamps work and this will add to the maintenance costs. A good thing, however, is that the system approaches the human optical sense, which turns out to be the favored sense when it comes to acquisition of information (Reif et al., 2010). Hence, due to this solid foundation for quick reactions in combination with the high costs, a pick-to-light system is most suitable for order picking stations with a high throughput of items (Reif et al., 2010).



Figure 9. Example of a sensor which feels when a hand picks something from the box (Camillo, 2010).

The bar code scanners, presented by Reif et al. (2010) and shown Figure 10 (1), are usually used together with a mobile data terminal, e.g. the hand-held terminals presented above. The good thing with using a bar code scanner together with a mobile data terminal is a possible reduction in the part of the human faulting factor related to telling the system what has been picked. On the other hand, it is one extra device to carry and handle for the picker.

In a pick-to-voice system the picker gets pick instructions from a computer voice function connected to the warehouse management system (Figure 10). According to Reif et al. (2010) this kind of system has some weak points crucial to consider before an implementation. The main problem arises when the environment, in which the system is to be employed, is very noisy since this will give the picker a hard time hearing what the system is saying. It can also be questioned whether the order picker likes to be told what to do by a monotone computerized voice all day long. On the other hand, Jezierski and du Preez (2009) emphasise the efficiency gains possible from implementing a pick-to-voice system. They say that employee efficiency increases with between 10 and 35 per cent and that the picking accuracy can reach 99,9 per cent. The employee efficiency is largely a result of the hands-free technique provided in the sound system as well as of the fact that the picker does not have to search through picking lists to find the picking information. The picking accuracy increases since the risk of reading the picking list wrong is eliminated. In addition, if the pick-to-voice system can recognize the picker's voice as well, the picker will be able to confirm the picks which further supports the accuracy increase. This is exactly what is possible in pick-to-voice systems with voice recognition. According to Jezierski and du Preez (2009), there are microphones available which can filter background sound so they can better understand what the picker is saying. The picker then has to confirm each pick to the system with, for example, a control number which can be found on the picked product's storage location.



Figure 10. Different picking aids: bar code scanner (1), pick-to-light (2) and pick-to-voice (3) (Reif et al., 2010).

In addition to the above mentioned picking aids there is one more option that is worth to mention here. This option is augmented reality supported picking, presented by Reif et al. (2010). The authors define augmented reality as “a combination of the real and virtual world with 3D registration and which is interactive in real time”. Hence, a virtual reality is used to give the order picker the necessary picking information. This system can be seen as a variant of visual picking support, as earlier presented in the form of pick-to-light. A big difference, however, is that the user of this system, called pick-by-vision by the authors, has a head-mounted display in which the picking information is presented (Figure 11). As shown in Figure 11 this system can also have sound support like the pick-to-sound system. A drawback with this kind of system is that it is fairly technologically advanced, something which comes with a higher price than the other systems presented. Reif et al. (2010) points out that the pick-by-vision system therefore has to provide a better performance compared to the cheaper alternatives in order to be economically justifiable.



Figure 11. Head-mounted display for visual picking support (Reif et al., 2010).

### 2.3.3 Picking Performance

In order to know how a system performs, as well as how to make it better and to see if changes really have any impact, some way to measure its performance is necessary. Different variables, or key performance indicators (KPI's), can be used to measure a systems performance and it is very hard to know if there is a right one. According to Maskell (1989), there are seven principles worth to consider when setting up a performance measurement system:

1. The measures should be directly related to the firm's strategy
2. Non-financial measures should be adopted
3. Measures should vary between locations (departments or companies)
4. Measures should change as circumstances do
5. Measures should be simple and easy to use
6. Measures should provide fast feedback
7. Measures should stimulate continuous improvement

Employing these principles, a wide range of different performance measures can be constructed. However, using too many performance measures can generate tensions within a system, especially if different results are conflicting due to the metrics used being isolated and/or incompatible (Gunasekaran & Kobu, 2007). Another problem might be present in the fact that there is a bias towards financial metrics when it comes to performance measures used by companies (Gunasekaran & Kobu, 2007). With this short background the intention is that it should be easier to relate to the following theory on picking efficiency.

As when measuring performance in general, there is more than one way in which a picking operation can be measured. The key performance indicators relevant for picking operations found in the literature are summarized in Table 1 and are further discussed below.

Table 1. Key performance indicators for picking operations.

Distance travelled by the picker
Picker efficiency
Picking accuracy
Picking cycle time
Picking output
Space utilization
Cost

Looking at the literature, it becomes clear that there is a great focus on identifying the most optimal route when using a warehouse wide picker-to-parts system, see for example Hsieh and Tsai (2006), Daniels, Rummel and Schantz (1998) and Manzour-al-Ajdad, Torabi and Salhi (2012). In addition, the distance travelled by an order picker can be reduced by assigning items to storage locations in a clever way and by batching, or grouping, two or more customer orders together into one picking order (Dukic & Cedomir, 2007; Petersen & Gerald, 2004; Brynzér & Johansson, 1996). Hence, one way of defining an efficient picking system is to say that this is a system where the picker travels the shortest distance possible when completing an order.

Another way, possibly the most common, of looking at picking efficiency is with starting point in the order picker. In more detail this can imply to look at the picking accuracy, as in how many of the orders are delivered as they were ordered, as well as at how efficient the picker is in terms of using the time for picking activities rather than other things like checking what to pick or thinking about obscurities (Jeziarski & du Preez, 2009).

Yet another way to address efficiency, common in supply chain management, is to connect it to time (Gunasekaran & Kobu, 2007). For order picking, this could be throughput time or cycle time, i.e. how quick a product travels through some part of the supply chain, but it could also be expressed as output, i.e. how quick products are coming out of some part of the supply chain. Performance and efficiency in relation to a picking station can also be measured in the area used for the picking operations or how well the available space is utilized (de Koster, Le-Duc, & Roodbergen, 2007).

Last, and connected to the other measures presented here, is the cost aspect which is also frequently mentioned by Gunasekaran and Kobu in their literature review on supply chain performance measures (Gunasekaran & Kobu, 2007). As mentioned above, it is important not to just look at costs but money can also serve as a unit for evaluation of other measures and as a unit for comparison of different alternatives. For example a change can create great results when looking at a throughput or area performance measurement, but if it costs a fortune it may not be the best solution anyway.

## **2.4 SAM-analysis**

SAM-analysis is the abbreviation for Sequential based Activity and Methodology-analysis (MTM-Föreningen i Norden, n.d. b). The methodology has its root in MTM, Methods-Time Measurement, which was first presented in a book with the same title (Maynard, Stegemerten, & Schwab, 1948). MTM is a way to analyze manual work methods and according to the analysis describe the work in an unambiguous and standardized way. With starting point in this description the aim is to identify and evaluate possible improvements of the working method, i.e. to identify ways to work smarter (MTM-Föreningen i Norden, n.d. a).

In Sweden today, the most common way to use MTM in the form of SAM and according to MTM-Föreningen i Norden (n.d. a) this system is quick and easy to use. As indicated by the name, the SAM-analysis is based on sequence thinking which means that the analysis is carried out in the same sequence as the analyzed activities (MTM-Föreningen i Norden, 2006). The SAM system provides a wide range of activities, where grip and place are the basic ones. These are then complemented with activities like bend, step and apply force, and also refined by adding distances, level of precision etc. Each activity is given a specific time based on a time measurement system first developed for MTM. The units used in this system are called TMU's or Time Measurement Units to measure the time, and one TMU = 1/100 000 hour. However, the SAM-system uses a slightly different time unit called a faktor, where 1 faktor = 5 TMU. A more thorough description of the system's parts and structure is provided by MTM-Föreningen i Norden (2006). Using the activities and the time assigned to each of them, in faktor units, it is possible to analyze a work sequence and quantify its performance. More complicated activities cost more in terms of faktors and the system makes it possible to calculate the cost of certain operation and compare it to the cost of performing the same operation in a different way. It also makes it possible to get an objectively determined cycle time for a work without using a watch or subjective judgments of the performance (MTM-Föreningen i Norden, n.d. a).



## 2.5 Lean Thinking

Lean Production was invented by Toyota under the parenting watch of the company CEO Taiichi Ohno, where the Toyota production system is still seen as the ideal production system other industries are striving to achieve (Liker, 2009; Lewis, 2000). The major building blocks of lean thinking are Quality and Just-in-time (JIT), where quality refers to internal quality related to the manufacturing and JIT meaning manufacturing according to customer orders with as little stock as possible (Bergman & Klefsjö, 2010).

Lean thinking is about eliminating/reducing waste in a production system. By noticing defaults in the production immediately using poka-yoke (refer to section 2.5.2 for poka-yoke information), a high quality production system is ensured along with less resources wasted (Liker, 2009). Womack and Jones (2003) describe lean thinking as a way of maximizing the production in the company by minimizing the usage of resources and at the same time manufacture according the idea of a pull system, meaning nothing is produced without a customer order. Lean thinking is about reducing waste and maximizing the resource utilization, with a strong connection to the customers. Lean is a philosophy that requires the entire organization to be a part of, and fully commit to, the way of thinking and the implementation requires five steps defined by Womack and Jones (2003) as follows:

- Define the customer value
- Define the flow of value
- Strive for a stable and even flow
- Produce according to Pull
- Aim for the highest quality.

Jones, Hines and Rich (1997) states the importance of seeing the entire supply chain as a system in need of lean thinking in order to achieve pleasing results and not just implement lean into one sub-system. The philosophy, as mentioned above, is built on finding activities that add value and ideally eliminating those that do not. According to Jones, Hines and Rich (1997) the percentage being value-adding activities are only five in a common factory; the rest is considered waste, which will be further explained in the next section.

With standardized work and continuously dealing with prevention of errors playing a major part of the Toyota Production System (TPS) and the lean thinking, it is also very important for the philosophy to have a process which to use in order to find the root cause of problems appearing. Minoura, a former managing director of global purchasing at Toyota, explains the possibilities in finding the root cause by asking five why's whenever a fault appears in a production process (Toyota Motor Corporation, 2003). He further states that, keeping the aim of the TPS of lasting cost reductions in mind, it is not the faults of the products that need to be placed in the spot light, but rather finding the root problem within the production process causing the faulty products. At last, when using the five why's it is very important to focus only on what has happened in the actual process. It is here the root cause of the problem is to be found, rather than in the workers own deductions (Toyota Motor Corporation, 2003).

### 2.5.1 Waste

Waste, also known as the Japanese word Muda, can be found everywhere in an organization and refers to activities that add no value to the customer. In order to eliminate or reduce waste the term

must be defined as to what it includes. Ohno identified seven types of waste within a factory (Jones, Hines, & Rich, 1997):

- Waiting
- Producing without order
- Rectification of mistakes
- Over-production
- Excess movement
- Excess transport
- Excess stocks

Waste can further be divided into non value-adding but necessary and non value-adding and unnecessary activities. Despite the part of the operations being essential the necessary activities should still be regarded as waste considering resources are being consumed without adding value (Finnsgr ard et al., 2011). Having a very large portion of the manufacturing regarded as waste makes it hard to categorize value-adding activities. However, activities dominating the value added in the manufacturing process are performed in the assembly of the products.

### **2.5.2 Poka-yoke**

Poka-yoke is the Japanese word for fail-safing and it is used to ensure a high level of quality within the finished products. A poka-yoke is a mechanism in a manufacturing process using lean thinking that helps an equipment operator avoid (yokeru) mistakes (poka). The purpose of the mechanism is to eliminate defects within products using prevention, correction or by appointing error made by operators at the time of occurrence. Companies embracing the lean thinking have a mechanism placed at each working station in the manufacturing factory (Liker, 2009). Each device has its own standardization on what fault to discover, what corrective measures to take, how often to confirm the device is working properly and how to alarm when the device needs to be exchanged. Poka-yoke is a very common device and method used across industries to ensure quality with the products (Liker, 2009).

## **2.6 Materials Flow Mapping**

Materials Flow Mapping (MFM) is a process for mapping material flows in order to identify unnecessary activities and possible movements. It builds on Value Stream Mapping (VSM) with the difference that it is applicable also in cases where the activities are not directly value adding. MFM was developed with focus in combining requirements on the assembly system, set by the end customer, into a support for the same system. In the assembly, the materials supply system has to maintain, and also improve, the efficiency of the system. VSM was developed as a toolkit to be used when improving production and also when implementing the improvements. Due to the lack of focus on non-value-adding but necessary activities in VSM, MFM was recently developed (Finnsgr ard et al., 2011). The MFM methodology can be seen as a spin-off from VSM and the mapping consists of several steps. To start off the mapping a definition of the improvement system is required, followed by a mapping and assessment of the current system. The method finishes with an implementation of the improved system. MFM is a further development of the two first phases in the value stream mapping toolkit. The process of the MFM consists of seven steps, which are each presented below.

*Set a scope:* As it is very important to set a scope for the project early on the first step is a means for deciding on an object and also the requirements for the project set by the end-user. The areas to establish requirements for are attributes, functions, settings, behaviors and properties needed in order to achieve set goals.

*Data collection:* Important and relevant data for a project is gathered using video recording and conducting interviews. The recording must provide timestamps of all relevant activities in the process in order to be able to follow the items upstream.

*Compilation of collected data:* A compilation of the data collection is made with aim of creating a visualized schematic view of the flow.

*Analysis of videoed process:* The video recording is analyzed with the purpose of constructing an MFM along with the activities recorded.

*Compile MFM:* A compilation of the constructed MFM is done to be able to identify earlier set requirements as well as a description of the process. The performance of the material flow is described through four dimensions: Productivity, Quality, Flexibility and Sustainability.

*HATS-analysis:* An analysis is made with regards to the four main categories – handling, administration, transport and storage – summarizing data consisting of number of activities, the total timing for the categories and the averages.

*Re-iterate:* In discussion with involved actors and the case company the procedure can be re-iterated until all data required is gathered and the compilation is validated.

The result is expressed through the earlier mentioned four dimensions describing the performance of the material flow. By doing so, it is not the performance of the supply chain that is being measured but the performance of the material flow, indicating how well it meets the set specifications and performance requirements. For example, the MFM might show that the material spend a considerable amount of time in storage and hence not meeting set requirements as it ties up more capital than it should. A conceptual sketch of a MFM result is shown in Figure 12. Each box represents an activity in the material flow, the letters represents the components of the HATS-analysis and the time line below the boxes presents the time occupied by each activity.

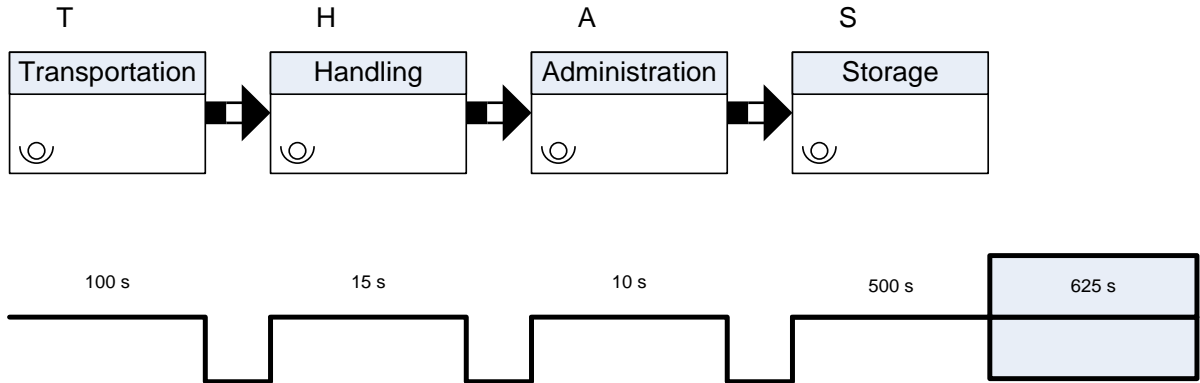


Figure 12. Example of MFM result.



### 3 Methodology

This chapter presents the design of the study used to answer the research questions presented in section 1.2.4. Generally speaking, a qualitative research approach is taken as there are not much quantitative data available as well as the data needed mainly constitutes of experiences from industry practitioners and ideas from academic research. The chapter starts off by an outline of the general research design and thereafter follows more detailed explanations of the different activities undertaken throughout the project. The chapter is concluded with an overall assessment of the validity and reliability of the chosen methodology.

#### 3.1 General Research Design

The process shown in Figure 13 illustrates the general outline of the methodology used in this thesis.

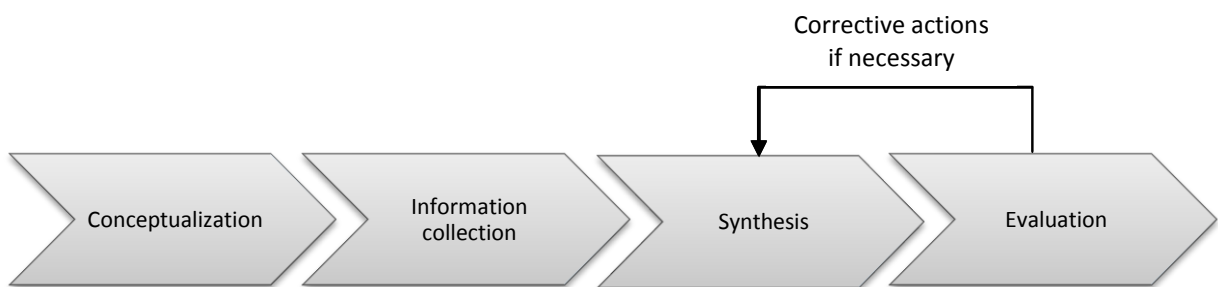


Figure 13. General outline of the research methodology used for the thesis work.

The purpose of the first phase, the conceptualization phase, was to get an understanding of what order picking in an automotive sequencing warehouse really means and how these very operations relate to the big picture of a car assembly plant. More precisely, the focus was on understanding the case company’s picking operations. This phase included some general reading on the topic, but the main contribution came from a couple of days spent at Volvo with interviews and observations of how the operations are carried out. As mentioned above, the idea was to get familiar with the processes, but also with the facilities in which they take place.

In the second phase, the information collection phase, information that was thought to be of help when answering to the research questions were gathered. This was done through a literature review, as presented above, and site visits combined with interviews and observations. Item characteristics of possible use for the classification system were proposed and possible picking station designs were mapped, which is presented in the empirical findings chapter (chapter 4).

In the third phase, the synthesis phase, ideas from the information collection phase are evaluated and synthesized to some guidelines for designing, or improving, picking stations. These guidelines consists of a classification system and, connected to the classes, a number of areas, or ideas, related to picking stations, which can be used when looking to improve picking performance with a main focus on area efficiency.

In the fourth and last phase, the evaluation phase, some of the proposed solutions are virtually tested on suitable picking stations at Volvo in order to validate their potential. In addition, the guidelines are discussed with supervisors and representatives from Volvo in order to identify possible improvements. After the evaluation, corrective actions are taken and, if necessary, a new evaluation

takes place. This iterative process is illustrated by the feedback loop in Figure 13, and was carried out as many times as necessary to ensure a good outcome of the work.

The methodologies used in each of the phases described above are presented in more detail below. First, the data collection techniques used are presented and thereafter follows the methodologies used to create the picking station design guidelines.

## **3.2 Data Collection**

There have mainly been two goals for the data collection in this thesis. The first was to understand the process in which a sequence picking station is a part, what the role of the station is and how the work at the station is carried out. Also alternatives available to picking stations and why picking and sequencing is necessary needed closer examination. The second goal was to get ideas, to see different ways of how to solve the picking problem related to sequencing, in order to thereafter be able to construct both a classification system for the items to be picked and a range of different picking station designs for the different item classes.

Data has been collected from an extensive literature review as well as through site visits combined with interviews. Hence, the data collection techniques used can be summarized as interviews, observations, and use and examination of existing academic knowledge. Also, the data gathered is mainly of the secondary type, with the exception of own observations at site visits and data collected for the Materials Flow Mapping, which is primary data. The following three sections present the different parts of the data collection process in a more detailed way.

### **3.2.1 Literature Review**

In order to get all background information needed to fully understand the problem, a thorough review of available literature is of great importance. With a literature review, a broad information search of other's work on the same, and closely related, issues is performed. This since gaining knowledge of already existing solutions is crucial in order to be able to contribute with new knowledge.

For the literature review to be as effective and structured as possible, it was very important to map up a clear strategy from the very beginning. This strategy included a search phrase strategy as well as to search in a variety of sources like libraries and electronic databases. As for the databases, remembrance of using more than one is critical considering one database rarely concludes with all possible answers. Instead looking through several, the percentage of missed out information decreases and the percentage of gathered valuable information increases.

Performing the search by structuring the search phrases is a good way to start. By doing so, a wide range of relevant phrases can be formed and extended as the search goes on. Starting off with a single phrase search a wide range of results may be received. The search phrase can further extended using double search phrases, which can then be extended into a triple search phrase narrowing the result down even further gathering only the most relevant journals or research articles, Table 2 This was repeated over several databases using the same search pattern; see Appendix A for more detailed information regarding the searches.

Table 2. Examples of search phrases.

<b>Single search phrase</b>	Picking station*
<b>Double search phrase</b>	Picking station* AND layout
<b>Triple search phrase</b>	Pick* AND auto* AND layout

\* = open ended word. AND = logic command.

In addition to the literature search, in contact with persons performing research on the subject in matter, access have been granted to yet unpublished material directly related to the problem of this master thesis. Through the same persons, sources of information have also been recommended, information which showed to be of good value for the background knowledge. At last, Volvo has also provided information important for the understanding of the current situation within the company and their way of working.

All information gathered has been carefully analyzed through visual inspection, comparing the relevance of the literature to the subject of this thesis. After reading through all the material that was found to be of use for the thesis, conclusions were drawn from the interpretations of what had been read.

### 3.2.2 Interviews

To gather real world information, interviews and site visits have been carried out with a couple of different actors with operations relevant for the thesis project, see Appendix B for a detailed list. Interviews and personal contact with people working in different organizations is a central part of a qualitative study and despite some criticism of this technique it was found to be the best way to acquire knowledge even in this project; especially as there is not much written information available in the area of interest. Some critics question the assumption that interviews are about mediating knowledge as they claim that the interview might tell more about role play and adjustment to social norms than about the actual reality surrounding the interviewee (Alvesson, 2011). It is also important to mention that the material gathered from interviews is very limited, as events unknown to the interviewees will be omitted (Alvesson, 2011). On the other hand, interviews and observations can be a very good start to get to know a process and even the only way to get information about certain interesting events or issues. Without saying the method is wrong, being aware of criticism like this is crucial when using the method. With this in mind the interview methodology has been used with care and the information acquired has been critically evaluated before being used in the thesis.

The interviews carried out in this project were semi-structured. This is an interview type that gives the interviewer the freedom to adjust the interview to the prevailing circumstances as it proceeds, but still in a structured way, e.g. by using some guiding questions, in order to ensure nothing important is left out (Alvesson, 2011). When the interview guide was formulated, three interview design issues raised by Karlsson (2010) were considered. The first is that one should move from general questions to more and more specific ones. For illustration, the questions can be thought of as that they should form a funnel. The second is that one should move from neutral topics and hence wait with more sensitive questions till the end of the interview when the relation to the interviewee hopefully has developed in a good way. The third is that one should start with questions on facts and save questions that require reflection and evaluation to the end of the interview. The questions used as the base for the interviews are shown in Appendix C. However, as the interviews were semi-

structured, and thus the interview guide not always strictly followed, the three issues just presented were considered also when the actual interviews were performed.

In addition, the lean principle of “five why’s” was kept in mind. It was not that five why’s were to be asked after each question but when creating the questions and, more important, when the interviews were performed the principle of really digging down to the root cause of the answer to the question was used. For example, it was very important to know why a picking station looked like it did. What was in thought when the station was designed? Why? And so on. The employment of this tool was thought to provide the authors with a thorough understanding of the present situation and its available alternatives as well as a sound platform for the rest of the thesis to stand on. When using the five why’s, it is also of great importance to be aware of the fact that if too many “why’s” are asked, or if the answers to each “why” are too extensive, you run a risk of being confused by all the information and by that find it hard to identify the actual root cause (Toyota Motor Corporation, 2003).

At last, the interviewees were selected with help from our supervisors at Chalmers and Volvo. The aim was to interview people from different companies and even in other industries than automotive, in order to get different viewpoints on the topic as well as to see different kinds of solutions to the picking issue related to a sequenced material flow. Interviewees within Volvo were also added as the thesis project evolved and the need for new input arose.

### **3.2.3 Observations**

An important part of the thesis, and closely connected to the interviews described above, were observations made in connection to the interviews. To fully understand what the interviewees were talking about, the picking operations were observed and documented in form of the drawings presented in the empirical findings of this thesis (chapter 4). These observations were nothing more than observations accompanied with the story told by the interviewees. However, another type of observation was also carried out during the project, observations that are closer explained in the following section.

### **3.2.4 Data for Materials Flow Mapping**

As previously described, the mapping of the material flow begins with relevant data being collected for later analysis. Collecting the data, tools such as a video recorder and a stop watch should be used. The filming records all data required for the analysis performed later on. However, as the mapping was limited to single picking stations, the recording was exchanged for using stop watch only. This as the relevant information to be gathered for this thesis was an approximation of the timestamps for the activities performed within a picking station.

Data was also collected through direct observations of the material flow, as well as through semi-structured interviews, as the mapping was made. The direct observations covered data collection within the areas of material handling, administrative activities, storage and transports.

## **3.3 Item Classification**

To put together a number of properties according to which it could be useful to classify items in a sequencing warehouse in the automotive industry, the information collected through the above presented methods of a literature review, interviews and observations was used. When a number of properties had been identified, each was evaluated in terms of its thought impact on the design of



the warehouse's picking stations. The properties that are thought to have an impact on the design of the picking stations were thereafter analyzed in relation to each other in terms of mutual influence and importance, such as which should be considered first and how they will affect each other. Taking their respective impact on picking station design and their relations into consideration, the properties are presented in the form of an issue tree.

### **3.4 Picking Station Design**

The information collected through the above presented methods of a literature review, interviews and observations served as a base for developing ideas for analysis, and possible new designs, of picking stations. By using the collected information as a point of departure, brainstorming as well as analysis of existing layouts and item characteristics according to the item classification presented above was employed to suggest picking station design improvements. In order to validate the work, some of the ideas were applied to picking stations used in Volvo's TB1 sequencing warehouse at the Torslanda factory.

### **3.5 Materials Flow Mapping**

The Materials Flow Mapping (MFM) tool was used to illustrate some of the proposed changes' impact on existing picking stations at Volvo. The use of MFM should be seen as a complement to estimated area savings, which is the main focus in this thesis, when assessing the outcomes of implementing a certain design change. A conceptual MFM for the picking stations used by Volvo was sketched, as was MFMs for picking stations modified using some of the proposed design considerations. With point of departure in the MFM for the present picking stations, the effects of the proposed changes on the activities performed at the picking station was evaluated and discussed.

### **3.6 Validity and Reliability**

According to Bryman and Bell (2011) there exist many definitions of validity and reliability. As many of these measures have their roots in quantitative research, some writers argue that they are inapplicable to, or inappropriate for, qualitative research. However, others argue that the measures, with slight changes, are applicable even for qualitative research. Hence, some of the measures presented by Bryman and Bell (2011) are here used to assess the validity and reliability of the work presented in this thesis. More accurately, four aspects of validity and one of reliability were chosen to be included. The four aspects of validity discussed are construct validity, internal validity, external validity and ecological validity.

Construct validity is concerned with the question of whether a measure used actually measures the concept of interest (Bryman & Bell 2011). Internal validity is concerned with how believable, or trustworthy, the findings are and it also relates to causality, i.e. can we be sure that it is input A and input not B that gives output C (Bryman & Bell, 2011). External validity is concerned with the question of whether the results from a study can be generalized beyond the context of the particular research from which the results are the outcome (Bryman & Bell, 2011). Ecological validity is concerned with whether the findings from a study are people's everyday, natural social settings (Bryman & Bell, 2011). Reliability is concerned with whether the findings from a study are can be replicated using the same method all over again (Bryman & Bell, 2011).

The construct validity of this thesis can be considered high as the focus on area is very clear and thereby measuring the outcome of the ideas presented in the same unit is not considered a problem.

However, one should be aware of the sub-optimization problem present in looking at only one measure and if broadening the scope the area would not be enough to account for the outcome and in that case the construct validity would be a bit lower. To partly counteract this, and increase the construct validity, material flow mapping is complementing the area as a tool to evaluate some of the ideas presented in this thesis. The internal validity can be considered high, given the design of the research as presented above; including a literature study, interviews, reference company visits and a clear process to guide the work. The external validity can be considered low to medium. The information gathered comes from different sources but there is a bias towards Volvo. In addition, references in terms of other companies within the automotive industry are limited. On the other hand, the sequence picking problem itself is fairly limited to the automotive industry as well. Concluding, more research has to be done to ensure the external validity and hence it cannot be seen as more than medium. The ecological validity can be considered medium as there are many different stakeholders involved. Decision makers' may not be directly affected by the changes they decide to implement so it would be wrong to say that the ecological validity is high. On the other hand, the work takes into consideration things such as work environment and ergonomic effects, and hence some kind of ecological validity is present.

At last, the reliability can be considered medium. The environment in which the study has been undertaken is constantly changing and developing but it is most likely possible to get the same kind of findings if the study were repeated with the same, or even different, companies. What goes against the reliability is that the study might have been too concentrated around Volvo and, as mentioned above, more reference companies might add value in terms of reliability to the findings. On the other hand, the methodology used is thoroughly described in terms of how data has been collected and processed, what questions have been asked and which techniques have been employed, something which enhances the reliability and the possibility to replicate the work.

## 4 Empirical Findings

In this chapter the empirical findings from the thesis project is presented. First the findings regarding classification of items are presented. This is followed by a presentation of how the picking operations are presently performed at the case company Volvo's Torslanda plant. The chapter is completed with a presentation of picking operations carried out by six reference companies visited during the work on the thesis.

### 4.1 Item Classification

There has recently been a classification made for items connected to the assembly at Volvo by Volvo in collaboration with Chalmers. This segmentation is as shown in Table 3 below.

Table 3. Segmentation proposed by Volvo and Chalmers.

Segmentation with respect to:
Pick one by one
Pick many at a time
Scoop/Pour
Ration packed, e.g. in bags
Orientation sensitive

These segments are mainly used when working with downsizing operations but they might also be useful for a classification system focused on sequence picking operations.

Further, a couple of possible segments with respect to characteristics which could have an impact on the design of picking stations were identified through the site visits and interviews. These are, together with their likely impact on the picking station, presented in Table 4 below. Some of the characteristics presented in this table are the same as, or similar to, the ones already proposed by Volvo and Chalmers, but below their likely impact on the design of the picking station is added.

Table 4. Item characteristics and their likely impact on picking station design.

Segmentation with respect to:	Likely impact on the picking station design:
Item weight	Ergonomics and the need for handling equipment.
Item size	Space requirement in the station.
Number of variants	The size of the picking station.
Pick or pour	Required handling and necessary picking aids.
Multi-picking possible	The efficiency of the station.
Ration packed, e.g. in bags	The picking operations, e.g. ergonomics
Orientation sensitive items	Need for space in the station and complexity of the picking.

### 4.2 Picking Operations at Volvo

As explained in the introductory chapter Volvo has a warehouse, called TB1, where both storage and picking is located. With the impossibilities of expanding the building due to an increased amount of items used in assembly, the main focus has instead been on better utilization of the space within the existing building. As mentioned earlier, Volvo has plans on outsourcing part of the storage and the focus has, thereby, been towards developing better utilization of area/space in the current

picking stations. In order to be able to create a more area efficient usage of the stations, an understanding of the current situation in TB1 is of great importance.

The items, stored and sequenced in TB1 are delivered from distributors to the entry of the warehouse from where the goods is transported to storage locations in the warehouse for later use in picking stations. Part of the storage is located on the warehouse floor, while other parts are stored on pallets on shelves or stored in racks for the returnable plastic boxes. The picking stations, in which the sequencing is performed, are located at the bottom of each pallet storage rack (Figure 15). The warehouse stores, and performs sequencing of, roughly 2000 items.

Currently in TB1 the picking stations are designed for picking to sequence racks (Figure 14). The racks, with numbered pigeonholes, are placed in the middle of each picking station and when filled they are transported directly in to the assembly line. The picker follows instructions using pick-to-voice, a system instructing what item to pick by telling a number pre-assigned to each item. The picker then has to confirm that the right item has been picked using one out of three check numbers for each item. The picker is then told, by the pick-to-voice system, to place the item in one of the numbered pigeonholes.

The items in the picking stations are placed according to the frequency of use. The most frequently picked items are placed opposite the racks or next to, classified A in Figure 14. The picking station is also designed carrying the more heavy items in an ergonomically friendly height and the lighter items above. The less frequently used items are places in the far ends of the station, classified as C. Picking aids are available at the stations with items that may require aids, creating a more ergonomic environment for the picker. The lifting equipment available for the picker are mounted in the ceiling, which makes the stations very inflexible regarding re-designs and potential movements being made of the station.

The picking stations are coordinated in order to shorten the cycle time for the picker to walk between different stations. It is the tact time of the assembly line that determines what stations that can be matched to the same picker. The picker then circulates between the assigned stations during the work shift.

Material presented to the picker  
on pallets or in plastic boxes.

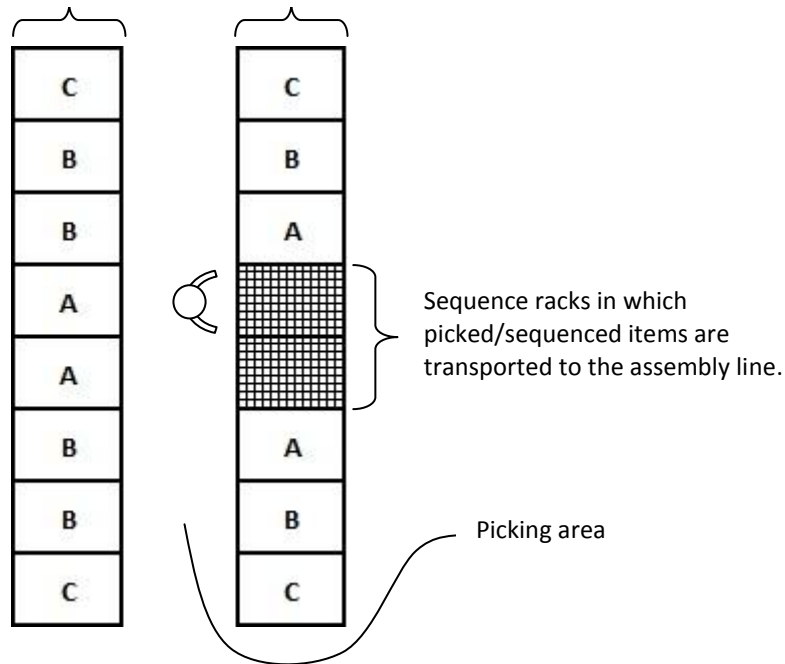


Figure 14. Picking station used by Volvo in TB1 at Torslanda.

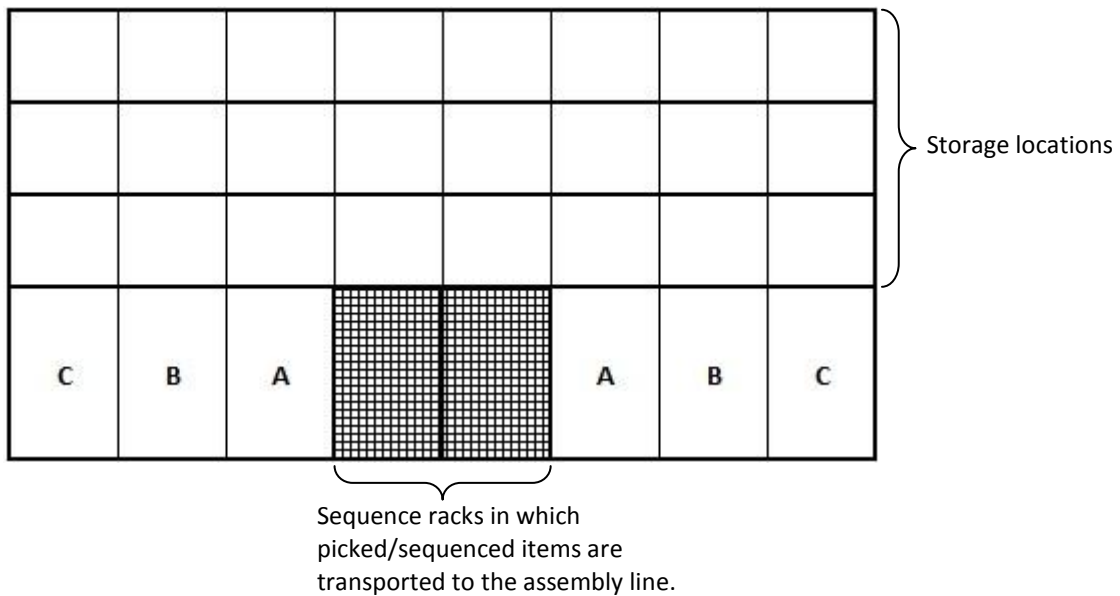


Figure 15. Side view of Volvo's picking station.

### 4.3 Picking Operations at Reference Companies

In the following sections, practical order picking solutions observed and discovered during site visits and interviews are presented. In total six companies in different industries were visited.

#### 4.3.1 Pininfarina Uddevalla

Pininfarina in Uddevalla is a small factory producing the C70 model for Volvo. The plant assembles roughly 10 000 C70's per year, which is just a fraction of Volvo's total production, and contains only

one manufacturing line. The items used at the various stations along the line are delivered to each station in racks and in plastic boxes. As for the boxes, each box is assigned to a specific car. Hence, the boxes are sequenced while their content consists of a number of different items belonging to the car in question. The warehouse consists of both a storage system, with pallet storage racks, and picking stations. 28 different items are sequenced in sequence racks and 250 are picked in plastic boxes, with a system well correlating to the theory on picker-to-parts (section 2.3.1.1).

Material delivered to the entrance is taken care of by personnel operating trucks, relocating the pallets from the entrance into the storage system. Not all picking stations are located beneath the pallet storage. Sequencing stations requiring lifting equipment are placed openly on the floor, while items stored in plastic boxes are stored on ledges in rows.

There are two different layouts for the picking stations in the warehouse, one for sequence picking in racks and one for kitting in plastic boxes. The former is used for larger items, often requiring lifting equipment and the latter is used for smaller and lighter items e.g. car handles and items re-packed into plastic boxes.

The sequencing stations are designed with respect to picking frequency (Figure 16). The most consumed items are placed closest to the sequence racks, later transported to the assembly line, while the less frequently picked items are placed further away. The picker is picking according to a paper order, from which the picker is manually reading and checking off.

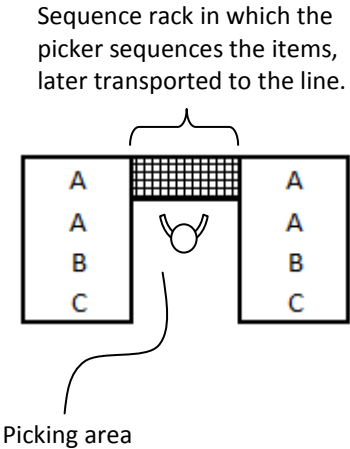


Figure 16. Pininfarina’s picking station design used for sequencing.

Regarding the kitting stations the layout has been planned according to two variables; picking frequency and similarity in shape and color. Different to the sequencing stations, the items are placed in three rows, where the items most frequently picked are placed in the middle row enabling easy picking for the operator (Figure 17). In addition, items with similar or same shape/color are never placed next to, above or below each other to prevent the picker from picking the wrong variant e.g. a left blue handle instead of a right blue handle.

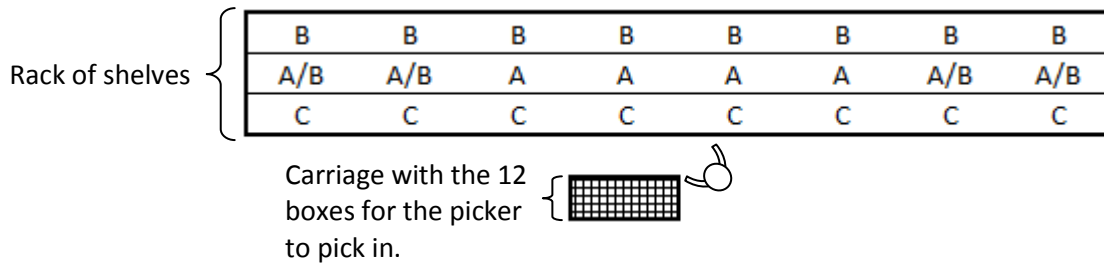


Figure 17. Pininfarina's picking station design used for kitting.

The picker receives an order on what to pick both on paper and on a small computer on a carriage connected to a truck driven by the picker (carriage and truck can be seen in Figure 18). The carriage consists of 12 boxes (Figure 18), illustrated on the screen of the electronic device to enable the picking and reduce mistakes (Figure 19). The number of each item to be picked of each item is shown on the screen in the equivalent box to the one in which the item should be placed. After finished picking each item group, e.g. the handles, the picker has to confirm and deliver the orders to the assembly line before moving on to the next pick. There is a total time of 30 minutes in which the picker has to finish one order and deliver to manufacturing.



Figure 18. Hand-held truck with attached carriage used in the picking process

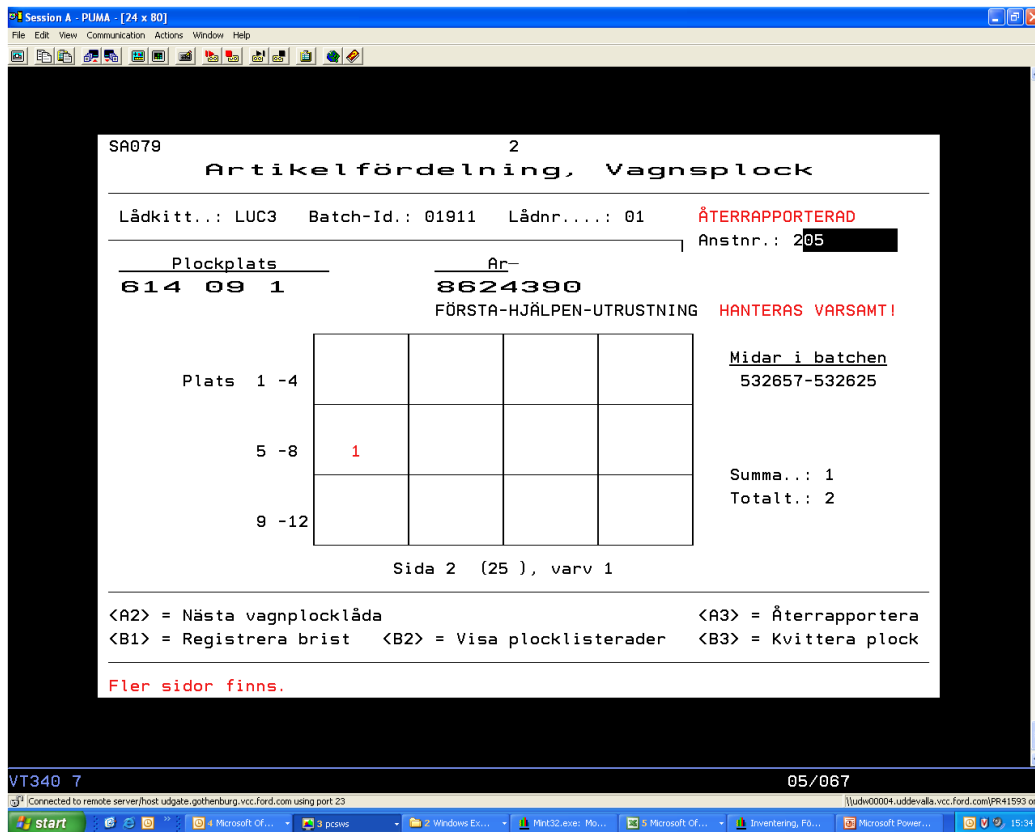


Figure 19. Screen shot from the electronic device illustrating the boxes and how many items to be picked in each box

### 4.3.2 Tamro Gothenburg

Tamro is a large pharmaceutical wholesaler with mainly two operational areas. One is acting as a middleman for pharmaceuticals sold to pharmacies and the other is to provide storage to pharmaceutical producers who are selling their products to hospitals and similar institutions. The biggest difference between the two areas is that as a middleman Tamro takes title in the products as well as they perform more advanced picking operations while as a warehouse provider they do not own any products and the products are shipped in larger volumes on pallets, making the picking operation less complicated.

The type of picking station used when Tamro acts as a middleman is illustrated by the conceptual drawing in Figure 20. This is more or less exactly what is described as pick-to-belt under picker-to-parts in section 2.3.1.1. Plastic boxes are travelling around the warehouse on a conveyor belt and pushed off the belt at each picking station from which one or more products should be added to the order connected to the plastic box. The pickers get information of what to add to each box from a hand-held computer with a bar code scanner. They simply scan the box they are about to fill and the computer provides the picking information for that specific box. Each picker works along a station of several meters and the material is presented in quite small quantities, due to many variants and traceability requirements, above and under the conveyor belt as well as behind the picker. The material behind the picker is presented on pallets or in bigger unit loads due to its high appearance in different orders. At last, the material is positioned along the picking station according to its frequency of use; hence A items are used more frequently than B and C items in the figure.



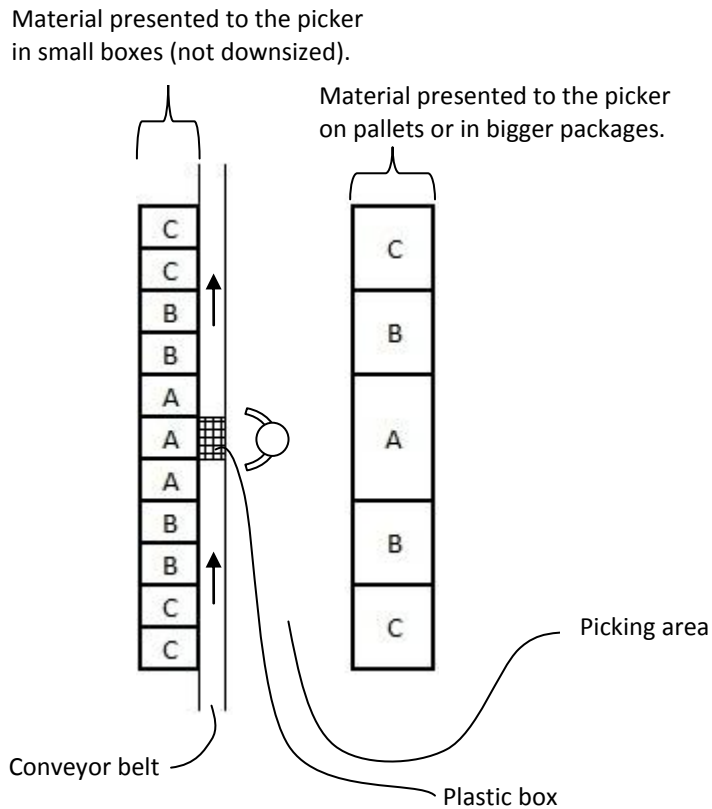


Figure 20. Picking station used by Tamro when they act as a middleman between pharmaceutical companies and pharmacies.

When Tamro acts as a warehouse provider for pharmaceutical producers they use a different picking layout, which is illustrated in Figure 21. In this case an AS/RS-system to bring pallets from a high storage to the picker, which is shown to the left in the figure. The picker takes what he needs from the pallet where after a new pallet with other products is presented to him. The picker places the picket products on a pallet which is to be delivered to the customer; this can be seen to the right in the figure. When the pallet is ready it is transported to the outbound delivery area and a new, empty, pallet is presented to the picker.

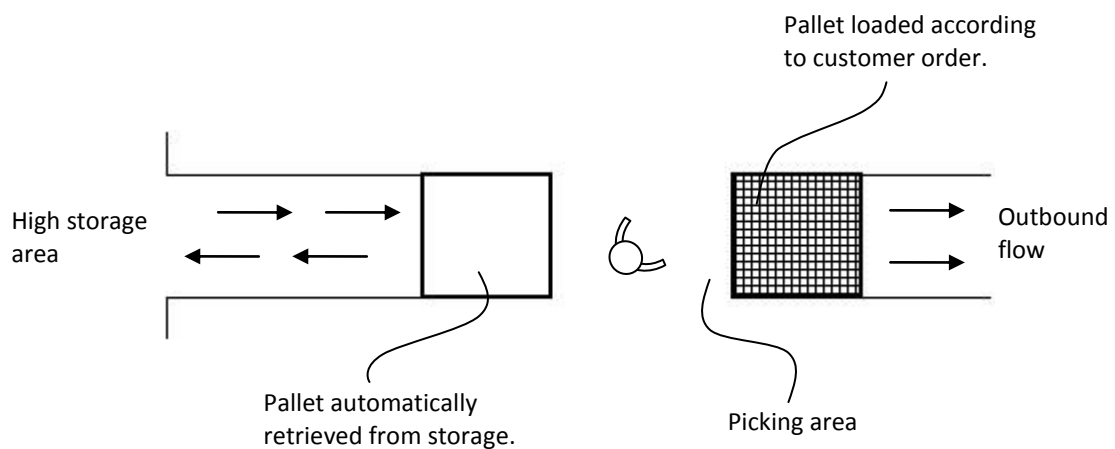


Figure 21. Picking station used by Tamro when they act as a warehouse provider for pharmaceutical companies.

At last, Tamro measures its performance in terms of picking accuracy, i.e. how many orders or order lines are picked and delivered according to what was actually delivered. Even very small inaccuracies automatically generate extensive action plans. Also space utilization is, however, important as the number of products handled recently has increased quite dramatically due to the privatization of Swedish pharmacies and the earlier mentioned traceability requirements. The new actors on the pharmacy market has also put new requirements on output capacity as new order peaks has appeared due to changing opening hours.

### **4.3.3 Carlsberg Falkenberg**

Carlsberg in Falkenberg is a brewery producing foremost beer but also cider, soft drinks and still drinks. In connection to the brewery is also a warehouse keeping about five days' demand of finished products. In addition to the drinks produced in Falkenberg and drinks from other Carlsberg facilities, the warehouse is also holding products for which Carlsberg is the distributor for the Swedish market.

The nature of Carlsberg's products calls for somewhat different picking operations compared to what is presented above. Tamro is also distributing to many different customers, but the more heavy products handled by Carlsberg has made them choose a different layout, of which a principle sketch can be seen in Figure 22. However, Carlsberg has considered a more line-like layout for the picking with a pallet travelling along a conveyor belt passing by different picking stations with different products. This system would then have been a pick-to-belt system, as presented in section 2.3.1.1. Even though considered, and still under consideration by some of the personnel, the system was thought to be too much of a change for the organization and its systems, and also a bit complicated with respect to the products and the many changes in the assortment. The change aspect was also connected to the fact that this kind of system is seen as more space consuming, space which is not available in the existing facilities.

The picking of today is carried out manually by pickers travelling around on small forklifts, as illustrated in the figure. The products are presented to the pickers on pallets. Different kinds of specially designed, roof mounted, lifting equipment are available at every picking location as ergonomics is a central concern for the organization. Each order is picked onto a pallet which after the picking is manually wrapped in plastic at the end of one of the product rows and left in one of the outbound goods areas. The pickers get the picking orders on a computer on the forklift. The orders are planned according to a route which follows an S-shape through the aisles in the picking area. However, the picker can ignore the route and take another one if that for some reason is better, e.g. due to better stacking of the picked products on the pallet. This stacking itself is also an interesting issue. If the picker gets a complicated order, i.e. an order with a lot of products which still can fit on one pallet, it becomes a skill to stack the pallet and if the puzzle does not turn out well the picker has to take on the unwanted extra task of re-stacking the pallet.

Concerning the layout of the whole picking area items are positioned according to their frequency of appearance on order and the amount of which they appear. More frequent articles, A articles, are placed closer to the plastic machines, which is also closer to where the finished pallets are left, illustrated by the "outbound flow of pallets ready for delivery" in Figure 22. The frequent ordering of these products, together with larger quantities ordered, calls for more pallets in picking position. This is illustrated in the figure by bigger areas for A articles than for B and C articles. Worth to mention is

also that Systembolaget has its “own” rows, as drinks with higher alcoholic content cannot be sold to any other customer in Sweden.

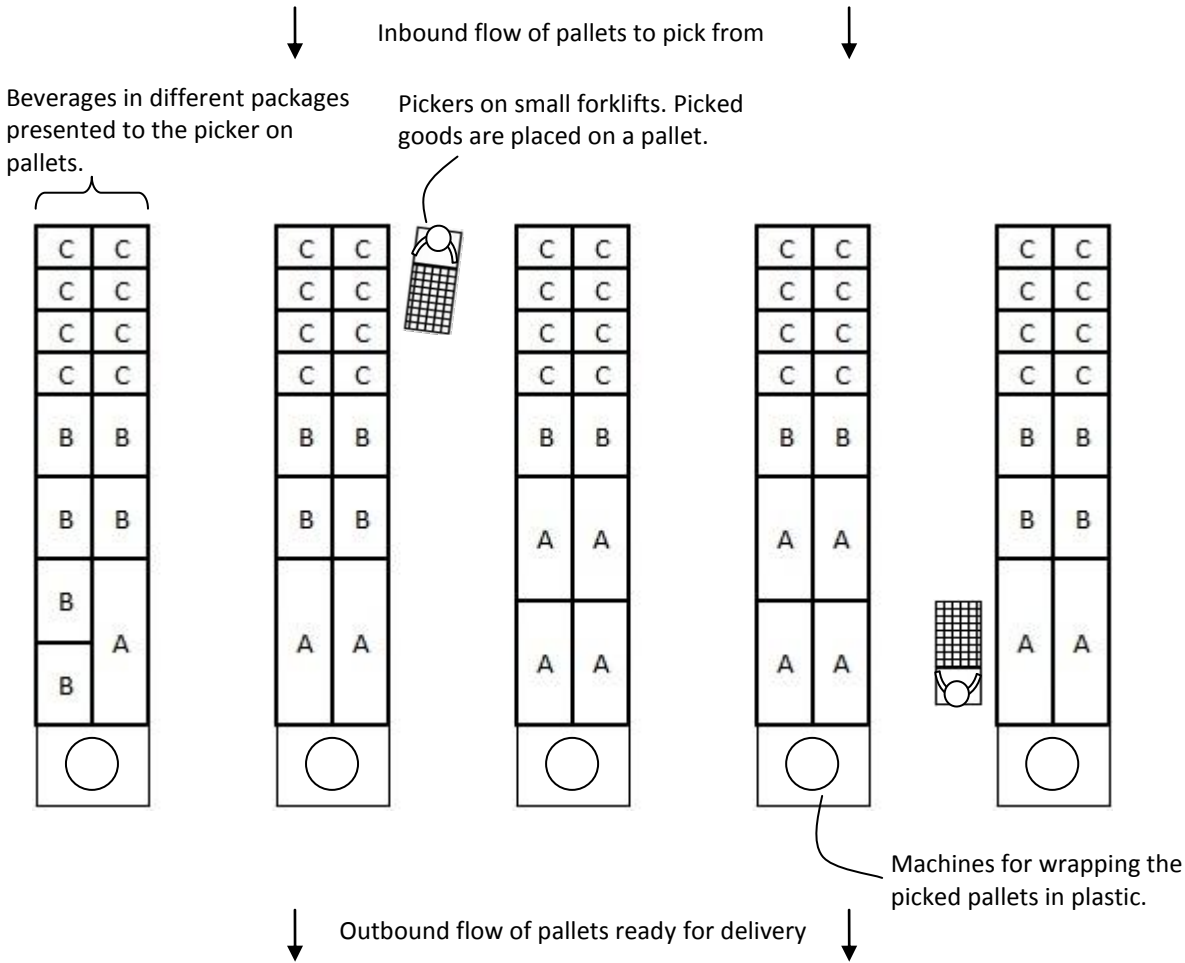


Figure 22. Picking area layout at Carlsberg in Falkenberg.

**4.3.4 Schenker Gothenburg**

DB Schenker Logistics in Mariefholm in Gothenburg is a part of DB Schenker, one of the world’s largest third party logistics providers. The operations performed in the warehouse mainly consist of storage and picking operations of products belonging to Nissan, providing spare parts to Sweden and Norway. The products range from small screws to big interior parts as well as car windows and are about 20 000 different items.

The warehouse is divided into two divisions, indicated by the wall in Figure 23, where all the larger and heavier items are placed in one part and the lighter, smaller and medium sized items are placed in the second division. During the first half of the day, unpacking the goods delivered to Schenker is performed, while the second half of the day is used for picking.

The picking area is divided into three zones; small, medium and large item zone as indicated by S, M and L in Figure 23. The items are placed in a zone depending on their size and weight. The small item zone can contain items such as screws or items that can fit on wagons. As for the medium item zone, the items are a bit heavier and larger in size. The picker may, in this area, have to perform one order in two routes. Last, in the large item zone, items which are big and heavy to handle are kept together. For this picking, a type of forklift in which the picker stands on the elevating part, here

referred to as an elevating forklift, is used. In all three zones the picker uses printed order tags to read what item to pick checking the article number on the tag compared to the shelves manually.

The small item zone consists of high metal racks, where the items are placed in the shelves depending on free space. The rack of shelves are also placed in two stories, where the picker self uses forklifts to transport a picking wagon with items up and down. In the medium item zone, all items are placed on the floor and the most frequently used items are placed closest to the consolidation area in order to facilitate the picking for the picker. In the large item zone, the pickers move around in the picking area using elevating forklifts, onto which the items are picked for later placement onto pallets. This zone consists of many high pallet storage racks in which the items are stored both in buffer storage and in picking positions in smaller quantities due to the large item sizes.

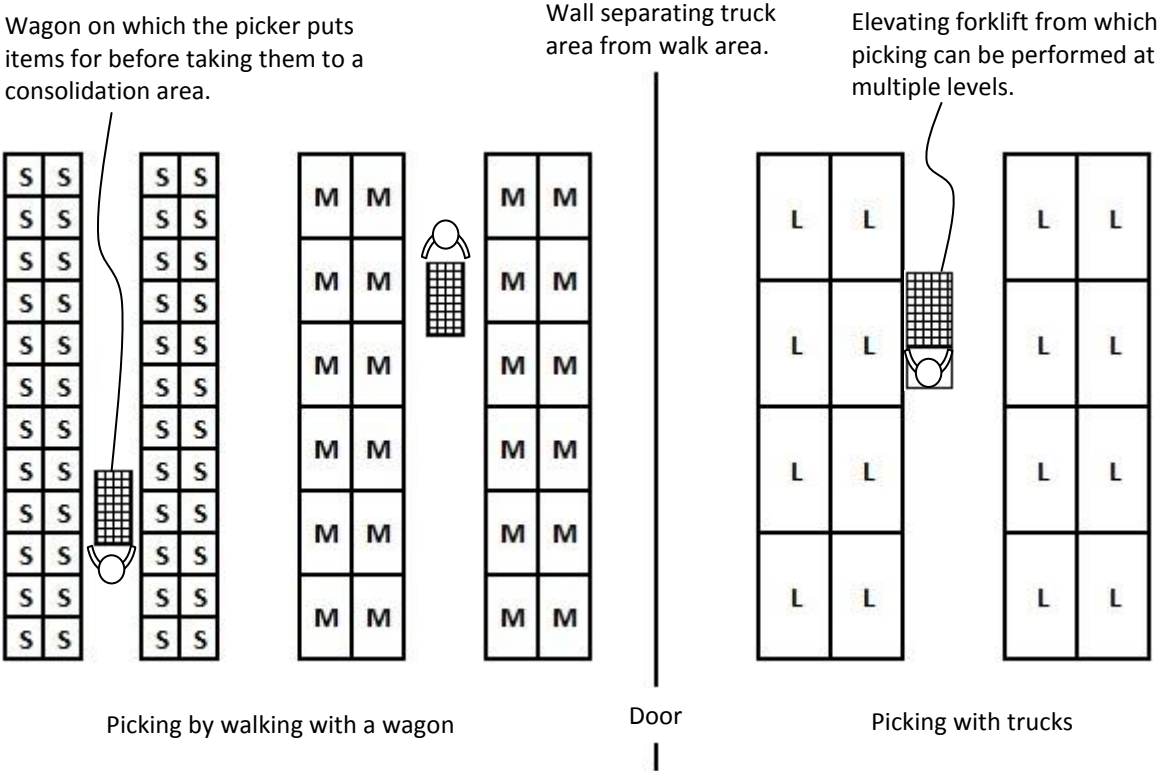


Figure 23. Picking layout used by Schenker in their Nissan spare part warehouse.

**4.3.5 DHL/SAAB Trollhättan**

The well known logistics company DHL is responsible for the sequencing operations at SAAB in Trollhättan and has set up a sequencing warehouse exclusively for SAAB. The layout of the warehouse, and its picking stations, is very much similar to the set up used by Volvo at Torslanda. The main part of the warehouse consists of pallet storage racks with five to seven levels of pallets above the picking stations which thus are located below the storage.

The type of picking station used by DHL/SAAB is illustrated in Figure 24 and as mentioned above it builds on the same idea as Volvo’s. The picker works in an aisle between two high pallet storage racks in which material is stored as well as presented to the picker on the floor level. Different from Volvo, DHL/SAAB has chosen to put the most frequently used items in one end of the picking station and the less frequently used ones in the other end, as illustrated by the letter A to C in Figure 24

where A represents the items with highest frequency. The wagon, onto which the picker puts the items in numbered pigeonholes, is placed in the end of the picking station. However, there is an idea about arranging the picking list in such a way that the picker can put the wagon through the station as it is filled up, starting in the end with the low frequency items in order to make the wagon as easy as possible to move.

In some picking stations, where the number of item variants is very high, the storage space above the picking station is replaced with picking locations similar to the ones on the floor. In order to pick from these above floor level picking locations the picker uses an elevating forklift and can thereby travel in two dimensions (back and forth as well as up and down) in while performing the picking. Here the picked items are placed in boxes rather than wagons or sequence racks. The boxes, however, are then put on wagons for further transportation to the production line.

The picking information, i.e. the order, is given to the picker in form of a list and one sticky label for each item to be picked. The picker then picks what is on the list, with no more help than visual labels on each item's position along the station, and attaches the sticky labels to the items before putting them in their assigned locations on the wagon. When the wagon is filled, the picker has to scan all items on the wagon with a bar code scanner to make sure that each item, and their positions, corresponds to what is stated on the picking order. A drawback here is that if something is found to be wrong, the picker has to manually find what it is, which in worst case can mean that he/she has to re-pick the complete order.

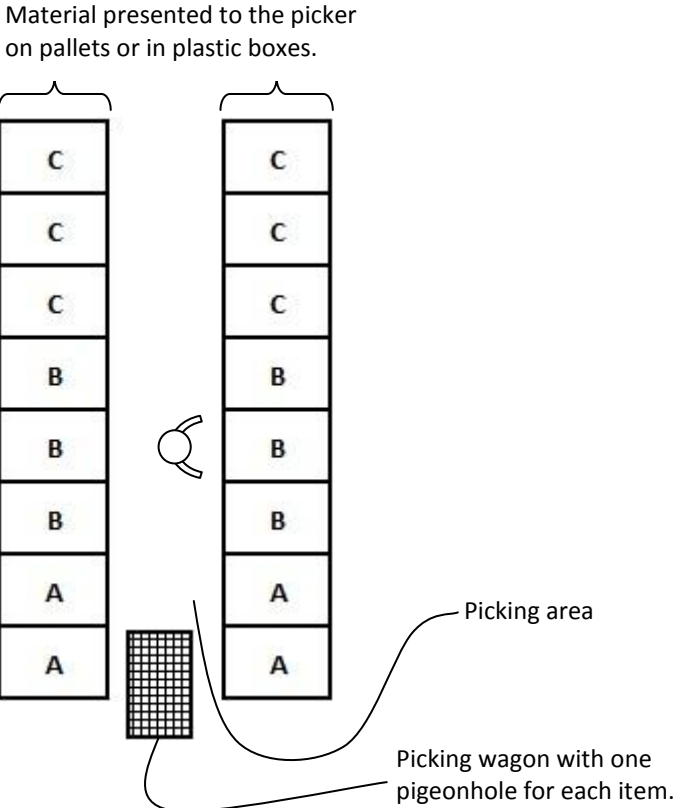


Figure 24. Picking station used by DHL/SAAB.

In terms of performance measurements the most important one for DHL/SAAB is picking accuracy, which they were very good at with 0.8 ppm in wrong picks compared to the requirement of 21 ppm. Another important performance metric is utilization of the workers. DHL/SAAB think it is more important to have a high utilization of the people working in the picking warehouse than to fine tune the picking operations at every picking station. It is no point in saving three seconds at a picking station if balancing losses makes the picker wait anyway. As a measure to tackle this problem, very flexible agreements with staffing companies were put in place. Interesting to add in relation to the balancing time, which is determined by the tact time of SAAB's production line, is that this time has a much greater role in affecting how picking stations are located together than the picked items' ergonomic impact on the picker. In other words, it is a higher priority to locate picking stations so that one picker can operate a number of stations with minimum idle time, or balancing losses, than to consider the ergonomic impact on the picker by bundling these very stations together.

#### **4.3.6 Elanders Mölnlycke**

Elanders is a big printing group with global presence. Their products span from books and magazines to packaging and manuals & product information. The site visit for this thesis was done at Elanders facility in Mölnlycke, just outside Gothenburg. At this site, Elander performs printing operations as well as warehouse and picking operations. The part of Elanders's operations connected to the automotive industry, and Volvo, was moved from Arendal to Mölnlycke in 2008 and at the same time the area for these operations shrunk from 10 000 m<sup>2</sup> to 600 m<sup>2</sup>.

To both Scania and Volvo Trucks, Elanders print chassis number specific manuals which they also ship in sequence according to the customers' production schedules. However, the most interesting operations from the perspective of this thesis are the ones concerning more standardized manuals for automotive companies such as Volvo Cars and SAAB. These are carried out in two steps. First, products are picked out from their storage locations in one of two vertical lift modules (VLMs). Thereafter, they are presented to the kitting personnel on trolleys where the staff picks up the products included in their kits and performs the kitting at a table. The complete kits are thereafter put in plastic boxes which are placed on a conveyor belt next to the kitting table. In the end of the conveyor belt, the plastic boxes are stacked onto pallets for delivery to the customers. The picking and kitting area layout is illustrated in Figure 25 below.

Both the pickers and the kitting personnel receive their orders via stationary computers. The picker then receives more accurate information about what to pick on a screen fixed at the vertical lift module. Every pick from the module is confirmed with pushing a pedal. In addition, the picker retrieves high frequency material from the pallet storage rack opposite to the vertical lift modules (indicated by the A:s in Figure 25, the C:s and D:s indicates items of lower frequency in the VLMs); he then uses a hand-held computer together with a bar code scanner to confirm the picks. The kitting personnel print labels from their computer for all kits they are to pick, and hence they realize if the picker has missed something as they do not get full kits or have labels left but no more material. When it comes to the above mentioned sequencing for Scania and Volvo Trucks, the picker is using a bar code scanner for two purposes. The first is to confirm that the right products are included in the kit, and the second is to ensure that each kit is positioned in the plastic boxes used for delivery according to the customers' sequencing demands.

Space is a major concern for Elanders and thereby the picking area design has to be area efficient. The fact that the area used was reduced by 94 % when the operations were moved in 1998 is a good sign of this and the vertical lift modules used are a big part of making it possible. Instead of having people travel around up and down aisles, everything is now concentrated to the machines. In addition to the space, which is more static, the most important KPI for the picking operations is the delivery performance. It is extremely important for Elanders to deliver the kits according to what is ordered and in time. Regarding the kits sequenced to Scania and Volvo Trucks no faults are tolerated; thereby the rigorous control with the bar code scanners. The kitting operation presented in more detail here has a customer requirement of at least 99.7 % precision, but Elanders themselves aims even higher.

At last, regarding the vertical lift modules, the introduction period was a bit cumbersome but after everything was adjusted and fine tuned the system has worked very well. There have been some down time but most of the problems have been possible to solve over phone.

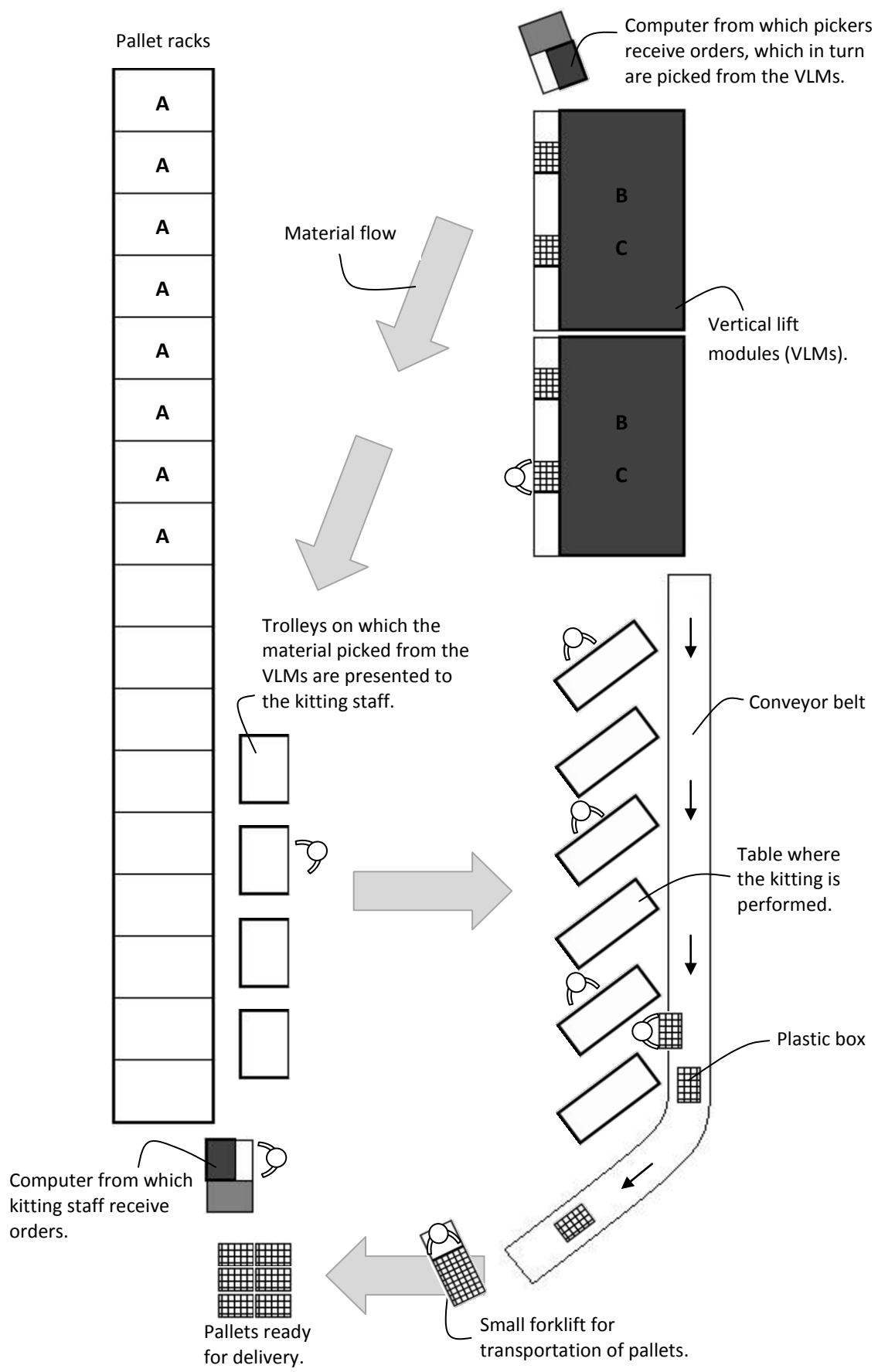


Figure 25. Picking area layout at Elanders in Mölnlycke.



## 5 Analysis

In this chapter the results presented in the previous chapter are analyzed and discussed in order to formulate solutions to the problem at hand. The chapter starts off with an analysis of the item characteristics presented in section 4.1 together with a classification system comprising the relevant characteristics. Following this comes an analysis and presentation of a couple of picking station improvements with main focus on area efficiency and a validation of some of these ideas using picking stations at Volvo as mini cases. The chapter is concluded by explicitly revisiting the research questions presented in section 1.2.4 in the very beginning of this thesis.

### 5.1 Item Classification

With starting point in the proposed classes presented in section 4.1 the most relevant item variables with respect to picking station design has been identified.

Considering the literature found on the topic, mainly two things were deducted from the theory. The first one being that classification can be very useful in order to deal with a large number of items in an efficient way. The second one being that there are numerous ways of doing the actual classification assignment. While different ways to divide the articles according to their economic contribution or to their importance are presented, this case calls for something else.

As an item can possess multiple characteristics, which will all affect a picking station design in different ways at the same time, this very problem called for a different way of classifying the items. First, the items have to be classified according to some characteristics which affect the picking station design. As mentioned in section 2.1, classification according to item characteristics have been touched upon by Brynzér and Johansson (1996) and Braglia, Grassi and Montanari (2004). Some of the ideas presented by these authors were revealed also in the characteristics identified as possible to use for classification and presented in the empirical findings of this thesis (section 4.1).

From an evaluation of the characteristics presented in the empirical findings with respect to their presence in, and likely impact on, a sequence picking station the following five characteristics crystallized as useful for this classification:

- Item weight
- Item size
- Orientation sensitive item
- Number of variants
- Multi-picking possible

In order to arrive at these five, two main questions were asked for each of the characteristics presented in the empirical findings (section 4.1). The first one was: Is this characteristic at all relevant for the type of picking carried out at the sequence picking station? If the answer to this was no, the characteristic was removed. If the answer was yes, the second question was asked as: Is this characteristic likely to have an impact on the design of the picking station; in terms of any of the performance measures presented in section 2.3.3? If the answer to this was no, the characteristic was removed. Going through this analysis procedure derived the characteristics presented above.

The next question was in which order to prioritize these characteristics. As mentioned above a single item can have an impact on picking station design in terms of more than one of these

characteristics so the conclusion was that they have to be ranked according to their mutual extent of impact. The ones that have the greatest impact have to be prioritized first. From this analysis the following prioritization and basic decision criteria was developed:

- Level 1:** Item weight – over or under a weight limit
- Level 2:** Item size – over or under a size limit
- Level 3:** Orientation sensitive item – yes/no
- Level 4:** Number of variants – over or under a quantity limit
- Level 5:** Multi-picking possible – yes/no

The decision criteria should be thought of in connection to a decision tree developed from the characteristics prioritization above, and which can be seen in Figure 26 below and in a larger version, including decision criteria, in appendix D.

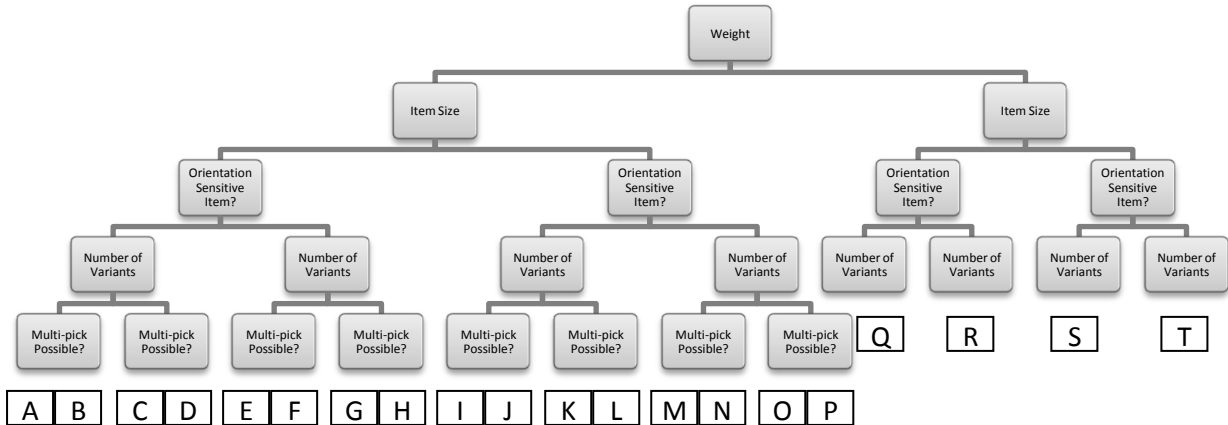


Figure 26. Decision tree for item classification (see Appendix D for a clearer version of the figure).

The item weight is on level one since it is critical for whether or not it is necessary to use lifting equipment to carry out the picking. For heavy items, ergonomic reasons and regulations make it harmful and impossible to perform the picking manually (refer to theory around ergonomics in section 2.2). Thus, lifting equipment is necessary at these picking stations, and since the lifting equipment is usually roof-mounted special requirements are put on the stations.

On level two is the item size since this also has a direct impact on the design of the picking station. For example, if an item is very long the station cannot be too narrow since in that case the picker would have a hard time maneuver the item within the station.

Level three separates orientation sensitive items from non orientation sensitive items. The sensitivity towards orientation will affect the picking operations as the orientation sensitive items require more care and a higher maneuverability within the picking station. However, we argue that this is important first after it is known if the items are very heavy or very big as these two characteristics will have a fundamental impact on the design of the picking station.

Level four is concerned with how many different types of the item there is. A lot of different types of the items requires a big picking station, a medium number of types makes the picking station more

manageable in terms of where in the facilities to put it and a very small amount of types opens up for a combined picking station in which different items are co-picked.

On the fifth, and last, level items possible to pick more than one at a time are separated from those that has to be picked individually. This will have implications for how the picker can work within the station as it might be possible to eliminate waste in terms of unnecessary walking for items that can be multi-picked. Regarding the order of the last two levels, this is more arbitrary than the order argued for the first three levels. This is since it does not make much of a difference if one shifts the order. However, worth to note is that the multi-picking level is not considered for items requiring lifting equipment, and thereby it became natural to put it as level five.

## **5.2 Picking Operations at Volvo**

In order to understand how the operations at the reference companies can be used as input for developing improvements in a picking system of the type used by Volvo, it is important to first analyze a system of this type.

The picking system used by Volvo can be seen as a picker-to-parts system, or partly as a put system (section 2.3.1.1); a picker-to-parts system as the picker walks along the picking station to pick the ordered parts and a put system as the pickers at the picking stations are fed with material by forklift operators.

The positioning of items along the picking station is supposed to minimize the walking distance for the picker as picking is performed. This through placement of the most frequently used articles in the middle of the picking station close to the racks. However, no consideration is given to highly infrequent items. Hence, there might be an opportunity to save area present in co-presenting certain low frequency items in one, or a few, C picking locations in the end of the picking stations (Figure 14). In connection to the presentation of the material at the picking station it is interesting to look at how items are presented as it might be possible to save space at each picking location by changing the way the material is presented.

At last, the picking support used by Volvo is a pick-to-voice system. Since this system was put in place the picking accuracy has improved. What is interesting with the picking support in the context of this thesis though, is whether it is able to support a suggested design change or not. If a design change is of such nature that it cannot co-exist with an existing system, proven to be as good as the pick-to-voice system, then the design change is probably not as good as it has to be.

## **5.3 Picking Operations at Reference Companies**

In the following sections each and one of the reference picking operations presented in the empirical findings are analyzed with the aim of finding ideas that could be applied in order to improve sequence picking operations.

### **5.3.1 Pininfarina Uddevalla**

Evaluating the picking stations at Pininfarina Uddevalla, they are a typical example of what a picker-to-parts system, described in 2.3.1.1, looks like. Worth noticing in the Pininfarina factory is that items similar to each other, e.g. in terms of color or shape, are never placed close to each other. This lowers the rate of picking mistakes made by the picker. Important to highlight is that not all

items are separable using color. Hence using color in order to decrease the rate of faults is a limited option.

As this thesis deals with picking efficiency, with a focus on space/area, it is interesting to look at the system used by Pininfarina from this perspective. The size of the facility depends on how far apart the items are placed in the warehouse. Currently it takes the picker approximately 30 minutes to pick one order and deliver it to the line. Combined with the facility size the picking operations are not only a rather time consuming activity, but quite area-demanding as well. When finished picking the picker self delivers the racks or boxes to the assembly line, which also prolongs the activity. Hence, for a company with a high number of produced products, e.g. Volvo, a system like this would be hard to implement keeping a focus on space/area as well as time efficiency. Looking at the KPI's identified in section 2.3.3, time efficiency can be related to the picking operations in terms of picking cycle time, the output of the picking or the picker efficiency.

Finally, the Pininfarina factory also use multi-picking, which would need an investment to conform to picking aids such as a pick-to-voice system. However, considering the multi-picking from a different viewpoint, the system enables items picked into all boxes being picked at the same time. This reduces the distance the picker has to drive, which could be seen as an increase in the efficiency of the picking operations.

To sum up, the two main lessons learned from the system used at Pininfarina. First come the possibility of separating the items thru color and size can help reduce the percentage of faulty picks. However, it is necessary to evaluate how great an effect these two variable can have combined with a pick-to-voice system used e.g. at Volvo. Second is the option of using multi-picking, enabling the picking operations to be more time efficient when the picker can pick several items at once instead of driving back and forth to the same items.

### **5.3.2 Tamro Gothenburg**

Tamro uses a pick-to-belt system, explained in section 2.3.1.1, where items are picked into boxes transported on a conveyor belt. Similar to the Volvo factory, each picker is responsible for one picking station; also the station layouts are very similar. The most frequently picked items are placed closest to the racks; behind or right in front of the picker, while the items with lower frequency are placed at the end of the station. It is interesting to elaborate on the fact that items are placed both above and below the conveyor belt. It can be argued that items placed close to the ground may have a negative ergonomic impact on the picker. However, if this layout is used only for low frequency items it will most likely neither have any harmful impact on the picker, nor will it conflict with the regulations on ergonomics set by the government, discussed in section 2.2.

Considering the placement of the items in the picking station, this layout, including items placed on different levels in the station, constitutes an interesting point of reference in the search for changes that could increase space/area utilization. Using a structure where low frequency, and/or small, items are placed above or below larger items constitutes a possible way of combining two, or more, picking stations and thereby increase the area efficiency. This structure might raise a concern about increased risk of faulty picks from combining different items in one station. However, the fact that Pininfarina uses the composition of items at a picking station as a measure to reduce this very same risk, and increase the efficiency of the system, suggests that it should not constitute an issue when combining stations. At least not as long as the combined items are clearly separable.

Eliminating faulty picks could be done e.g. using the color and size separating method used at Pininfarina (section 4.3.1).

Additionally, having a system automatically scanning a bar code attached to the boxes indicating what items to be contained is a way Tamro uses to increase the efficiency of the system. However, using automated systems increases the risk of system failure, which could highly affect a company like Volvo, where a system failure could result in racks not being delivered to the assembly line on time, which in turn might lead to a production stop. On the other hand, the fact that Tamro uses an automated system like this can be seen as a case in favor of using automation as they still are able to reach their set performance requirements. Hence, this should be possible for Volvo as well, as long as the automation is managed in a proper way suitable for their specific operations and needs. The “proper management” could for example include plans for how to act in order to secure material deliveries in case of a system failure.

At last, it is interesting to take a look at Tamro’s other system, namely the automated storage system, which can be categorized as a parts-to-picker system. The system delivers a pallet, automatically retrieved from the storage system, from which the picker self picks the required amount of items before the pallet is automatically restored in the system. That means that the picking stations and the whole storage are located at the same place, which makes the system very area efficiency. However, considering the fact that the system is fully automated along with the fact that all items are depending on the functionality of the system, the risk increases as the event of a system failure will lead to inability to fulfill orders. In the context of this thesis, this would, as in the case mentioned above, lead to a production stop, something which is very expensive and highly undesired in the competitive automotive industry. In the event of this situation happening, the consequences would be a complete inaccessibility of the items considering that the system contains the entire warehouse. Some might argue that it is possible to manually pick from this kind of system in case of a break down, but it is likely to imply problems for the inventory management system. Items can be misplaced during the performed picking operation or the picker forgets to manually register the pick in the system, which results in an inaccurate inventory balance.

Summing up, two main lessons were learned from Tamro; the station layout and the automated storage system. Using all areas of possible placement for items in the picking station, Tamro are utilizing the space/area of the station by effectively using all available space/area. This is highly relevant when designing a new station or when combining two into one. The automated storage system being area efficient, it is in this case considered more of a plain storage system. Despite picking operations being performable, there are inventory management risks attached to it. However, some automation might be an important part of increasing the space/area efficiency as long as the automation is managed in a proper way.

### **5.3.3 Carlsberg Falkenberg**

The picking stations at Carlsberg were not separated into individual stations for different classes of items. It correlates well with the picker-to-parts system presented in section 2.3.1.1, this since the picker uses a forklift driving around and picking the items on the order onto a pallet. Because of the layout inside the warehouse a lot of driving is required by the picker and along with the risk of having to re-stack the pallet the operation can be very time consuming. This set up is probably more suitable for companies transporting the picked items on the same type of, or very similar, pallets. The picker

develops knowledge on how to stack each pallet during the picking. Considering a company carrying many different items, which in turn may require alternatives to pallets Supportive to this is also the fact that automotive companies of today are working with an increasing amount of components in each car. The frequent appearance of items not being very similar in size and/or shape, hence suggests that a layout such as Carlsberg's will not be space/area efficient. Instead, for a company as Volvo, the introduction of such a picking system could be viewed as reverse development for the organization rather than an improvement contributing to better performance.

More interesting is how Carlsberg works with lifting equipment to protect the workers and to facilitate heavier lifts than otherwise possible. At each picking location, there are lifting equipments available for the pickers to use if they feel they need to. As mentioned in the empirical findings, the lifting equipment is, similar to the equipment used by Volvo, mounted in the ceiling. However, there is a factor making Carlsberg's lifting equipment interesting to look at, namely the special design. Firstly, the equipment is designed according to the design of the items to be picked. Hence, it enables the picking operations for the picker and at the same time user-friendly encouraging usage. For some high frequency items, the lifting equipment also allows the picker to multi-pick. Secondly, using vacuum and suction cups instead of a mechanical design allows for faster usage of the equipment, as well as reduced risk of damaging the lifted items. The picker only has to press a button in order to grip the item and perform the same procedure in order to release. This not only decrease the potential negative ergonomic effects on the workers the heavy lifting could have resulted in, but also increases the picking efficiency. Picking several items at once instead of one at the time together with the easy usage of the equipments are examples of two things contributing to increased efficiency.

Summarizing, at Carlsberg two main lessons were learned. First comes the picking system designed with respect to specific variables, e.g. picking onto pallets, which would be problematic for more flexible needs, e.g. using racks or plastic boxes. The variable can be items' shapes and sizes and the way the items are transported e.g. racks, wagons, pallets or boxes. Secondly, using vacuum based lifting equipments would not only be positive ergonomically for the pickers but also result in an increase of the efficiency of the picks thru faster usage and in some cases allowing multi-picks to be performed.

### **5.3.4 Schenker Gothenburg**

The system Schenker uses, for both big and small items, is what is referred to as a picker-to-parts system in section 2.3.1.1. The picker walks, or drives a forklift, up and down aisles in order to pick ordered items from their respective warehouse locations.

An interesting feature in Schenker's picker-to-parts system is picking locations above floor level. In the part of the inventory handling small items, some of the picking is carried out using a two level set-up. A second floor is built, thus doubles the utilization of floor area for picking operations. The fact that the picker has to lift his/her picking wagon up to the second floor using a forklift can be seen as a cumbersome risk moment, however this increased risk has to be traded off against the increase in floor area utilized for picking operations. In addition, the stairs used to get up to the second floor takes up space but as the upstairs picking area is quite big the space used by these stairs comprises just a fraction of the extra area made available for picking operations.

In the part of the inventory handling bigger items the picking is carried out using a multi level set-up. As the items are stored on pallets in high storage racks and the picking is carried out using elevating forklifts on which the picker self is elevated up to the right picking location, it is possible to use a lot more than just the floor area for picking operations. However, there is a risk present in dropping items, and in a setting for automotive sequence picking a problem arises in how to efficiently put the picked items in the right sequence on a vehicle for transportation to the assembly line.

At last, notable for the operations at Schenker is that no lifting equipment is used; resulting in that only a few employees can work in the part of the warehouse handling big items. According to the theory around ergonomics presented in section 2.2, this is not a preferable way of designing the operations as the risk is high for a negative physical impact on the workers. The negative impact may also be present in terms of psychological effects as the lack of lifting equipment prevents the personnel from rotating between different assignments.

To sum up, the main lesson learned from Schenker is that floor area can be saved by picking in multiple levels. This can be carried out by using trucks in which the picker is elevated to the picking locations or by building an extra floor level in a part of the warehouse. The bigger the extra level is, the lower the impact on the space occupied by the non value-adding stairs required to reach the extra level.

### **5.3.5 DHL/SAAB Trollhättan**

The picking operations carried out by DHL/SAAB are very interesting as a point of reference for this work, this foremost as the picking operations supports an assembly process very similar to the one at Volvo. As explained in the empirical findings, DHL/SAAB's picking station designs build on the same ideas as Volvo's, however the stations are used a bit differently. As in the case with Volvo, DHL/SAAB's system can be seen as picker-to-parts system, or partly as put system (section 2.3.1.1); a picker-to-parts system as the picker walks along the picking station to pick the ordered parts and a put system as the pickers at the picking stations are fed with material by forklift operators.

The positioning of the material along the picking station at DHL/SAAB differs from the one used by Volvo (Figure 24 and Figure 14). The positioning used by DHL/SAAB, with high frequency items in one end of the station, might be good to use for a set-up where the picker walks along the picking station with a wagon, or a rack, and picks all the items as he/she walks along. However, with the currently used layout where the picking wagon, or rack, is fixed we believe that a layout with the most frequently used items positioned together with the wagon, or rack, in the middle of the station is preferable. Hence, no new important lesson was learned from DHL/SAAB in this case.

For small items, however, DHL/SAAB uses an interesting system. This is very much similar to the multilevel picking with elevating forklifts used by Schenker, but in this case for smaller items. The systems saves a lot of floor area as the extensive range of different items can be stored on multiple levels in the same picking station. In terms of picking performance this operation may add some time to the picking itself and hence this extra time has to be traded off against the savings in area usage.

At last, it is worth commenting on the sticky labels used by DHL/SAAB to confirm their picks. As explained in section 4.3.5 a label is attached to each item and then used to confirm that the items are put in the correct pigeonhole on the sequencing wagon. However, if the wrong item is picked the

sticky label will be put on the same wrong item, something that might create problems since the sticky label still can be located correctly on the wagon but together with the wrong item. This is well worth considering when evaluating the performance of this kind of system and might be part of the reason to DHL/SAAB's very high picking accuracy.

To sum up, two main lessons were learned from DHL/SAAB. The first is that it might be possible to carry the picking wagon, or rack, through the picking station and pick everything ordered by just walking through the station once. With this set-up, the items are preferably positioned along the picking station according to their frequency of use so that the ones with lowest frequency are picked first, just as shown in Figure 24. This set-up will reduce the distance walked by the picker and hence in that respect increase the picking efficiency. In addition, some area will be saved as the wagons, or racks, no longer occupy area that could be used as picking locations. The second is the possibility to pick at multiple levels by using a truck in which the picker can be elevated to picking locations above floor level and hence the floor area used can be reduced by having picking locations at multiple levels.

### **5.3.6 Elanders Mölnlycke**

The order picking operations at Elanders illustrates in a very good way what is presented as a put system in section 2.3.1.1. In the retrieval part of the process ordered items are retrieved from a vertical lift module and delivered to pickers who perform the order distribution part of the process.

The put system as such is, according to the theory, a very efficient set-up when many smaller orders have to be picked and delivered to a scattered customer base. Elanders might not have this big customer base as they operate in a business to business environment and serve big customers such as Volvo and SAAB, but they pick and kit a lot of catalogues and hence the system suits them well. However, this complete system as it is set up at Elanders is not likely to suit Volvo as their picking operations are not of the same scale.

In the context of this thesis it is more interesting to look at a part of the system used by Elanders, namely the vertical lift modules as they are very area efficient. These machines can be used as picking stations in themselves. They can also be used as storage, as is the case at Elanders.

To sum up, the main lesson learned from Elanders is the value of vertical lift modules as they can be very efficient in terms of floor area utilization.

## **5.4 Picking Station Design Improvements**

Starting by looking at the classification system, presented in section 5.1, it is believed that the greatest potential for space/area improvements are to be found for items belonging to class A through H (Figure 26); this since picking stations for items in need of lifting equipment are very restricted in terms of this equipment. As can be seen in section 4.3.3 about Carlsberg as well as in the presentation of the current operations at Volvo (section 4.2) lifting equipment is commonly ceiling-mounted. In addition, not many items at Volvo, based on size and weight, require lifting equipment; the same was the case at DHL/SAAB. The low amount of heavy items, together with the restrictions put on the associated stations, indicates that it is more rewarding to focus the efforts on the classes mentioned above, and hence not on class I to L in Figure 26.



With focus on items not requiring lifting equipment, the ideas found through the analysis of the reference companies have been condensed into a couple of design considerations or ideas that mainly aims at increasing the area efficiency of sequence picking stations. These ideas are presented below<sup>1</sup>, and further discussed in section 6.2.

- Use vertical lift modules as a substitute for small item picking stations. (1)
- Combine two, or more, picking stations into one. (2)
- Use elevating forklift to pick from above floor level picking locations. (3)
- Build an extra picking level. (4)
- Move sequence rack through picking station while picking. (5)

In addition, the following ideas evolved from meetings, interviews and brainstorming as the work proceeded, the root to some of these can also be found in the analysis of Volvo above:

- Consolidate low frequency items to a few locations at the picking station. (6)
- Downsizing before items are presented at picking station. (7)
- Presentation of the material at the picking station. (8)
- Picking of more than one item at a time. (9)

## 5.5 Picking Station Design Improvement Evaluation

In order to assess the validity of the results presented above, the effects from implementing three of the ideas at Volvo were approximated. As the changes were too big to be physically tested in the TB1 facility it has to be stressed that this evaluation is nothing more than a virtual implementation indicating the directions of the results from implementing the ideas. The design ideas virtually implemented are the first three from the first list above, namely:

- Use vertical lift modules as a substitute for small item picking stations.
- Combine two, or more, picking stations into one.
- Use elevating forklift to pick from above floor level picking locations.

The third alternative is more or less a special case of the second one and hence these two will be addressed together even though the differences will be commented on. The reasons for evaluating these three design ideas are the extensive area savings possible from using the vertical lift modules in the case of idea (1) and the easier implementation procedure, together with still quite big area savings, for idea (2) and (3).

As a point of reference, additional to the area occupied by the picking station, a conceptual Materials Flow Map (MFM) was constructed for the existing picking station layout used at Volvo (Figure 27). One MFM is used to represent the picking stations in general as the differences among the different picking stations is thought to be the same in the reference MFM's as in the MFM's illustrating the changes.

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<sup>1</sup> The numbers in the brackets are for reference/identification purposes only and hence do not represent any kind of hierarchical order among the alternatives.

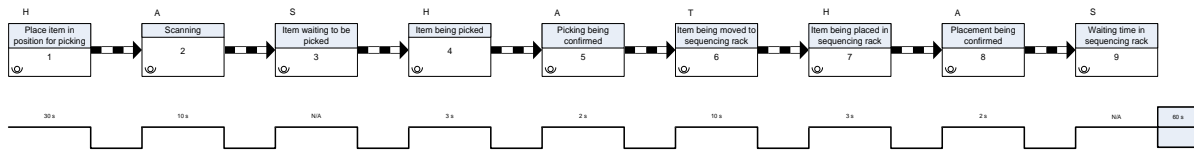


Figure 27. Conceptual picking station (larger version of the picture can be seen in Appendix E).

As can be seen in the MFM in Figure 27 (larger version in Appendix E), the picking station consists of nine activities with an estimated total time of 60 seconds. Further, in this MFM no times are approximated for activity three and nine, “item waiting to be picked” and “waiting time in sequence rack”. The exclusion of these times is valid partly because they are hard to approximate on a general level as they are different for different items and partly because they are not thought to have an impact on the outcome of the analysis for which the MFM is used here. The time for activity three will depend on the frequency of use for the item and the amount of the item presented at the picking station. Hence, the consolidation (6) and downsizing (7) alternatives will have an impact on this time for some items. However, it is not sure that the total time in inventory, and thus the inventory level, will be reduced as it may just be relocated from picking locations to storage locations. The time for activity nine will depend on the balancing between the picking at the picking station and the tact time at the production line. Hence it is regarded to be outside the scope of this thesis, not relevant for the outcome and thereby not considered.

### 5.5.1 Vertical Lift Modules

Referring to the vertical lifts modules (VLMs) used by Elanders, see Appendix F for data, it should be possible to combine the picking stations for e.g. door handles and antenna covers. In addition, already combined stations, such as door mirrors and door mirror covers, or stations with many items, such as the manuals, can be substituted with a VLM to save area.

As can be seen when comparing the MFM for present picking stations presented in the previous section with the MFM for a picking station using a VLM shown in Figure 28 no extra activity is added when using a VLM; the number of activities is still nine. The only difference seems to be the time for the step of moving a picked item from its picking location to the sequence rack, activity 6 in the MFM. This difference is to the favor of the VLM since the picker now has to walk a shorter distance to the sequence rack as all items are picked at the same place, in the VLM. The difference is shown in the MFM as the total time has decreased from 60 seconds to 54 seconds. Worth noticing in relation to the activity making the difference is that this activity is frequently repeated as it occurs for every pick, hence the positive effect from a VLM on this time will be greater than it appears to be when looking at a MFM representing just one discrete pick. On the downside though, and not shown by the MFMs, is the activity of loading the VLM. This activity is the first one in the MFMs presented here but represents only the positioning of the items. Considering the whole loading procedure might change things a bit in the favor of the old design as the refilling speed for the VLM is constrained by the speed of the machine. However, the refilling is not an activity as frequent as the picking, so looking at the whole set of activities the VLM will most likely be able to save some time, and walking, for the picker.

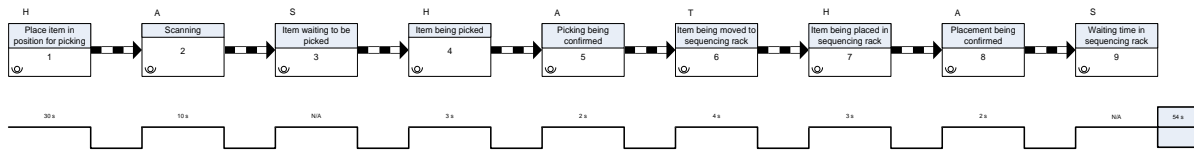


Figure 28. Conceptual picking station using a vertical lift module (larger version of the picture can be seen in Appendix E).

So comparing the MFMs, using a VLM for smaller items seems like a viable option. However, this is what could be called a qualifying property in the context of this thesis as the focus is on space/area efficiency, and indeed the VLM is a very area efficient alternative as is shown below.

Using the examples of items mentioned above and looking at the data presented in Appendix F it is possible to estimate the area savings possible. Elanders has about 1200 positions per VLM but considering that Volvo is using larger packaging, e.g. 800x600 mm<sup>2</sup> and 600x400 mm<sup>2</sup> compared to Elanders 300x200 mm<sup>2</sup>, it seems fair to assume that Volvo could have 500 positions in the same VLM as Elanders employs. The bottom area of such a VLM is 9 m<sup>2</sup>. This should be compared to the areas of the picking station being replaced.

Looking at the data in Appendix F and the number of storage positions in a VLM estimated above one can see that it should be possible to combine door handles, antenna covers and manuals into one VLM. The combined area of these stations is around 200 m<sup>2</sup>, so even though a bit more area than occupied by the VLM itself would be required for a VLM-based picking station, the area saving would be quite dramatic.

Again looking at the data in Appendix F, but this time on the side mirror- and side mirror cover station, which is already a combined station similar to what is evaluated in the next section, one can see that the area of this station is close to 150 m<sup>2</sup>. So, even here a fairly substantial area saving is possible and in this case there would be room for more items left in the VLM as only about 150 storage positions will be occupied.

So, the VLMs seem to be able to provide area savings for more than one picking station at Volvo without affecting the existing performance here addressed using MFM. However, some issues worth considering in connection to VLMs will be addressed in the discussion chapter of this report (section 6.2).

### 5.5.2 Combine Picking Stations

The second idea to be evaluated is the combination of two or more picking stations into one, where the evaluation will address two different ways of doing this. These ways are fairly similar, with the major difference present in how many picking stations that are actually combined into one. The basic idea is to combine two picking stations, one for smaller items with one for larger, and continue to pick in the same way as before. However, it would be possible to take the combination a step further by using either some solution with a height adjustable floor within the picking station or by using elevating forklifts in order to combine more than two stations into one.

Comparing an MFM for these both alternatives, see Figure 29, with the MFM for present picking stations shown in Figure 27 one can see that there are no major differences; the number of activities

is still nine. The picking itself, activity 4 in the MFM, is thought to take a bit more time due to the increased complexity for the picker when he/she is facing more items. This increases the total time shown in the MFM from 60 seconds to 62 seconds. In the case of using an elevating forklift, the time for travelling up and down also has to be accounted for. Important to notice here is that this extra picking time, whatever the origin, might have a larger impact than illustrated by the MFM. This follows the same logic as in the VLM case, as the frequency of the picks will give the extra time a greater impact than what appears in the MFM.

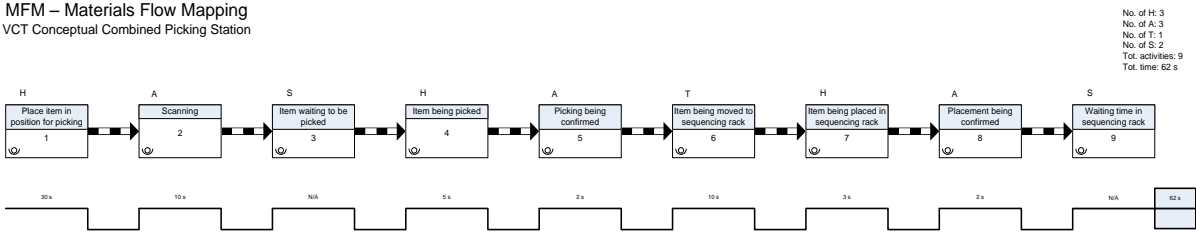


Figure 29. Conceptual combined picking station (larger version of the picture can be seen in Appendix E).

Even though the picking time might be slightly increased, no drastic changes were to be found when comparing the MFMs. But as above, this is a qualifying property in the context of this thesis as the most important thing here is space/area utilization.

As the station layout of this design change is pretty much similar to the one currently used, the major determinant of how much area is going to be saved is how many picking stations that is combined. Without using an adjustable floor or an elevating forklift it is most likely hard to combine more than two picking stations as the picker has a limited reach. So, assuming that the two stations are of the same size the area of one picking station will be saved. If the stations are of different sizes, the area of the smallest station will be saved. Looking at the data in Appendix F, combining e.g. door handles with pedals or lower door strips would save the area of the door handles station which is about 80 m<sup>2</sup>. However, even though the door handle station contains small items, there are a lot of variants which will make the presentation at a combined station of this type difficult.

Using an elevating forklift, or some kind of adjustable floor, opens up new possibilities sine it is then possible to locate picking stations on top of each other without being restricted by the picker walking on the floor. This also means that more area can be saved as three, or maybe more, stations can be combined into one. For example the many variant of door handles could now be located above, or even below, for example pedals. Again, the area of the smallest station will be saved.

So, combining stations seems to be an option when looking to save area, but it is important to evaluate which items are possible to combine. Just because the door handles are small it is not necessarily possible to combine them with larger items due to their many variants. However, using elevating forklift might help to solve these kinds of problems. At last, as was the case with the VLMs, some issues worth considering in connection to the combination of picking stations and the use of elevating forklifts will be addressed in the discussion chapter of this report (section 6.2).

## 5.6 Research Questions Re-Visited

Before moving on to a discussion of the results presented above it is of great value to re-visit the research questions stated in the beginning of this thesis (section 1.2.4). So, below each question is re-stated followed by a very condensed answer together with a note on where in the thesis more information is to be found.

**RQ1:** *With respect to what variables is it possible to segment items picked in sequence?*

A number of variables, possible to segment with respect to, were identified and further analysis condensed the following five as the most appropriate for an item classification system used in relation to sequence picking stations:

- Item weight
- Item size
- Orientation sensitive item
- Number of variants
- Multi-picking possible

For more information, refer to section 5.1.

**RQ2:** *On what key performance indicators could a picking station be evaluated?*

In order to know where to start looking for design improvements and what to focus the discussion chapter on the following key performance indicators were deducted from the theory:

- Distance travelled by the picker
- Picker efficiency
- Picking accuracy
- Picking cycle time
- Picking output
- Space utilization
- Cost

The use of these was also, to different degrees, confirmed by the reference companies visited throughout the work with the thesis. For more information, refer to section 2.3.3.

**RQ3:** *With what measures can a picking station design be improved?*

A number of possible improvement ideas have been presented and three of them have also been closer evaluated in the form of virtual implementations on picking stations at Volvo. The improvement suggestions are the following:

- Use vertical lift modules as a substitute for small item picking stations. (1)
- Combine two, or more, picking stations into one. (2)
- Use elevating forklift to pick from above floor level picking locations. (3)
- Build an extra picking level. (4)
- Move sequence rack through picking station while picking. (5)
- Consolidate low frequency items to a few locations at the picking station. (6)
- Downsizing before items are presented at picking station. (7)
- Presentation of the material at the picking station. (8)

- Picking of more than one item at a time. (9)

The origins of these are explained in section 5.3 and 5.4. For a discussion refer to section 6.2.

**RQ4:** *Are some picking station design changes especially suitable for specific items?*

In general, it was found that there is a greater improvement potential for smaller items, items in classes with letters earlier in the alphabet in the item classification system. However, combining larger items with smaller in the same picking station also constitutes a promising area for area efficiency improving design changes. The design changes developed and presented in this thesis are thought to have a rather limited value for items requiring lifting equipment, i.e. items in classes with letters late in the alphabet.

## 6 Discussion

In this chapter, the results coming out of the analysis above are discussed. First, the item classification system, presented in section 5.1, is discussed. Thereafter follows a general discussion around the reference companies and the picking station design improvements presented in chapter 5. The chapter is concluded with shorter discussions around each and one of the ideas presented in section 5.4 and further addressed in section 5.5.

### 6.1 Item Classification

It can be discussed whether the classification system presented in this thesis is a good way to classify items or not. In relation to that, it is important to stress that this classification system is developed with point of departure in the operations carried out by Volvo in their Torslanda plant. It is therefore likely to be biased towards the kind of items subject to sequence picking in TB1 at Volvo. However, it is believed that a classification system that could be of use also for other automotive companies should not differ substantially from the one presented here.

In hindsight, it proved to be difficult to connect different picking station design suggestions with each and every class of items, A to T in Figure 26 (see answer to RQ4 in section 5.6). Rather, when using the system in order to connect items with possible design changes, some of the classes has to be bundled together to form a bigger class while others might be excluded altogether, all depending on the specific situation. As shown in section 5.4, this is also what happened when the system was used within this thesis. We could see a clear bias towards a usefulness of the proposed changes for smaller items even though some of the changes are thought to work even for larger items.

Although some difficulties in clearly connecting item classes with design suggestions, the classification system is thought to bring useful insights regarding the items handled in an automotive sequencing warehouse such as TB1. An example of such insights, in relation to the changes proposed in this work, is when looking for picking stations to combine as it is then necessary to find smaller and larger items that could share a station.

At last, it should be stressed that the system not necessarily has to be used in the way that a design suggestion has to be connected to an item class. It could also be used when a company wants to implement a certain change and wonder what items to target. In this case the decision criteria along the decision tree have to be set according to the change in question. If one for example wants to implement change (5), move sequence rack through picking station while picking, one can use the criteria in the classification system in such a way that the items suitable to this change are identified. The possibility to change the criteria is also a part of why it is hard to statically connect an item, and hence also a specific design change, to a specific class. Depending on the criteria used, the same item can end up in different classes and depending on the same criteria the same design change might be suitable for different classes.

### 6.2 Picking Station Design Improvements

The picking operations in a facility like TB1 at Volvo are quite special. Most other picking operations similar to the ones performed in TB1 are carried out for products assigned to different customer orders. These customer orders can be seen as fairly random in terms of what they include and when they occur. The orders received in TB1 can of course also be seen as random as each car is assigned to a specific customer order. However, as soon as a car is ordered the presence of a product

structure makes it possible to know exactly what is going to be needed. In addition, the locations to which the products are going to be sent are pre-determined and known. So, the special thing with the operations is that each picking station serves only one customer and the location of this customer is fixed and known. The order fulfillment process is here also very intertwined with other operations, which makes sub-optimizations a very important issue to consider. These are things that make the whole process very interesting, but they also make it possible to question the validity in the reference companies used. The majority of these companies, Tamro, Carlsberg, Schenker and to some extent Elanders, lacks product structures. This puts quite different demands on their systems as they do not know what is going to be ordered and the order compositions as far in advance as TB1 does. However, the reference companies are still considered an important contribution to this work as they have provided many useful ideas and insights related to order picking.

As mentioned above, when implementing changes like the ones coming out of this thesis in a big organization, possibly the most important thing to address is if a sub-optimization will be the result of the implementation. As the main focus of the ideas presented here is on area efficiency, this is also the main performance indicator on which the ideas have been evaluated. Looking to implement some of the ideas, it is very important to consider their effect on other dimensions of performance such as cost, quality, productivity, ergonomic impact and employee satisfaction. Assessing all these variables is outside the scope of this work; however it is interesting to discuss some a bit closer. Quality and overall efficiency are two main concerns for Volvo and the impact on these should thereby be carefully evaluated before a possible implementation. In addition, it is very important not only to look at purely production related indicators but also on soft factors such as employee satisfaction and ergonomic implications of the changes. Talking to employees at Volvo it was found that there were concerns of too much walking related to the picking operations, something that should be taken into account when evaluating a possible change. Looking at the design suggestions presented in this thesis, some will reduce the walking distance and none is thought to have any negative ergonomic implications compared to the currently employed picking stations. It might even be the case that employing some of the changes presented here will add some variation to the work. If for example using vertical lift modules and/or elevating forklifts, the walking will be reduced or eliminated at some picking stations. In addition, the new work environment at some picking stations will provide some variation to the picking work which might be perceived as positive by the pickers.

When looking to implement a change it is also important to consider how existing systems might impact the adoption of the change or vice versa. The most prominent example of this in the case of Volvo is probably the pick-to-voice system and hence this will be used as an example here. If a change is not supported by an existing system, this will constitute an obstacle for the introduction of the change; especially if the existing system was a larger investment which is thought to work well. In terms of the changes presented here, consolidation of low frequency items to one picking location (6) and multi-picking (9) are the alternatives that mainly might be constrained by the pick-to-voice system. This as these changes will require changes in the picking support that might be hard to implement. However, the main point here is that, when looking to implement a change, it is important to be aware of the existence of constraints set by existing systems, and not exclusively focus on the obvious benefits shown by performance indicator estimates.

At last, before giving some short notes on each of the design improvements presented in section 5.4, it is well in place to comment on the sustainability aspect of this work. The main thing to



mention is that to save area also means to save resources, something which is good from a sustainability perspective. However, it is important not to take the resource saving for granted. If, for example, more effective area utilization for the sequence picking stations leads to lower inventory levels, a consequence might be that more transportation is necessary and thereby the overall resource usage might not decrease at all. Thus, increased area efficiency might be a change in the direction towards increased sustainability, but in order to be sure a more comprehensive analysis, covering more than only the area used, must be performed.

### **Vertical Lift Modules (1)**

When looking to implement an automated solution like this as close to the production as is the case in an automotive sequencing warehouse like TB1 it is very important to closely consider what effect this might have. These considerations include both what items to put into the VLMs and how to deal with possible mechanical problems. Regarding the items put in the VLM, it could be of value to evaluate them in terms of whether or not they will stop the assembly line. If they will to stop the line one should have a well thought through back-up plan or design the use of the VLMs in such a way that the likelihood of a stop is minimized. Some argue that this system is too similar to an automated storage system for pallets. However, we argue that there are considerable differences which make this system worth to consider even for use as close to an assembly process as is the case here. This is due to three main reasons. The first one is that the whole inventory is not kept in the VLMs and thereby the system is not as sensitive to technical problems as an automated pallet storage system. The second is closely related to the first, namely that the VLMs should be seen as picking stations rather than a storage system and in an emergency situation it would be possible to get items out of the other storage positions. The third is that it is possible to use more than one VLM and thereby keep the same items in different machines. Thereby all VLMs has to face problems at the same time if the consequence should be a production stop. At last, the VLMs are connected to an investment and hence the value of this investment is largely determined by the value put on area savings and picking efficiency compared to the risk of the investment.

### **Combine Picking Stations (2)**

The idea of combining picking stations is, in its simplest form, a fairly basic way of saving area. The idea is to find items which can be combined in one picking station, preferably over and under each other, similar to what is the case at Tamro. In the best case, this can be done using the existing way of presenting items to the picker and hence minimal investments are required. It might be hard to find items this easy to combine though, so another way to facilitate the combination is to have some kind of adjustable floor. Referring to what is presented in the ergonomics section of this work (section 2.2), picking even small and light items in a bad position can harm the worker. Hence, limitations are put on how it is possible to combine picking stations. However, by using a floor with adjustable height, it might be possible to stretch these limits and in that way save area. An adjustable floor would unfortunately require some investments. So, which solution is the best becomes a tradeoff between the necessary investments and the value of the possible area savings.

### **Elevating Forklifts (3)**

This idea is pretty much a variant of the one presented above. The main difference is that an elevating forklift is used for the picking and hence picking can be carried out on higher picking locations. This, of course, requires investment in the elevating forklifts, but using these more picking stations can be combined and thereby more area can be saved. In relation to this though, it is very

important to consider the storage issue. As the space above the picking stations at the moment is used as storage, the usage of this space for picking locations requires either new space dedicated to storage or outsourcing of the storage activities. There is a great potential for area savings for picking stations in this design suggestion. However, the storage problem has to be addressed and the cost for solving this together with the necessary investments has to be traded off against the value of the area savings.

#### **Extra Picking Level (4)**

Adding a fixed extra picking level will increase the area efficiency, but similarly to the elevating forklifts discussed above this will create issues in relation to the storage located above the picking stations. Another concern is that the sequence rack has to be lifted to the second level in some way; something that might constitute a safety issue as well as it will add activities to the material supply process. In addition, the area taken up by the stairs used to reach the second level will counteract the area saved as the area occupied by the stairs can be seen as waste. So, if the added level is too small the area saving effect will be limited. Accounting for the concerns raised here, implementing this idea or not becomes a tradeoff between the cost of the second floor, together with its implications for the picking operations, and the value of the area savings.

#### **Move Sequence Rack through Picking Station (5)**

The area savings available from using this idea is equal to the area currently occupied by the sequence racks, in other words no substantial area efficiency improvement. What is more interesting is that this alternative also might increase the picking efficiency considering the reduced walking time during the picking due to the picker constantly being close to the rack. Two possible problems are however important to highlight. The first is that pushing or pulling a heavy wagon might be ergonomically bad for the picker. The second is that when pricing the operations at picking stations, at least at Volvo, SAM-analysis is used and in this it is very expensive to get a wagon started. Hence, moving the sequence rack through the picking station, constantly starting and stopping, would be very expensive according to the SAM-analysis. So, as long as this method is used to price the activities this alternative might face rejections based on the virtual reality of the SAM-system. However, before rejecting the idea solely on these grounds, we would recommend a physical evaluation of the alternative together with consultation with the worker regarding the ergonomic aspects mentioned above.

#### **Consolidate Low Frequency Items (6)**

In the ends of the picking stations, low frequency items are presented in boxes, or on pallets, similar to the ones used for items with higher frequency. Even though these items can be used very infrequently they are presented in the same way as items with much higher turnover. This contributes to poor utilization of the area along the picking station, especially at stations with a high amount of very infrequent items. Using this idea, some extra handling will be required as will a way to identify which item is positioned where at the shared picking location. The extra handling is thought not to have that much of an impact since it only concerns low frequency items. The bulk of the items, in terms of frequency and handling, are managed as before. The position identification issue on the other hand might face obstacles in terms of compatibility with the pick-to-voice system. As long as this issue can be solved, this solution is a simple way to save some area. In order to know the extent of the saving, an evaluation of the frequency for the items at the different picking stations

is necessary. Having the result of this evaluation the estimated area saving has to be traded off against the cost for the saving in terms of necessary changes.

#### **Downsizing before Picking Station (7)**

Downsizing before presenting the items at the picking station would save area as fewer items are presented to the picker, hence the area for each item position can be reduced. On the downside, this adds extra activities in terms of extra handling. With this extra handling, even extra administration might appear. On the positive side, the change might be fairly easy to implement, depending on how the new material presentation is designed. A problem is however present in where the material removed from picking locations should be stored. If the total amount of items in the warehouse shall be the same as before, more items has to be assigned to the storage area, an area which, in the case of Volvo, already is limited. So, the usefulness of this idea again becomes, after making sure that the storage space is large enough or deciding to outsource storage activities, a tradeoff between the cost of the extra activities and the saving in terms of area.

#### **Presentation of Material (8)**

This is a minor idea thought to be used together with other ideas rather than on its own. Changing the packaging in which the material is presented is a smaller improvement which is not likely to have a big impact on its own, but since every change to the better is good it is thought to be an important idea to consider. An example of where this type of change could make a difference is at the picking station for door handles. The door handles are now presented lying next to each other in a box similar to a chocolate box. If the handles instead were delivered in a standing position, it should be possible to reduce the area taken up per box considerably without any major consequences for the picking operations.

#### **Multi-Picking (9)**

This is not considered an area saving solution, but rather a way of increasing picking efficiency. As the work proceeded, we saw a number of picking stations where small items were picked individually, e.g. antenna covers and door handles, resulting in a lot of walking carrying only small items. This raised the idea of some way of carrying more than single items by using for example a belt in which items can be put as the picker walks along the picking station. When all positions in the belt are filled, the picker moves the items from the belt into the sequence rack. This way of solving the problem might however be restricted by the pick-to-voice system, as discussed above, and it might also add a risk of reduced picking accuracy as the extra handling might cause items being put in the wrong positions. After evaluating the implications of the pick-to-voice system and the extra risk, the impact on the efficiency from multi-picking becomes a tradeoff between the reduced walking and the added handling.



## 7 Conclusions

The work presented in this thesis suggests a number of ways in which sequence picking stations can be re-designed in order to increase their area efficiency. Hence, by using one or more of these ideas, companies can, with various degrees of investment, increase the area efficiency of their picking operations. Worth to notice, though, is that the ideas presented are general with a focus on the automotive industry. Hence, the suitability for each company, and the items being picked, has to be carefully evaluated before an implementation decision is made. In addition, an item classification system has been presented, a system that might constitute a valuable tool for the evaluation.

As not much work is previously done on sequence picking stations, neither in general nor for the automotive industry, this work is a step in the right direction to fill a gap. The sequencing operations are a very important part in the process of supplying material to assembly lines in the automotive industry and even though this thesis mainly focuses on area efficiency, many other areas are, and have to be, included as well. A change in the sequence picking operations will affect the material flow in other parts of the supply chain, as well as it will affect the employees working in the process. Hence, this thesis is positioned somewhere between supply chain management, operations management, production engineering and work environment together with ergonomics. This position is right in the gap referred to in the beginning of this paragraph. So with this thesis, a piece of work on area efficiency, including connections to the other areas mentioned above, is starting to fill that gap.

In order to continue to fill the gap, more research is needed. This thesis provides ideas and one way of connecting these ideas to items with different characteristics in form of the item classification system presented. However, the validity of the ideas presented has to be further evaluated, as has the question of how easy they are to implement. An interesting thing to examine would be how other companies in the automotive industry, in addition to SAAB and Pininfarina, deal with sequencing operations. Are the ideas presented here possible to implement in such companies? Or are some already used? It would also be of great value to add new design considerations, like for example non-straight picking stations. Can some other shape be preferable in some context? Which shape is in that case better and why? As sequence picking is quite un-explored and since measures to increase effectiveness and efficiency are always coveted, especially in the automotive industry, we argue that there are great opportunities for interesting future research present in this corner of the field of logistics and supply chain management.



## **8 Recommendations to Volvo**

Volvo is recommended to consider the ideas presented in this thesis, as quite substantial area saving could be achieved. The extent of the possible area savings of course depends on which design idea is considered, and according to what is presented in the discussion chapter (section 6.2) the area efficiency is only one interesting parameter to investigate when evaluating the ideas. The value of the area savings often becomes a tradeoff to some other parameter where the most common one is the cost of the change, the required investment.

When an interesting idea is chosen, the next step is to find items/picking stations to apply them on. For this the item classification system presented in section 5.1 can be used. Appropriate selection criteria have to be set for the decision tree. After this, the tree can be used as a tool to perform a structured analysis of the items subject to sequence picking in TB1.

At last, a general conclusion from the work is that it seems likely that the greatest area savings are to be reached from re-designing picking stations for smaller items. According to the Pareto-rule, also known as the 80/20-rule, one can achieve good results by focusing on the 20% of something that commonly generates 80% of the outcome in the other end. Having this said, we recommend Volvo to focus on some picking stations, probably for small items or high variety items, with potential for great area savings and use these as pilot studies.





## References

- Alvesson, M. (2011). *Intervjuer - genomförande, tolkning och reflexivitet*. Malmö: Liber.
- Anon. (1986). Part-to-man systems keep order pickers busy. *Modern Materials Handling*, 41(4), 26-30.
- Arbetsmiljöverket. (2011). *Arbetsmiljölagen*. Retrieved from Arbetsmiljöverket: <http://www.av.se/lagochratt/aml/> June 27, 2011.
- Arbetsmiljöverket. (1998). *Belastningsergonomi*. Solna: Arbetarskyddsstyrelsen.
- Arbetsmiljöverket. (2000). *Manuell hantering*. Solna: Arbetarskyddsstyrelsen.
- Baker, P. & Canessa, M. (2009). Warehouse design: A structured approach. *European Journal of Operational Research*, 193(2), 425-436.
- Baudin, M. (2002). *Lean assembly: the nuts and bolts of making assembly operations flow*. New York: Productivity Press.
- Bergman, B. & Klefsjö, B. (2010). *Kvalitet från behov till användning*. Lund: Studentlitteratur AB.
- Braglia, M., Grassi, A. & Montanari, R. (2004). Multi-attribute classification method for spare parts inventory management. *Journal of Quality in Maintenance Engineering*, 10(1), 55-65.
- Bryman, A. & Bell, E. (2011). *Business Research Methods - 3rd Edition*. New York: Oxford University Press.
- Brynzér, H. & Johansson, M. (1996). Storage location assignment: Using the product structure to reduce order picking times. *International Journal of Production Economics*, 46-47(51), 595-603.
- Camillo, J. (2010). Guided assembly. *Assembly*, 53(13), 44-47.
- Daniels, R. L., Rummel, J. L. & Schantz, R. (1998). A model for warehouse order picking. *European Journal of Operational Research*, 105(1), 1-17.
- de Koster, R. (1994). Performance approximation of pick-to-belt orderpicking systems. *European Journal of Operational Research*, 72(3), 558-573.
- de Koster, R., Le-Duc, T. & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, 182(2), 481-501.
- Dukic, G. & Cedomir, O. (2007). Order-picking methods: improving order picking efficiency. *International Journal of Logistics Systems and Management*, 3(4), 451-460.
- Finnsgård, C., Medbo, L., Johansson, M. I. & Wänström, C. (2011). *Materials flow mapping: a tool for describing and assessing performance of material flows in supply chains*. Göteborg: Chalmers University of Technology.
- Goetschalckx, M. & Ashayeri, J. (1989). Classification and design of order picking. *Logistics Information Management*, 2(2), 99-106.

- Gu, J., Goetschalckx, M. & McGinnis, L. F. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*, 203(3), 539-549.
- Gunasekaran, A. & Kobu, B. (2007). Performance measures in logistics and supply chain management: a review of recent literature (1995-2004) for research and applications. *International Journal of Production Research*, 45(12), 2819-2840.
- Gunasekaran, A. & Ngai, E. (2005). Build-to-order supply chain management - a literature review and framework for development. *Journal of Operations Management*, 23(5), 423-451.
- Howard, M., Miemczyk, J. & Graves, A. (2006). Automotive supplier parks: an imperative for build-to-order? *Journal of Purchasing and Supply Management*, 12(2), 91-104.
- Hsieh, L.-f. & Tsai, L. (2006). The optimum design of a warehouse on order picking efficiency. *International Journal of Advanced Manufacturing Technology*, 28(5-6), 626-637.
- International Ergonomics Association. (2010). *International Ergonomics Association*. Retrieved from What is Ergonomics: [http://www.iea.cc/01\\_what/What%20is%20Ergonomics.html](http://www.iea.cc/01_what/What%20is%20Ergonomics.html) July 25, 2011.
- Jeziarski, R. & du Preez, A. (2009). Voice recognition - The sound of productivity. *The Engineering*, 294(7782), 33.
- Jones, D. T., Hines, P. & Rich, N. (1997). Lean Logistics. *International Journal of Physical Distribution & Logistics Management*, 27(3/4), 153-173.
- Karlsson, M. (2010). *Data Collection*. Gothenburg: Chalmers University of Technology. Lecture November 17, 2010.
- Lewis, M. A. (2000). Lean production and sustainable competitive advantage. *International Journal of Operations & Productions Management*, 7(8), 959-978.
- Liker, J. K. (2009). *The Toyota Way - Lean för världsklass*. Malmö: Liber.
- Malmberg, C. J. (1996). An integrated storage system evaluation model. *Applied Mathematical Modelling*, 20(5), 259-370.
- Manzour-al-Ajdad, S., Torabi, S. & Salhi, S. (2012). A hierarchical algorithm for the planar single-facility location routing problem. *Computers and Operations Research*, 39(2), 461-470.
- Maskell, B. (1989). Performance measures of world class manufacturing. *Management Accounting*, 67, 32-33.
- Maynard, B. H., Stegemerten, J. G. & Schwab, L. J. (1948). *Methods-Time Measurement*. New York: Toronto: London: McGraw-Hill Book Company.
- Michalos, G., Makris, S., Papakostas, N., Mourtzis, D. & Chryssolouris, G. (2010). Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. *Journal of Manufacturing Science and Technology*, 2(2), 81-91.

- Min-Chun, Y. (2011). Multi-criteria ABC analysis using artificial-intelligence-based. *International Journal of Expert systems with applications*, 38(4), 3416-3421.
- MTM-Föreningen i Norden. (n.d. a). *MTM-systemens utveckling och spridning*. Retrieved from Nordisk Produktivitet: <http://www.nordiskproduktivitet.com/?id=25> August 26, 2011.
- MTM-Föreningen i Norden. (n.d. b). *SAM*. Retrieved from Nordisk Produktivitet: <http://www.nordiskproduktivitet.com/?id=71> August 26, 2011.
- MTM-Föreningen i Norden. (2006). *Sekvensbaserad Aktivitets- och Metodanalys*. Västerås: MTM-Föreningen i Norden.
- Ohno, T. (1988). *Toyota production system: beyond large-scale production*. Cambridge: Productivity Press.
- Petersen, C. G. (2002). Considerations in order picking zone configuration. *International Journal of Operations & Production Management*, 22(7), 793-805.
- Petersen, C. G. & Gerald, A. (2004). A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics*, 92(1), 11-19.
- Prevent. (2007). *Ergonomi för ett gott arbete*. Stockholm: Prevent.
- Reif, R., Günthner, W. A., Schwerdtfeger, B. & Klinker, G. (2010). Evaluation of an augmented reality supported picking system under practical conditions. *Computer Graphics Forum*, 29(1), 2-12.
- Rowan, M. P. & Wright, P. C. (1994). Ergonomics is good for business. *Work Study*, 43(8), 7-12.
- Sarker, B. R. & Babu, S. P. (1995). Travel time models in automated storage/retrieval systems: A critical review. *International Journal of Production Economics*, 40(2-3), 173-184.
- Speaker, R. L. (1975). Bulk order picking. *Industrial Engineering*, 7(12), 14-18.
- SSI Schäfer. (2009). *Warehouse picking systems, automated picking with S-Pemat*. *Warehouse logistics solutions*. Retrieved from YouTube: <http://www.youtube.com/watch?v=lQDtp7d7cnA> July 28, 2011.
- Tompkins, J. A., White, J. A., Bozer, Y. A. & Tanchoco, J. M. (2003). *Facilities Planning - Third edition*. Hoboken: John Wiley & Sons.
- Toyota Motor Corporation. (2003). *Toyota Georgetown - The official website of Toyota in Kentucky*. Retrieved from The Toyota Production System: <http://www.toyotageorgetown.com/tps.asp> July 27, 2011.
- Vitasek, K. (2007). On picking and packing. *Multichannel Merchant*, 3(2), 41-42.
- Volvo Cars. (n.d. a). *Business Areas*. Retrieved from Volvo Cars: <http://www.volvocars.com/intl/top/about/corporate/career/pages/businessareas.aspx> August 10, 2011.

Volvo Cars. (2011). *Nyheter - Volvo Personvagnar AB 2010*. Retrieved from Volvo Cars:  
<http://www.volvocars.com/se/top/about/news-events/pages/default.aspx?itemid=164> August  
1, 2011.

Volvo Cars. (n.d. b). *Working at Volvo Cars*. Retrieved from Volvo Cars:  
<http://www.volvocars.com/intl/top/about/corporate/career/pages/working-at-volvo.aspx>  
August 17, 2011.

Womack, J. P. & Jones, D. T. (2003). *Lean thinking: banish waste and create wealth in your  
corporation*. 2003: New York.

## Appendix A – Literature Search Strategy

The following methodology should be followed when searching for academic articles in databases:

1. Determine a number of relevant words.
2. Start with the most relevant word, thereafter combine the words, first two and thereafter three and more.
3. Record which words and combinations that have been used as well as which databases have been searched.

The article selection will be based on the presence of the selected relevant words in articles' headlines and key words. In the case of no hits or no relevant articles found, the search will be extended to contain abstracts as well.

In addition to the strategy presented above, more random searches will performed and suggestions given by the searched databases, e.g. in the form of cited articles, will be explored.

The searches documented in the initial literature search are presented below; this in order to give the reader a feeling for how the search for literature was performed.

### Order Picking

#### Databases used:

Business Source Premier, Scopus, Emerald, Informit, ProQuest.

#### Relevant words:

Picking station, work station, layout, configuration, picking aid, pick-to/by-voice, pick-to/by-light, pick to belt, picking policy, picking technology, robotized picking, automated order picking

#### Searched combinations:

##### *Single search phrase:*

Pick\* station\*, work\* station\*, pick-to-belt, pick-to/by-voice, pick-to/by-light, pick\* technology, pick to belt, pick\* policy,

##### *Double search phrase:*

Pick\* station\* AND configuration, pick\* station\* AND layout, work\* station\* AND configuration, work\* station\* AND layout,

### Ergonomics

#### Databases used:

Business Source Premier, Scopus, Emerald.

#### Relevant words:

Ergonomics, picking, health, automotive

#### Searched combinations:

##### *One word search:*

Ergonom\*

##### *Two word search:*

Ergonom\* AND automotive, ergonom\* AND auto\*, ergonom\* AND pick\*

*Triple search phrase:*

Ergonom\* AND pick\* AND auto\*

## **Segmentation**

### **Databases used:**

Business Source Premier, Scopus, Emerald.

### **Relevant words:**

Classification, segmentation, identification, evaluation, elements, characteristics, attributes, hierarchy, automobile, car manufacturer, manufacturing, spare parts, warehouse, inventory, picking stations, sequencing.

### **Searched combinations:**

*One word search:*

Classification, Segmentation, Characteristics, Warehouse, Sequencing

*Two word search:*

Classification warehouse/inventory/picking station, classification/segmentation/sequencing spare parts, automobile warehouse/inventory/spare parts, identification picking station/sequencing/elements/spare parts, picking station/car manufacturer/warehouse sequencing/evaluation.

*Triple search phrase:*

Classification articles picking stations, segmentation articles picking stations/warehouse/inventory, characteristics/classification/segmentation spare parts warehouse/picking station.

*Quadruple search phrase:*

Identification characteristics articles warehouse/picking stations/inventory, characteristics/attributes evaluation warehouse/picking station automobile, hierarchy characteristics warehouse/inventory automobile/car manufacturer.

*Quintuple word search:*

Attributes sequencing automobile/car manufacturer/spare parts/warehouse.

## Appendix B – Performed Interviews

Date	Company	Interviewee	Title
2011-06-01	VCT*	Bengt-Göran Larsson	Produktverkstadschef
2011-06-13	VCT*	Michael Lindström	Material Handling Expert
2011-06-22	VCT*	Peter Hultman	Logistic Engineer
2011-06-28	VCT*	Michael Lindström	Material Handling Expert
2011-06-28	VCT*	Roine Johnsson	Material Handling Expert
2011-07-04	Pininfarina	Peter Andersson	Logistics Engineer
2011-07-12	VCT*	Linus Svanström	MP&L Project Manager
2011-08-03	Tamro	Tomas Björkman	Site Manager
2011-08-16	Carlsberg	Gert-Arne Ekman	Arbetsledare Plock
2011-08-23	Elanders	Mikael Hallgren & Anna Grönwall & Christoffer Liljesson	Head of Department, Storage Supply Chain Planner Supply Chain Planner
2011-08-31	DHL/SAAB	Martin Blom Jörgen Svensson	Operations Manager Supervisor
2011-09-02	Schenker	Ted Kahnvik	Gruppledare
2011-09-21	VCT*	Vande Petkovski Rolf Ros	Lokalt Hälso- & Skyddsombud Logistik & Kvalitet Vice President IF Metall Material Handling

\* - VCT – Volvo Cars Torslanda

## **Appendix C – Interview Template**

Denna intervjumall ska användas vid informationsinsamling gällande plockstationer och sekvenseringslagerlayout. Mallen är inte på något vis fullständig utan ska fungera som ett ramverk för att få med det viktigaste, som på förhand känns relevant. Intervjuerna kommer sedan utformas efter, och anpassas till, vad som händer under intervjuerna/besökens gång.

### **1. Generella frågor**

1.1 Hur sker materialförsörjningen till linan?

1.2 Hur många artiklar hanteras/sekvenseras här? Kommer resten sekvenserat från leverantören eller presenteras det i leverantörsemballage vid linan?

1.3 Kittas och/eller monteras några komponenter i lagret?

1.4 Använder ni SAM-analys (Sekvensbaserad Aktivitets- och Metodanalys) och TMUs för att beräkna tid/kostnad för stationerna?

1.5 Förslag på egenskaper hos komponenter som kan påverka stationslayouten? (vikt, storlek, antal varianter, plocka/häll, möjlighet till multiplock)

1.6 Vad för KPI:er används för att utvärdera plockstationer? Alternativt förslag på KPI:er.

1.7 Är plockhastigheten/genomloppstiden i sekvenseringslagret ett problem/hinder? Om inte: Kan den komma att bli ett problem/en begränsning om linans taktid skulle minska eller är det "gott om tid" för att utföra plockningen?

### **2. Stationslayout**

2.1 Vad för stationslayout används i dagsläget?

2.2 Hur har layouterna ändrats över tiden? (fler artiklar, hårdare sekvensstyrning)

2.3 Hur bestäms vilken layout som ska användas? Hur har nuvarande layouter utvecklats?

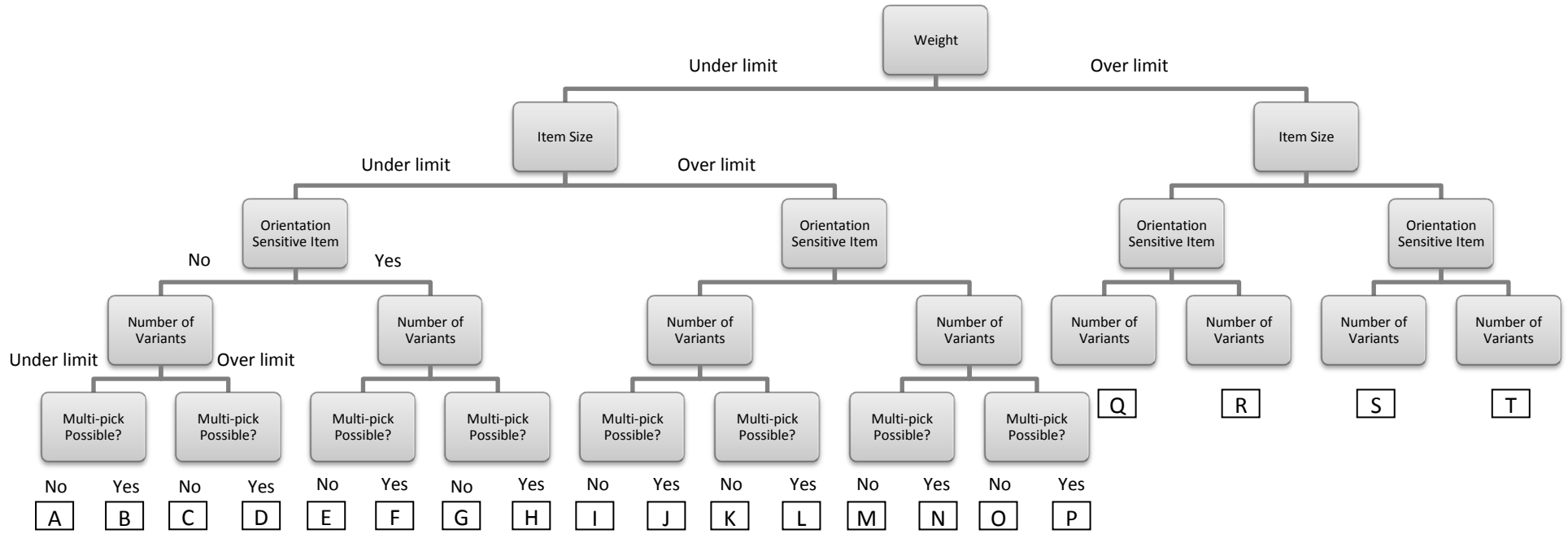
2.4 Används olika layouter för olika stationer? Och i så fall vad är anledningen till att ha olika?

### **3. Plockhjälpmedel**

3.1 Vad för plockhjälpmedel används idag? (pick-to-voice, pick-to-light etc.)

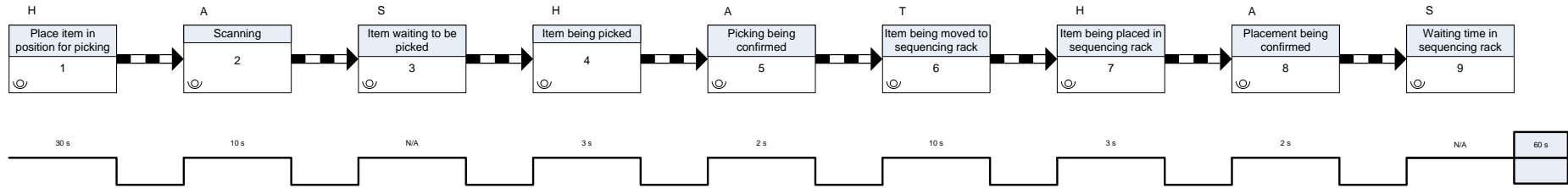
3.2 Hur har hjälpmedlen ändrats över tiden? Positiva/negativa effekter.





MFM – Materials Flow Mapping  
 VCT Conceptual Picking Station  
 August 2011

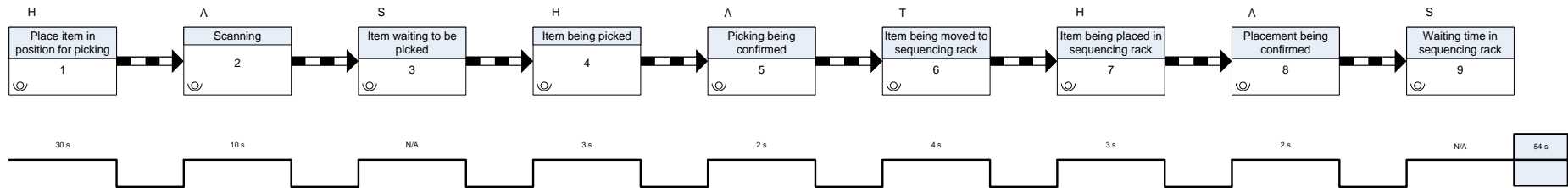
No. of H: 3  
 No. of A: 3  
 No. of T: 1  
 No. of S: 2  
 Tot. activities: 9  
 Tot. time: 60 s



78

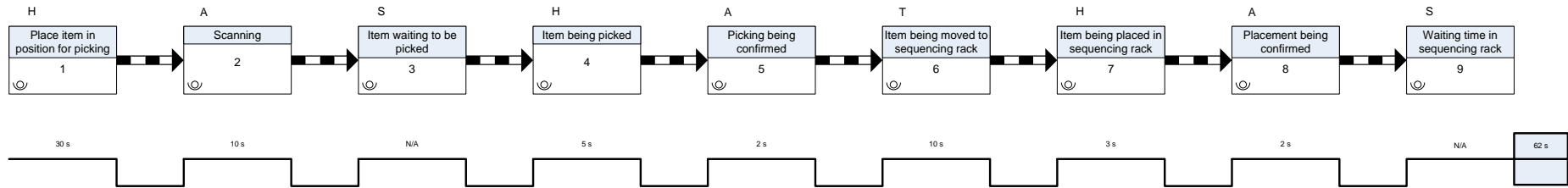
MFM – Materials Flow Mapping  
 VCT Conceptual Picking Station with VLM

No. of H: 3  
 No. of A: 3  
 No. of T: 1  
 No. of S: 2  
 Tot. activities: 9  
 Tot. time: 54 s



MFM – Materials Flow Mapping  
 VCT Conceptual Combined Picking Station

No. of H: 3  
 No. of A: 3  
 No. of T: 1  
 No. of S: 2  
 Tot. activities: 9  
 Tot. time: 62 s



## Appendix F – Data for Evaluation of Design Changes

Below is the data used for the evaluation presented in section 5.5. Presented first is data regarding the vertical lift modules used by Elanders and after that follows station specific data for some present picking stations at Volvo.

<b>Vertical Lift Modules</b>	
Data from VLMs used by Elanders.	
More details available e.g. at: <a href="http://www.welandlagersystem.se/sv-se/compact-twin.htm">www.welandlagersystem.se/sv-se/compact-twin.htm</a>	
Base area per VLM	3x3 = 9 m <sup>2</sup>
Trays per VLM	45
Positions per tray	27
Positions per VLM	1215
Area per Position	310x215 mm <sup>2</sup>
Distance between trays	270 mm

<b>Picking Stations at Volvo</b>	
Data collected for some picking stations at Volvo Cars Torslanda.	
<b>Item type</b>	<b>Door handles</b>
Item class according to classification system	B or D *
Approx. no. of items at station	192
Bottom area of item presentation box	600x400 mm <sup>2</sup>
Height of item presentation box	< 270 mm
Approx. Picking station area	5x16 = 80 m <sup>2</sup>
<b>Item type</b>	<b>Side mirrors</b>
Item class according to classification system	A or C *
Approx. no. of items at station	71
Bottom area of item presentation box	800x600 mm <sup>2</sup>
Height of item presentation box	< 270 mm
Approx. Picking station area**	4x37 = 148 m <sup>2</sup>
<b>Item type</b>	<b>Side mirror covers</b>
Item class according to classification system	B or D *
Approx. no. of items at station	72
Bottom area of item presentation box	600x400 mm <sup>2</sup>
Height of item presentation box	< 270 mm
Approx. Picking station area**	4x37 = 148 m <sup>2</sup>
<b>Item type</b>	<b>Antenna covers</b>
Item class according to classification system	B or D *
Approx. no. of items at station	33
Bottom area of item presentation box	600x400 mm <sup>2</sup>
Height of item presentation box	< 270 mm
Approx. Picking station area	5x5,5 = 27,5 m <sup>2</sup>

<b>Item type</b>	<b>Manuals</b>
Item class according to classification system	B or D *
Approx. no. of items at station	165
Bottom area of item presentation box	600x400 mm <sup>2</sup>
Height of item presentation box	< 270 mm
Approx. Picking station area	5x20 = 100 m <sup>2</sup>
<b>Item type</b>	<b>Pedals</b>
Item class according to classification system	- ***
Approx. no. of items at station	53
Bottom area of item presentation box	N/A
Height of item presentation box	N/A
Approx. Picking station area	4x30 = 120 m <sup>2</sup>
<b>Item type</b>	<b>Lower door strip</b>
Item class according to classification system	- ***
Approx. no. of items at station	122
Bottom area of item presentation box	N/A
Height of item presentation box	N/A
Approx. Picking station area	2x(4x33) = 264 m <sup>2</sup>

\* - Depends on "number of variants"-limit.

\*\* - Side mirrors and their covers are already combined in one station.

\*\*\* - Depends on too much to be valuable to specify here.