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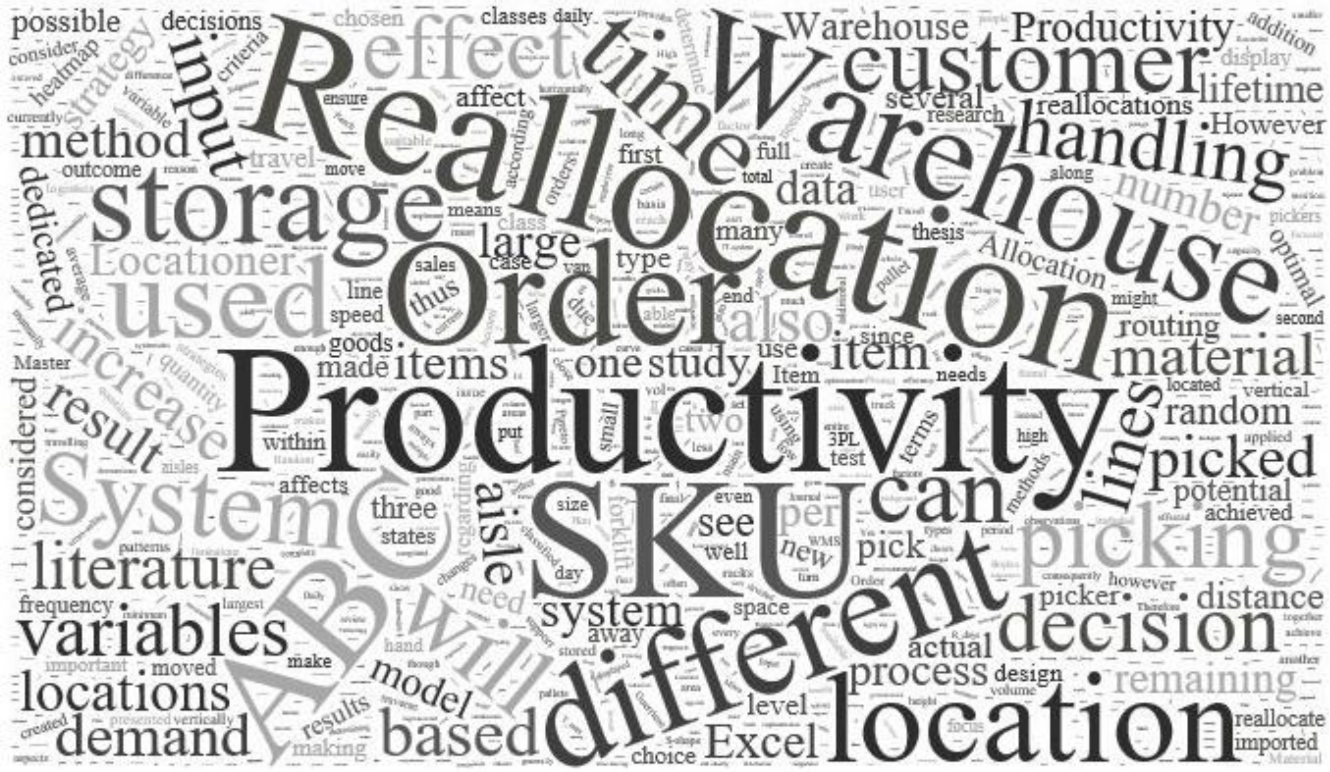

Variables used in a warehouse reallocation decision and an evaluation of an ABC-analysis system

A multiple-case study at a 3PL company

Master of Science Thesis
in the Supply Chain Management Programme

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Thank you and enjoy!

Sincerely,
Erik Asker & Fredrik Claesson
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Abstract

In today's increasingly competitive and globalized market, companies are forced to focus on their core competencies to stay competitive. Within the 3PL market the conditions are no different and 3PLs are forced to optimize their operations to stay competitive. One approach to stay competitive is to reallocate products within the warehouse to maximize productivity and minimize costs. Reallocation is an improvement strategy that could improve the productivity, defined as order lines picked per man-hour, by moving high-volume movers to more accessible locations and low-volume movers to less accessible locations. This to ensure that the picking process can be completed as efficiently as possible.

This thesis is a multiple-case study of the customers of the 3PL Schenker Logistics AB (SLOG), located in Landvetter, Sweden. SLOG is working with reallocations on a daily basis but are currently unsure of what criteria to consider before a reallocation decision is made and what the resulting productivity effect could be. As a means to improve the reallocation decision, SLOG has acquired a decision support system called System X that classifies products by applying an ABC-analysis. The purpose of this study is to investigate what variables that should be considered in a reallocation decision and how they affect the productivity outcome as well as evaluating System X. Throughout the study, qualitative interviews with key employees and managers of each customer at SLOG were the main technique used for collecting empirical data. The empirical findings were later compared with literature within the field to conclude what variables should be used in a reallocation decision.

The study shows that the reallocation decision is very complex, with many potential variables to consider. In total 20 variables were identified that directly or indirectly affects the reallocation decision and the related productivity outcome. The variables were divided in two categories; input variables and wildcards. The first category having a direct and measurable effect on the productivity whilst the second category has a non-quantifiable effect on the productivity outcome. In addition, an Excel model was developed that calculates the productivity outcome of a reallocation decision, based on the identified input variables. Reallocation tests were performed and it was concluded that in general, reallocations should not be made in a random storage setting unless the remaining inventory level is high and the average pick quantity is low. In contrast, within a dedicated storage setting, reallocations generally result in a productivity increase. Finally, it is not recommended that System X should be used in its current form, due to its many limitations.

Keywords: Warehouse reallocation, Picking productivity, ABC-analysis, SKU characteristics

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Terminology

- 3PL — Third Party Logistics
- DC — Distribution Centre
- Locationer — The person responsible for the reallocation and allocation of goods
- Most Optimal location — The most optimal location, is the most accessible pick location in the warehouse determined by the Warehouse Improvement Specialist
- Productivity — Order lines picked per man-hour
- SKU — Stock Keeping Unit
- SLOG — Schenker Logistics AB
- WMS — Warehouse Management System

1 Introduction

This first chapter will provide a background of the Master's thesis and the logistics industry itself. Following the background, the problem will be presented leading up to the aim and outline of the thesis.

1.1 Background

The market conditions of today are changing and products are now being exchanged on a globalized market (Javalgi et al., 2009). As more companies begin with international trade, the competition on the market has increased (Kakabadse & Kakabadse, 2005). With this increased competition companies have started to focus on their core competencies to stay competitive (Javalgi et al., 2009; Kakabadse & Kakabadse, 2005). Consequently, companies outsource non-core activities and build their supply chains with a larger number of actors than before. The more trading that is performed on a globalized market the more important the logistics has become (Dotoli et al., 2015).

With the globalization trend and increased focus on core competencies, the view of competing companies has changed into competing supply chains (Hult et al., 2007). From a supply chain perspective logistics play an important role, which has increased the interest in the utilization of a Third-party Logistics (3PL) service provider (Hertz & Alfredsson, 2003). A 3PL service provider is acting in between the company and its customers and is responsible for all, or parts, of the logistics services needed by the company (Hertz & Alfredsson, 2003).

In recent years, more 3PL companies have entered the market and created a wider selection for the customers, which has created a situation where a 3PL no longer can use the same warehouse system for all customers and must offer customer tailored solutions. By offering customer tailored solutions for each customer Schenker Logistics AB (SLOG) are able to reduce the cost for the customer and stay competitive. A customer tailored solution implies that SLOG creates a different warehouse solution for each customer in terms of racking, picking processes, material handling equipment and picking tools based on its characteristics, to ensure maximum productivity (order lines picked per man-hour), without compromising other customer set KPIs. Apart from these KPIs, productivity also has an effect on the sustainability of a company. Not only in an economic perspective but also from a social and environmental viewpoint as it could affect stress levels for workers as well as energy consumption of operations. Providing a customer tailored solution however, remains to be the main challenge of a 3PL (Hertz & Alfredsson, 2003). While creating this solution the 3PL must consider the physical product and its order pattern. Setting this demand profile could be rather complicated as it can change due to factors such as competition, seasonality and new product releases (Pazour & Carlo, 2015). All these factors makes the work of the 3PL very complex to perform efficiently (Hertz & Alfredsson, 2003).

As the end users are demanding a wider product range and customers change the inbound order pattern, the warehouse planning of the 3PL has changed. To meet the requirements of their customers the 3PL now must work with stock-keeping unit (SKU) classifications to be able to quickly identify high-volume movers and reallocate goods for an optimized warehouse. Getting an optimized warehouse in terms of item allocation is an important task in distribution centres (DC) today (Pazour & Carlo, 2015). Warehouse performance can be founded on several different KPIs such as; productivity, quality, storage capacity etc. (Accorsi et al. 2014). However, at SLOG a possible reallocation is only evaluated based on the productivity outcome, since a reallocation of an item does not have an effect on the other KPIs according to SLOG. Reallocating products is a strategy that is commonly used to improve the picking route and increase warehouse productivity (Pazour & Carlo, 2015).

This Master's thesis will have its focus on SLOG and the logistics industry as well as finding input variables (defined as a variable that should be included in the decision making) that affects the decision to reallocate an item in the warehouse. SLOG is a part of DB Schenker, DB Schenker in their turn is a division of one of the largest logistics and transportation service providers in the world: Deutsche Bahn Group. SLOG, which this Master's thesis will focus on, has different warehouses located across Sweden: Stockholm, Nässjö, Jönköping and Gothenburg. The headquarters of SLOG has since 2011 been located in the DC in Landvetter, Gothenburg. The DC in Landvetter has numerous different customers and each of them have its own customer tailored logistics solution. According to SLOG the main aim is to run the logistics operations as efficiently as possible and reduce the total logistics cost for the customers. To reach an efficiently run warehouse and a low logistics cost for the customers, SLOG has to continuously evaluate and improve their operating processes and storage allocations procedures.

1.2 Problem description

SLOG is working with numerous different customers and provides each of them with a customer tailored logistics solution, resulting in that SLOG is not able to utilize the same approach to every customer. However, as Dotoli et al. (2015) state, some customers can utilize the same assignment strategies, as random and dedicated storage. Each customer of SLOG has different products with different characteristics in terms of weight, size and order patterns etc. The weight, as an example, is a determining factor regarding if the goods can be stored in a rack or not. If the weight of the goods exceeds the load limit of the rack, it has to be stored on the floor. As all characteristics of the product affects how and where the goods can be stored, the warehouse optimization of SLOG becomes very complex.

Currently, SLOG is applying a vertical ABC-analysis based on experienced people's judgment to optimize the order picking. A SKU classification such as ABC-analysis is necessary in warehouse optimization and is widely used (van Kampen et al., 2012). The ABC-analysis can be performed in several different ways, mostly in terms of dollar volume and order lines picked (Flores & Whybark, 1985). The classification of items is usually based on storage volumes, customer demand, criticality, and lead-time, amongst others (van Kampen et al., 2012; Hatefi & Torabi, 2015; Ravinder & Misra, 2016). The experienced people at SLOG working with reallocations and warehouse optimization have the title Locationer. Their job is to maximize the productivity of the warehouse and allocate incoming goods, which is a manual process where the Locationer must gather an Excel spreadsheet and combine the information with data in the system. Consequently, this is a process that takes time and could be bias. Jenkins and Wright (1998) have found some commonly made mistakes during the execution of an ABC-analysis, one is not ensuring the accuracy of the information input, another is missing the packaging complexity factor and lastly cost of goods sold.

As the competition and order volumes are increasing the unutilized available space within each warehouse has decreased, thus warehouse optimization is becoming even more important. When SLOG starts working with a new customer or receives new products, SLOG does not know how they should be classified in accordance with the ABC-analysis, as their ABC-analysis is based on order lines picked per man-hour. Decisions on how to initially classify the products are thus only based on the Locationers judgment. SLOG has started to notice a change in the customer's incoming orders. The incoming order frequency has increased and the size of each shipment has decreased. Dealing with smaller order volumes results in that SLOG must reallocate the items more often than before. At the same time as they need to fit all the items in the available slots they also need to ensure that the picking routes are as efficient as possible, as the outbound orders are increasing in frequency as well. Increasing the productivity in a manual process based on judgment can be criticised, firstly as the criteria behind the reallocation can change and decrease the productivity and secondly as not all the information is evaluated and time constraints are a factor. One criteria that is not commonly included at SLOG is the actual performance of the material handling equipment. The material handling equipment used at each customer varies, and so does its performance, which in turn can result in that the reallocation process becomes more (or less) time consuming. Having to include several criteria in the reallocation decision has according to van Kampen et al. (2015) resulted in that many companies today struggle with their warehouse system.

When the order patterns for inbound/outbound shipments are changing, it requires the Locationer to spend more time on reallocations, to either create space for incoming goods or to improve the picking route. The reallocation process, at SLOG Landvetter, is now more than a full time job as they need to consider many different input variables when making the reallocation decision. Above, some input variables such as weight, size, order patterns, order lines picked and the performance of material handling equipment was mentioned. There are however several more characteristics that the Locationer could include in the reallocation decision, for example inventory on hand, seasonality and provided forecasts etc. According to

Dotoli et al. (2015) companies are in need of a software to deal with this increased complexity.

Schenker Asia Pacific has created an IT-system, in this report called System X, to deal with this issue. System X is an ABC-analysis tool, which uses order lines picked as a basis for its classification of products, which is in line with the standardized way of ABC-classification at SLOG. The development of System X is finished but has not been implemented on a large scale, only three Schenker sites worldwide have implemented the system to date. After importing information about the product, its location, sales per day and picking date, System X creates a visual map of the actual warehouse and all products, colouring each product according to its ABC-classification (see Figure 1). System X therefore does not display how the items should be stored, rather where they currently are located and the classification they have received. Utilizing this IT-system would potentially reduce the amount of manual work needed by the Locationer and ensure a systematic approach to the warehouse reallocation process. An IT-solution could also ensure that the criteria behind a reallocation can be set beforehand and the reallocation outcome can be measured and compared. According to Dotoli et al. (2015) it is hard and not that common to have a systematic approach to warehouse optimization.

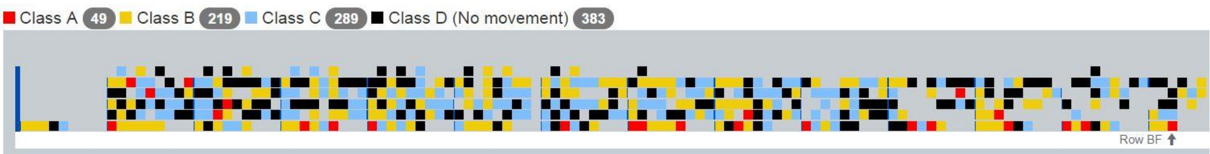

Figure 1. Final result of System X with the white divider representing the warehouse floor and each row of coloured dots representing a level in the racks.

1.3 Purpose

The purpose of this Master's thesis is twofold. The first part is to determine what input variables that should be considered in a reallocation decision in accordance with an ABC-analysis, with the purpose of increasing the productivity. The second part is to evaluate System X, to understand for what kind of customers it can be used and if SLOG should implement it or not.

In order to fulfill the purpose of this Master's thesis the following research questions will be answered:

1. What input variables are commonly used in a reallocation decision at SLOG and in theory?
2. How does the reallocation of products affect the productivity of the warehouse?
3. What is System X evaluating in its ABC-analysis?
4. How can the results of System X be used for different customers?

1.4 Thesis outline

1. **Introduction**	This section introduces the research area, provides a background to the problem, presents the aim and lastly gives the outline of the thesis.
2. **Method**	The methodology chapter describes how the research of the thesis was conducted. It describes how the data was collected, how the interviews were performed and how the literature review was conducted.
3. **Literature Review**	In this section theoretical background information relevant to the purpose of this thesis is presented. Concepts presented in the literature study are Warehouse Management, Warehouse functions, Warehouse routing, Material handling equipment, Item classification and Warehouse Reallocation.
4. **Empirical Data**	Contains general information about SLOG and its customers, but also specific information regarding the operation of the three chosen customers. Furthermore, this chapter present information collected from experts and managers of SLOG.
5. **Analysis**	The analysis chapter contains two different parts. The first part is the analysis of the different input variables of a reallocation decision. The second part is a thorough evaluation of the IT-system System X, its limitations, areas of use and finally how it should be applied.
6. **Development of Excel model**	This chapter presents how the Excel model was created and the purpose behind it. It also presents how the Excel model can be used and how it was applied in the evaluation of a reallocation decision at SLOG.
7. **Discussion**	In this chapter a deeper discussion of how the routing method and storage assignment affect each other will be presented as well as future suggestions for HeatMapper, the sustainability aspect of a reallocation decision and finally the credibility and usability of the Master's thesis results.
8. **Conclusion**	Short presentation of the conclusions of the performed thesis.

2 Method

This section describes the intended design, approach and strategy of the study as well as specific methods that were used. The aim is to describe the methodology that was used when conducting the study to enable the reader to more easily follow and understand the results and conclusions as well as, as far as possible, enable replication of the study.

2.1 Research design and approach

The research design aims to provide a framework for collecting and analysing data (Jacobsen, 2002). Bryman and Bell (2015) lists five types of research designs; experimental design, cross-sectional design, case study design, longitudinal design and comparative design. Each design has different merits and its applicability will differ depending on the context of the study and the research questions. In a comparative design multiple cases are investigated and compared with close to identical methods (Bryman & Bell, 2015). With the comparative approach the researchers are better equipped to understand what is investigated and to draw conclusions concerning when a theory will or will not hold (Bryman & Bell, 2015). As this Master's thesis was supposed to investigate the customers of SLOG, to find specific variations between them and the information collection could not be performed at a specific point in time, a comparative research design was employed.

While the research design sets the overall framework of the study, the approach to a greater extent steers the choice of concrete methods. There are two basic approaches, the qualitative and quantitative approach (see Chapter 2.3). A qualitative approach was used in addition to the comparative research design, as the thesis was mostly built on observations and interviews. Some quantitative data was used, but only to a small extent. By applying a qualitative approach, the researchers mitigates the risk of being restricted in their perception of the studied problem by already available information and knowledge, and therefore get a broader understanding of the problem (Bryman & Bell, 2015). When a qualitative approach is combined with a comparative design the result is a multiple-case study, where the goal is to compare and contrast findings from different cases related to the individual characteristics of each case (Bryman & Bell, 2015). The research design of this thesis is thus a multiple-case study with each customer constituting a case in itself. By denoting the customers as cases, making them the focus of the study, it is also possible to incorporate additional customers from other SLOG DC:s.

When conducting a case study, it is appropriate to use research questions focusing on "how" and "why", but "what" questions can also be applied (Yin, 2009), the latter being a more explanatory approach to a problem. Case studies are often used for detailed investigations within both qualitative and quantitative business research (Yin, 2009) and emphasis is put on the inbound complexity and specific nature of a single case (Bryman & Bell, 2015). Yin (2009) further states that using multiple cases has the advantage of making the study more robust than a single case study. When performing a study, there are three different approaches describing the relationship between theory and research; deductive, abductive and inductive (Bryman & Bell, 2015). Selecting an inductive approach means putting focus on findings and observations made throughout the study and based on this, produce theory. This is an often used strategy when doing qualitative research (Bryman & Bell, 2015; Jacobsen, 2002). In this study the researchers took an inductive stance, putting emphasis on observations and interviews in an actual working environment. Theory was mainly used as a means for the researchers to understand and interpret what was being observed but also as a support for the development of the resulting theory.

Bryman and Bell (2015) further states that it is important to define the level of analysis in a study, where measurement and analysis will be applied and made. As a consequence of the chosen research design, the level of analysis in this study was the customers of SLOG, which was represented by their Warehouse Manager and Locationer.

2.2 Time plan

This short chapter describes the time horizon of the Master's thesis and display the different parts of the study and when the respective phase was started and finished (see Figure 2).

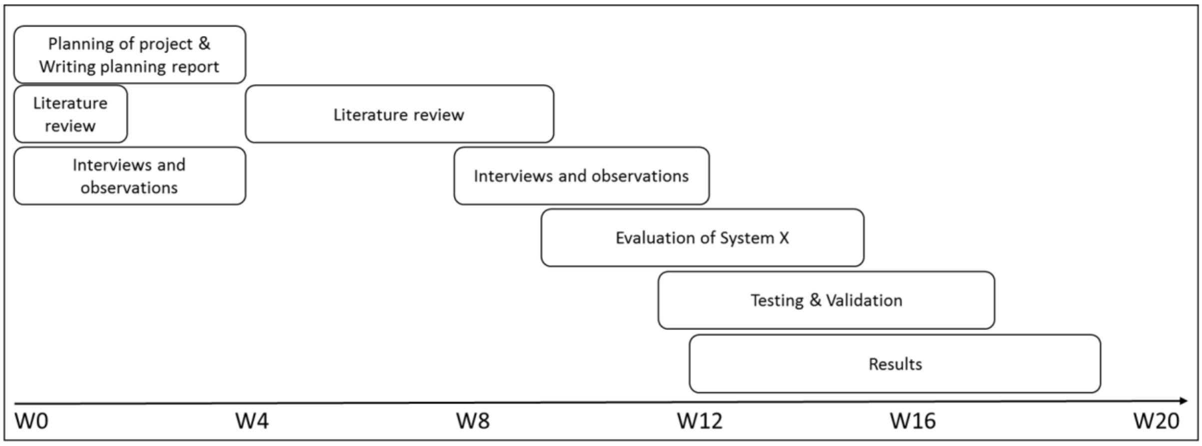

Figure 2. Gantt chart of the Master's thesis process weeks

2.3 Data collection

A qualitative research approach has its focus on people's values and their understanding of a phenomenon (Jacobsen, 2002), qualitative data tends to be more descriptive of the investigated situations context. The qualitative approach is less structured than the quantitative and is more flexible in terms of letting findings affect the research design and choice of methods. Typical methods of a qualitative approach are participant observations, qualitative interviews, focus groups, language-based approach to data collection and collection and qualitative analysis of texts and documents. The qualitative research is often inductive and focus on generation of theory rather than testing of theory (Bryman & Bell, 2015).

This thesis was constructed based on data from several different sources, which according to Yin (2009) provides an opportunity to distinguish their specific connections and differences. Firstly, the primary data was collected through qualitative interviews with: a Warehouse Improvement Specialist, Warehouse Managers, Warehouse Planners, Locationers and Operators at SLOG. Secondly, data was also collected through secondary sources as databases and SLOG catalogues. Thirdly, information regarding the actual warehouse operations was collected through the Warehouse Management System (WMS) and with the help of the IT department. Lastly, general information about the customers and SLOG operations was gathered through semi-structured interviews with SLOG headquarter personnel.

2.3.1 Literature review

Bryman and Bell (2015) describes two basic types of literature searches: systematic and narrative. The narrative method is more suitable for qualitative studies with an inductive approach, that often reviews literature as a means to get an initial understanding of the topic of the study. Typically, the narrative study is less focused than the systematic approach and covers a wider range of topics (Bryman & Bell, 2015). Consequently, the literature search method that was used in this study was the narrative literature review.

Two rounds of literature searches were made in the study, the first of which was superficial and served as a first familiarization with the following subjects: Warehouse Management, Warehouse Optimization and ABC-analysis. By the applied approach the researchers were able to obtain the initial knowledge needed to understand what would later be investigated and to be able to set up the design, approach and research questions. The subsequent literature search was more structured and covered similar areas as in the first search but used an appropriate set of keywords and was hence more focused on the relevant subjects. Both searches were made in databases available at Chalmers Library, Proquest, Scopus and included books and published articles as well as relevant Master theses.

2.3.2 Interviews and observations

In order for the researchers to stay objective and have an open mind regarding the information needed for the assignment, methods such as participant observations and semi-structured interviews are recommended (Bryman & Bell, 2015). These methods helped the researchers with theorizing and conceptualization. The interviews conducted in this study were qualitative, in most cases semi-structured but initial pilot-interviews were unstructured.

When conducting an unstructured interview, a starting question might be posed and the interviewee will then be allowed to steer the conversation himself. The semi-structured is more structured, using an interview guide with pre-formulated questions. Gillham (2007) states that a semi-structured interview is flexible and allowed to divert from the made up plan of the interviewer, picking up on tangents brought up by the interviewees. Thus, resulting in comprehensive and detailed answers. In addition, Jacobsen (2002) mention that it is common that one or more follow up interviews are made. As the researchers aimed to collect relevant information regarding the customers, the semi-structured interview was utilized to ensure that the answers had its point of departure in the proposed subject. Furthermore, to ensure that the information collected was correct and to attain deeper understanding of the problem, several follow up interviews were performed.

The interviewees were selected based on a purposive sampling strategy that took the research questions into consideration. The interviews were performed at different levels of the organization to get their specific expertise and all viewpoints of the problem. Warehouse Managers and Locationers represented the largest selection, which also was the main group used for the observations. As stated, initial pilot-interviews were held with the Warehouse Improvement Specialist at SLOG as well as the Warehouse Manager and Locationer for one chosen customer. The result of these interviews together with the initial literature review then became the basis of the interview guides for the subsequent semi-structured interviews.

Bryman and Bell (2015) states that the researchers can adopt different roles when making the observations; complete participant, participant-as-observer, observer-as-participant and complete observer. In this study the researchers took the role observer-as-participant, which entails observations and interviews without much participation besides being on site for a period of time (Bryman and Bell, 2009; Jacobsen 2002). During the observations, mental and jotted notes were taken to later be written up as full field notes.

2.4 The development of an Excel model and the purpose behind it

In order to be able to evaluate the potential productivity effect of a reallocation decision numerous calculations are required. Manually performing these calculations takes time and can result in errors. Therefore, an Excel model was developed to create a standardized approach, that quickly could determine the potential productivity effect of a reallocation, at the same time as it removed the possibility of manual calculation errors.

The developed Excel model was coded in Excel Visual Basic For Applications (VBA), which essentially are macros that are run in the background when the user activates them. Coding all the formulas in VBA ensured that every calculation formula was computed in the same manner every time and as it is hidden in the background, the user is not able to remove the calculations by accident. In order for the user to change the calculations the user has to enter the background environment of Excel and make changes in the written code.

The Excel model is to be considered as a decision support system prototype for SLOG, where it is possible to see the effect of a reallocation and the calculations that are required. The calculations that are used in the Excel model was a result of the input variables that were found to affect the productivity of the picking process and can be found in Chapter 6.3.

2.5 Evaluation of System X

The evaluation of the ABC-analysis tool System X was made throughout the study. The first step in its evaluation was to understand the different input variables which it considers. Secondly, an understanding of the current operations and the decision process of the Warehouse Managers and Locationers of each customer needed to be gathered. The gathered information was vital to review how comprehensive and realistic System X can be. The required information was mainly collected through interviews with the Warehouse Managers/Locationers and by observing their work procedures.

When an initial understanding of the daily operations and what information decisions are based upon was achieved, an evaluation of System X could be attempted. Data was gathered from SLOG’s warehousing system regarding three chosen customers, which then was fed into System X for processing. The three chosen customers of SLOG had different characteristics to cover the three different storage assignment strategies used at SLOG and at the same time covered the full range of demand/order volume patterns. The first customer to be evaluated was Customer H, which was a low-volume customer which used dedicated storage. Starting with a small customer with dedicated storage was preferred as the imported data was then not too large to grasp manually and at the same time items remained in the same slot for a long time. Customers with these characteristics enabled the researchers to easily enter the warehouse and physically visit the location, without risking that the item had been moved or sold. In addition, as the items did not change location the researchers were able to test the different settings in System X and see their effect. The second customer to be evaluated was Customer G that had fairly high order volumes on a daily basis, but applied a random storage allocation instead of dedicated as the first customer. The third and last customer was Customer D, a large customer of SLOG Landvetter, which had very large order volumes and applied the final assignment strategy; class-based storage. These three customers together covered the full spectra from dedicated storage locations with small order volumes to class-based storage with large order volumes. Furthermore, having large differences in order volumes and input information tested the scalability of System X and its limitations.

Finally, the researchers reviewed the generated heatmaps and used the developed Excel model to calculate the potential productivity increase of reallocating a SKU. The review was based on three different reallocation tests, each of which testing a different type of reallocation decision. The first reallocation test investigated if a productivity increase could be achieved by only reallocating a high-volume SKU vertically to a more accessible location. Secondly, the Excel model was used to determine the potential productivity effect of moving a SKU both vertically and horizontally and lastly moving away a SKU to a location further into the warehouse. Furthermore, each individual heatmap was reviewed to distinguish if and for what type of customers that SLOG could use System X.

2.6 Quality of study

The typical way of evaluating a study is to consider aspects such as reliability, replicability and validity. According to Bryman and Bell (2015) these aspects are most applicable to quantitative studies and suggest that an alternative set of parameters is used when evaluating the quality of a qualitative study. These are credibility, transferability, dependability and conformability which taken together, shows the trustworthiness of the study. (Bryman and Bell, 2015)

Yin (2009) states that a case study can have issues with generalization to other cases. In this Master's thesis this is mediated through the multiple-case design since each case, with its individual and unique context, contributes to a more complete set of parameters to consider. Approaching the problem in this manner adds to the reliability or dependability of the study and consequently adds to the credibility as well as transferability of the results to other contexts.

The data that was gathered from SLOG's WMS is deemed to be reliable since it has been reviewed and evaluated during a long period of time by professionals and experts on warehousing optimization. In addition to this, two Master theses have already been made based on this data, Frankin & Johannesson (2013) and Jösok & Gärdefors (2015), and have confirmed the reliability in their results, in one case with the help of time studies.

Interviews conducted throughout the study were of a qualitative type, which means that the gathered data consisted of personal and judgmental opinions on the subject. In addition, a qualitative interview is vulnerable to influences by the researchers own values (Gillham, 2007). To mitigate this issue, interviews were held with a Warehouse Improvements Specialist, a Warehouse Manager and Warehouse Planners, Locationers and regular Order pickers for each customer of the warehouse. To prevent the researchers to influence the result of the interviews to a large extent and to strengthen the confirmability of the study, interview templates were made before the interviews, see appendix A. However, since the interviews were semi-structured, some complementary questions were allowed.

In order to ensure that the results given by the Excel model became reliable rigorous testing of the system was made. First the system was tested with dummy variables to ensure that the logic behind the calculations worked as intended. When the calculations were correct the testing of each input variable in the userform began. Here each input field was tested individually with both dummy variables and actual information pulled from the Excel model itself. When each of the input fields were tested final tests were made on the total. The number of tests and the level of detail, thus result in that the Excel model created can be considered reliable and thus trustworthy.

3 Literature review

In this section theoretical background information relevant to the purpose of this thesis will be presented. Concepts that are involved in a reallocation decision or affects it in any way will be raised and described. In the end of the literature study a summarizing table of the described concepts, that will create the foundation of the analysis, will be presented.

3.1 Warehouse management

Warehouse management aims to minimize the operational costs and to maximize the quality and overall supply chain performance (Accorsi et al, 2014; Guerriero et al., 2015; Hou et al., 2010) and is thus vital to achieve competitive operations. The two warehousing functions that have the largest influence on the warehouse performance, is storage and order picking (Gu et al., 2007). Consequently, a large part of warehouse management concerns material handling and increasing order picking productivity.

Guerriero et al. (2015) states that warehouse management and inventory management are interlinked from a strategical, tactical and operational viewpoint, decisions made at the higher levels will inevitably affect the operational level. The design of the warehouse includes warehouse management decisions on a strategic level and entails decisions ranging from the physical layout of the warehouse to what type of allocation strategy that is most suitable (Gu et al. 2010). These decisions affect the operational level of warehouse management to a great degree and sets the foundation for the decisions in the daily operation of the warehouse. Operational decisions entails decisions regarding receiving and shipping, storage and order picking (Gu et al. 2010).

Managing warehouse operations is a complicated task as it includes many different viewpoints that have to be considered and incorporated in the decision making. Hou et al. (2010) states that storage management has become increasingly important as the 3PL constitutes a hub in the customer's supply chain, and is representing a cost, and thus needs to be handled efficiently. Together with the continuously changing product lines and reallocation of items have made the warehouse management more complex (Hou et al., 2010). In a traditional warehouse, decisions such as reallocation of goods are based on the expertise of individuals. Basing the decision solely on expertise makes warehouse operations subjective and inconsistent, ultimately affecting the performance of for instance order picking (Hou et al., 2010). Hou et al. (2010) states that when making a reallocation decision, traditional managers have to inspect the warehouse and use the WMS to control the status of the investigated item. They further argue that this is a work intensive and time-consuming approach that is ultimately complicated and inefficient. To handle these challenges, Accorsi et al. (2014) suggest that in addition to the WMS, warehouse managers should use a Decision Support System. A decision support system is an IT-system that helps the manager in making difficult and complex decisions in the daily operation of the warehouse (Accorsi et al., 2014). Having a systematic approach with the help of a decision support system could improve the efficiency of the decision making. In the studies performed by Accorsi et al., (2014) they found that warehouses are facing several different complications in terms of demand variability, storage allocations and changing inbound order patterns. Applying a decision support system could hence be of particular use as it reduces the complexity involved.

3.1.1 Challenges for warehouse management

Demand changes

Globalization and new customer preferences have caused great demand changes regarding increased order frequency and decreased order quantities, order accuracy and shorter response times, which altogether affect warehousing operations and consequently warehouse management (Accorsi et al., 2014). A possible consequence of changes in order frequency and quantities could be that earlier design decisions becomes inefficient, as they are no longer adapted for the context at hand, which in turn affects the operational efficiency, and can prove to be very expensive to remedy (Gu et al. 2010). An example could be that storage locations in racks are dimensioned for full pallets and when the order frequency and quantity changes, the racks needs to be rebuilt to better suit the new demand, which could be a challenge as it can change again. Order accuracy and shorter response times are on the other hand related to increased customer requirements on productivity and quality of warehouse operations (Accorsi et al., 2014).

Increased requirements puts pressure on warehouse operators and management to improve or change the warehouse processes to fulfill the new customer specifications. Besides the general and global trends mentioned above, demand changes in terms of demand variability can be a result of seasonality, the product life cycle (Gu et al., 2007; Pazour & Carlo, 2014), competition and introduction of new products (Pazour & Carlo, 2014). The variability in demand due to factors such as these could, as with the order frequency and quantity, result in that the current storage allocation is no longer suitable as items that are no longer frequently picked are occupying an easily accessible location and consequently, a need for reallocations arises (Gu et al., 2007).

Complexity of decisions

A great challenge in warehouse management is the vast number of parameters connected to each decision (Accorsi et al., 2014), regarding for instance the design of the warehouse (Gu et. al, 2007), the choice of order picking system (Dallari, 2009) and choice of assignment strategy (Chan & Chan, 2011). These decisions all have a large effect on warehouse productivity and quality of operations (Gu et al., 2007; Gu et al., 2010). Taking the choice of assignment strategy as an example, Chan and Chan (2011) states that factors to consider are for instance order picking method, demand trends, space requirements, layout of the warehouse, chosen routing methods and item characteristics. To make it even more complex, Chan and Chan (2011) also states that many of these factors are interlinked and that different combinations will yield different results. The issue with having many parameters to consider at the same time are that it makes it a very complex problem to solve in a consistent manner for human warehouse managers (Chan & Chan 2011). Put differently, the consequences and quality of such complex decisions might vary and ultimately affect operations quality and performance.

3.2 Warehouse functions

Warehouse management consist of several different functions and by investigating the warehouse operations in particular, there are four main areas of interest: the receiving of goods, storage, order picking and lastly the shipping process (Gu et al., 2010). As the focus of the reallocation decision is on increasing the productivity and creating space by reallocating items, the shipping function will not be considered as it is not affected by the reallocation of an item.

3.2.1 Reception

The receiving process is the first step of getting the goods into the warehouse, thus acting as the interface for inbound shipments (Gu et al., 2006). The receiving process in itself is built upon several different process steps (de Koster et al., 2007; Gu et al., 2001). The first process step is the identification and verification of products, ensuring that it is the correct items that are received. Secondly, counting the material to see that it is the right quantity and updating the inventory record. In addition to these process steps, Roodbergen (2001) mention that the receiving process includes the transportation of material either directly to the loading docks, to be sent out, or driven into the assigned location in the warehouse (Roodbergen, 2001).

Before the arrival of the inbound shipments it is important that the people responsible for the receiving area gets informed of the products that are to be received (Gu et al., 2007). If they manage to determine the inbound products before the receiving process starts, the receivers can ensure consolidated put aways and that the most appropriate material handling equipment is allocated to the receiving process. Having consolidated put aways and the right equipment results in that the receiver does not have to drive to the same location several times and therefore increases the productivity.

3.2.2 Storage

How products are stored in a warehouse have an impact on the warehouse performance in terms of storage capacity, space utilization and order picking productivity (Gu et al., 2007). The storage area can be divided into several storage zones based on for example unit size (full pallets, cases or pieces) or customer (one zone per customer) (Gu et al., 2007).

In a warehouse, an issue to deal with is the storage location assignment problem, which entails assigning goods to a storage location in the warehouse (Gu et al., 2007; Guerriero et al., 2015; Pazour & Carlo, 2014). The goal of the storage assignment problem is to make the assignment in such a way that the productivity and space utilization are maximized, resulting in high-performance operations (Accorsi et al., 2014; Chan & Chan, 2011; Gu et al., 2007). In addition, Guerriero et al. (2015) claims that to achieve this, the most popular products should be assigned to storage locations close to the inbound/outbound doors. There are however many principles that guides the actual assignment of goods to storage locations and three widely used methods are: random, dedicated and class-based storage (Chan & Chan, 2011; de Koster et al., 2007). In addition to this, Gu et al. (2007) and Accorsi et al. (2014) claims that the demand volume of the product or maximum inventory levels can steer the allocation of an item within the chosen assignment strategy.

Chan and Chan (2011) states that the choice of assignment strategy is the most influential factor on order picking performance and thus, a more thorough description of the mentioned strategies will follow:

Random storage: means that goods will be put in a randomly chosen storage location, that is, all suitable empty locations are as likely to be chosen. (Chan & Chan, 2011; de Koster et al., 2007; Guerriero et al., 2015). The advantage of the random storage strategy is that it enables high space utilization but its disadvantage is the increased travel distance (Chan & Chan, 2011; de Koster et al., 2007). Furthermore, while Chan and Chan (2011) states that this storage strategy is easy to use, de Koster et al (2007) points out that a computer based inventory system is necessary to keep track of locations and inventory levels.

Dedicated storage: reserves a fixed number of locations for each product, meaning that a product will always be stored at a specific location in the warehouse until it is moved (de Koster et al., 2011; Guerriero et al., 2015). The strategy is simple to use but will have a low degree of space utilization since it needs to account for maximum inventory levels for each product, resulting in many empty locations, especially if the product have a high seasonality (Guerriero et al., 2015). However, advantages are that it is easy to organise the products logically, saving time and increasing productivity as the order pickers will learn where the products are located in the warehouse. In addition, it makes easier to achieve a good pallet order building since it is easier to ensure that the goods are allocated in the correct order in terms of weight and size etc.

Class-based storage: collects products into different classes based on a set of criteria such as demand volumes (de Koster et al., 2007), but there are no general rules to defining a class regarding number of products per class or number of classes (Chan & Chan, 2011; de Koster et al., 2007). In terms of space utilization, the class-based storage is somewhere in between dedicated and random storage since it needs to have empty locations in each class to accommodate incoming goods (de Koster et al., 2007). At the same time the division of products into classes may lower the order retrieval time more than the other two assignment strategies (Chan & Chan, 2011).

Although the described strategies are distinct, it is possible to combine them, for instance by using dedicated storage in the forward area but random in the reserve area or by using random storage within a class (de Koster et al., 2007). By combining the two it would enable the company to reap the benefits of several different assignment strategies simultaneously. Another factor that is important to mention is the cross-selling of products, that is, that customers often order certain products together. The methods that take cross-selling of products into consideration assigns related products to locations near each other, resulting in improved picking performance (de Koster et al., 2007; Guerriero et al., 2015). de Koster et al. (2007) states that it is possible to combine the random, dedicated and class-based assignment strategies with a cross-selling perspective. However, Chan and Chan (2011) claims that for cross-selling strategies to work there has to be some level of stability regarding order content, that the set storage policies are being followed and that products on the picking lists are in a predetermined order.

3.2.3 Picking

Out of all of the warehouse operations the picking process represent the largest operating expense due to its labour and capital intensive character (Chan & Chan, 2011; de Koster et al., 2007). Generally the picking process represent more than half of the company's total warehouse spend (Dallari et al., 2009; de Koster et al., 2007). Poor performance in the picking process can therefore have a large effect on the supply chain as a whole and is thus the focus of productivity improvements (de Koster et al., 2007). In addition, Chan and Chan (2011) mention that the picking process also can affect the storage assignment used in the warehouse.

When evaluating the picking productivity of the actual order picking process there are three different components that needs to be considered: firstly the time spent for horizontal transportation, secondly the time that is spent on vertical movement and lastly the time that is spent actually picking the items (Chan & Chan, 2011). Together, these three components create the foundation of the time duration for the picking process. These components in combination with other internal and external factors usually make the picking process very complex (de Koster et al., 2007)

Order picking implies that goods are collected from a location in the warehouse, could be storage or buffer locations, to fulfill an actual customer order that has been received (Chan & Chan, 2011; de Koster 2007). A customer order in turn consists of a few to numerous different order lines. These order lines each equal a specific item, usually referred to as SKUs (de Koster et al., 2007). Furthermore, order lines can be picked in different ways, ranging from a full pallet pick to box order picks and finally individual unit picks (de Koster et al., 2007).

The order picking process is mainly performed by humans in a picker-to-part system (Dallari et al., 2009; de Koster et al., 2007). A picker-to-part system means that the worker uses different material handling equipment to get to the location of the item and to pick the product. In a picker-to-parts system you could either have the worker traverse the aisles and pick from the shelves (low-level pick) without having to be raised up, but you can also have pick systems where the worker needs some kind of lifting equipment to reach the higher levels (high-level pick).

The picker-to-parts system in itself can be constructed in several different ways (de Koster et al., 2007). Two methods that can be used according to de Koster et al. (2007) is either discrete picking or batch picking. Discrete picking means that the order picker only picks one order at a time. In batch picking on the other hand, the order picker simultaneously collects several orders that includes the same article and then picks them all at the same time. These are two extremes and there are numerous different combinations in-between these two (de Koster et al., 2007). How well the picking system will perform depends on the type of picking process that is used (discrete, batch or something in between), how the items are actually sorted and also where the item is located (Dallari et al., 2009).

When referring to order picking it is also important to investigate the setup of the actual warehouse. If the warehouse is set up as different storage zones, the order picking process must be adjusted to handle this (Gu et al.,, 2010). In zone picking, a company usually have allocated specific people to a picking zone and the orders are divided so that they perform all the item picks in that picking zone. When all zones have completed their specifically appointed order the orders are consolidated, this so that the customer only will receive one order (Gu et al., 2010).

3.3 Warehouse routing options in the picking process

A warehouse includes several different processes, each of which represent a cost for the company in terms of time, labour and equipment etc. As previously stated, the operation that represent the largest operating cost and is the most labour intensive is the picking process (Chan & Chan, 2011; de Koster et al., 2007). Therefore, it is important that the company is trying to optimize the warehouse operations to increase the productivity of each worker by increasing the availability of the items and improving the system used for picking as much as possible (Chan & Chan, 2011). The objective of optimizing the picking system includes the choice of routing method, which implies how the order picker should travel through the warehouse during his picking round (de Koster et al., 2007). Working with route optimization methods is a good way for the company to increase the productivity of the pickers (Roodbergen, 2001). According to de Koster et al. (2007) there are two factors that needs to be considered when opting for an optimized routing method. Firstly, there is not an optimal solution for all existing warehouse designs and secondly you are dealing with people who might deviate from the provided course.

In the study performed by Roodbergen (2001) he found a couple of different routing methods: S-shape, Return, Mid-point, Largest-gap, Combined and Optimal. The first methods are simple to apply and implement, but the further down the list the more complex the routing method becomes to implement. However, it is important to remember that the more complex routing methods does not have to result in a higher productivity as each method has its own benefits (Roodbergen, 2001).

S-shape: This method is very simple to apply as the picker starts in an aisle and then traverse the entire aisle, even if it only contains one pick, before the order picker enters the next aisle. However, having the order picker traverse the entire aisle does not imply that every aisle has to be entered.

Return: This method is also fairly simple to implement and the difference from the S-shape is that the order picker moves on one side of the aisle and always enter and exits on the same side, thus the name return.

Mid-point: This is a version of the return method, but in this method the order picker can enter from both sides, but is only allowed to pick to the Mid-point of the rack before the picker has to traverse back to the entry point.

Largest-Gap: This method uses the distance between the item locations to determine if the order picker should pick the next item in the aisle or traverse back to where the order picker entered.

Combined: When applying the combined method, an algorithm is used to investigate the next aisle that is to be picked and decides which of the above options that is the most optimal in combination with the aisle after that.

Optimal: This is the most advanced method and also the most complex. The algorithm that is used takes all the above methods into account before the order picker starts his route and optimizes each pick in correlation to all other stops that needs to be made. Taking all stops into account is the main difference between the optimal and combined, which only considers one pick ahead.

3.4 Material handling equipment

In a warehouse there are several different types of material handling equipment that can be used to fulfill a task, each of which have their own specific advantages. The advantages of a specific material handling equipment can be in terms of height, load capacity or speed abilities (Schenker AG, 2012). The speed, which depends on the make and model, can directly affect the productivity of the warehouse, as the horizontal and vertical speed represents two out of three factors of picking productivity. Therefore, in the presentation of the material handling equipment below, their respective speed will be compared to each other.

Furthermore, when constructing a warehouse a company thoroughly needs to consider the type of customers, racking, layout etc. when purchasing its material handling equipment (Chan & Chan, 2011). The different material handling equipments below will be described based on the definitions in the presentation by Schenker AG (2012).

Figure 3. Pallet jack and a three level push cart with ladder (Gigant, 2017)

3.4.1 Push Cart

When a warehouse have small, light items that are easy to retrieve and considered low-level picks, a push cart is of interest. The push cart is manually pushed around the warehouse by the order picker, and could have several shelves and a ladder to reach some higher levels as well (see Figure 3). Operating the push cart is simple and the operator can with ease operate it even in narrow aisles. As it is manually pushed around the warehouse its speed is depending on how fast the picker can walk and thus considered relatively slow.

3.4.2 Pallet Jack

The pallet jack is used to manually move pallets in a warehouse. It cannot be raised more than a couple of centimeters and is thus only preferred for horizontal movements (see Figure 3). The capacity of the pallet jack is around two tons but as it is manually moved, the travelling speed is drastically reduced as the weight increases. As it is manually operated, it does not require a license to drive, it is considered as slow as the push cart, and as it is manually raised it also makes it a small investment.

Figure 4. Counterbalance forklift and Reach truck (Unicarrier,2017)

3.4.3 Counterbalance forklift

A commonly used material handling equipment is the counterbalance forklift. The counterbalance forklift has the goods in the front and a counterweight in the back to create a balance. Being able to change the counterweight makes it flexible in terms of loading capacity. The counterbalance forklift can be bought with different load capacities, but commonly for an electric forklift is five tons and a lift capacity of up to almost five meters. The counterbalance forklift is built as a small car (see Figure 4), which enables the highest travelling speed out of the here mentioned material handling equipments.

3.4.4 Reach truck

The Reach Truck is a little bit different from the commonly used counterbalance forklift. Here the operator is sitting sideways in the cockpit (see Figure 4) and the extendable mast enables the operator to pick pallets at a much greater height, up to 12 m. At the same time as it provides the opportunity of building higher racks it only needs a three meter radius to turn, which imply that the racks can be placed closer to each other as well. The reach truck is however, slower than the counterbalance forklift and much more expensive.

Figure 5. Narrow aisle forklift and high-level order picker (Unicarrier,2017)

3.4.5 Narrow aisle forklift

In order to drive in a narrow aisle, with a width of 1.5 - 2 m, a company need a specific forklift called narrow aisle forklift. The narrow aisle forklift has a load capacity of up to two tons and can have turnable forks (see Figure 5). Being able to drive in these narrow aisles has however created a limitation for the narrow aisle forklift, which is that it requires an inductive guiding system. The narrow aisle forklift needs the guiding system to keep straight and thus the narrow aisle forklift actually has to be connected to the inductive guiding system before it can even enter the narrow aisle. The guiding system and turnable forks together results in that the forklift is more expensive than all of the above mentioned material handling equipment, but only a little bit slower than the reach truck in terms of speed.

3.4.6 High-level order picker

The high-level order picker is very commonly used (Schenker AG, 2012). The high-level order picker enables the picker to travel up to the actual location, up to 14 m, and pick the items from the side of the forklift and then putting them on the forks in the back (see Figure 5.). As the picker moves with the forklift and is not able to turn the forks, it is most suitable for boxes and smaller light items. In terms of speed it is the slowest of the above mentioned motorised material handling equipments.

3.5 Item classification

The following section will describe what the frequently used SKU means and how the SKU classification process is performed. Secondly, the most commonly used SKU classification method ABC-analysis will be described, followed by the input variables in an item classification.

3.5.1 Stock-keeping Unit

Companies that are working with warehouse storage and production have to deal with numerous different items. Each of these items have an item number and characteristics that are unique to them. Therefore, companies are now using SKUs to ensure that each item receives a unique name (van Kampen et al., 2012). The SKU name can include specific features of the product as size and colour amongst others. After the products have been given a SKU name it will affect the different processes of the warehouse and production, as their characteristics are different (van Kampen et al., 2012). According to Boylan et al. (2008) the SKU is what is used to determine which forecasting and inventory control method that is most suitable for the company. Warehouse management is complex in itself and IT-systems are required to help with these SKU naming conventions (Boylan et al,. 2008). Dealing with many different SKUs is one reason behind why companies might struggle with their warehouse management system (van Kampen et al., 2012).

3.5.2 SKU Classification

Providing each item with a SKU name is the start of the SKU classification. SKU classification is about organizing the SKUs into specific classes based on distinguishable characteristics of that specific group (Boylan et al., 2008). As an example Boylan et al. (2008) mention that each SKU has its own specific demand pattern and thus aggregation of items into classes is necessary. In companies today the SKU classification can be used to achieve several different objectives (van Kampen et al., 2012). Some companies want to reduce the inventory levels whilst others prefer focusing on picking productivity. These objectives have its focus on inventory management and production strategies, but SKU classification is also frequently used in the choice of forecasting method and its process (van Kampen et al., 2012). According to van Kampen et al. (2012), using the SKU classification for forecasting enables the company to consider all items with the same characteristics at the same time, in comparison to investigating the items individually (van Kampen et al., 2012).

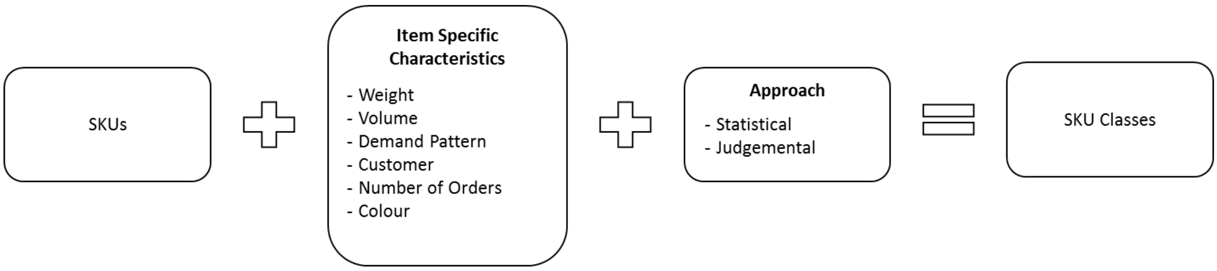

Figure 6. How the SKU classification is created based on van Kampen et al. (2012) and Boylan et al. (2008)

The SKU classification process consist of three different areas: SKUs, item specific characteristics and chosen approach (see Figure 6.). After the SKUs are determined van Kampen et al. (2012) state that the SKU classification can be based on several different characteristics, but in their research they found four primary criteria: volume, product, customer and timing. In addition to the four variables of van Kampen et al. (2012), Boylan et al. (2008) found characteristics as number of orders and demand patterns to be important. When performing this SKU classification there are two different approaches that can be taken: judgmental and statistical (van Kampen et al., 2012). In the judgmental approach experienced people give their input on the different classes that has been created. By applying this approach the manager's assessment of the situation is included. In the statistical approach on the other hand, van Kampen et al. (2012) mention that the SKU classification is only based on the actual statistical data of the different SKU characteristics. According to Boylan et al. (2008) it is here important that a company does not get convinced into basing the decision on average demand, this as it can drastically remove the effect of seasonality. As a company is able to apply either a judgmental or statistical approach in its SKU classification, it can be applied in many different types of industries (van Kampen et al., 2012).

By applying the SKU classification, the company needs to consider what kind of complexity to work with (van Kampen et al., 2012). In order to reach the highest productivity van Kampen et al. (2012) argue that the SKU classification theoretically should be on each individual item. However, by applying this level of analysis the classification becomes very complex. As a result the company needs to compare the productivity increase that arise based on the different levels of complexity (van Kampen et al., 2012).

3.5.3 ABC-analysis

The ABC-analysis is a method that is using the SKU and its specific characteristics to gather SKUs into the different classes: A, B and C (Bhattacharya et al., 2007; Flores and Whybark, 1986; Ravinder & Misra 2016). Each of the ABC-analysis classes should be based on the specific characteristics of the SKU (Bhattacharya et al., 2007). As the ABC-analysis is categorising items into different classes based on its SKU and characteristics it is a version of SKU classification. The ABC-analysis is the most commonly utilized SKU classification method in inventory management (Flores & Whybark, 1986; Hatefi & Torabi, 2015; Ravinder & Misra, 2016; Xiao et al., 2011). The A-classification represent the highly important items where the company should focus its efforts, B represent products that are not as important and lastly the C-items are relatively unimportant (Hatefi & Torabi, 2015). The ABC-analysis in itself can be performed either horizontally or vertically in the racks (Chan & Chan, 2011). In a high pick density setting, the horizontal ABC-analysis is appropriate if the customer´s demands a high-variety of products, but if the main objective is the picking productivity the vertical ABC-analysis will result in a better performance (Chan & Chan, 2011).The foundation of the ABC-analysis, to determine which items that should be prioritized, is constructed based on the Pareto principle (Ravinder & Misra, 2016). As soon as the Pareto curve is finalized the ABC-analysis can be performed and the classes can be appointed (Flores & Whybark, 1986). When the different classes are set they will be used to steer the work and prioritization of the items (Flores & Whybark, 1986).

Aggregating items into larger classes as A, B and C is necessary in inventory management since the number of SKUs are too large to handle efficiently otherwise (Xiao et al., 2011). In the ABC-analysis the different classes are most commonly based on either dollar volume or order lines picked (Flores & Whybark, 1986). Even though these are the most common criteria for the ABC-analysis they are only two out of several others that the analysis could be founded on (Flores & Whybark, 1986). However, the company needs to be careful in its choice of criteria as several of them actually are in conflict with each other (Flore & Whybark, 1985). Even though different criteria are in conflict Ravinder & Misra (2016) mention that several authors including themselves believe that more than one criteria is needed. According to Flores & Whybark (1986) the company needs to find the criteria that is the most suitable in their specific context.

According to Ravinder & Misra (2016) multiple criteria can be implemented in several different ways, some more complicated than others. Depending on which criteria that has been chosen, the ABC-analysis will turn out differently. Flores & Whybark (1986) mention the Joint Criteria Matrix (see example in Figure 7), which is used to categorize the different items into different classes. The Joint Criteria Matrix method consist of three different inputs; item number, criteria 1 and criteria 2. Criteria 1 and criteria 2 are chosen by the company and are the characteristics that the company wants to base its ABC-analysis on. For each item the criteria 1 and 2 will be given a rank, A, B or C and then the items will be plotted into a two dimensional matrix. An example of a criteria could be criticality and how it is weighted against order lines picked, see Figure 7. If the item number receives an AA, BB or CC the ABC-classification for those items are given A, B and C respectively. But, for AB and BC etc. you need to re-evaluate these items in order to only end up with AA, BB and CC, an example of how this can be performed is displayed by the arrows in Figure 7. The re-evaluation can be done with managerial or personal judgment. It would be possible to apply a third dimension as well but Flores & Whybark (1986) state that it becomes too complex and that two dimensions usually are enough.

Item #	Criticality	Order lines picked
1	A	B
2	C	C
3	C	A
4	B	B
5	A	A
6	C	B
7	B	C
8	C	C
9	B	C
10	C	C

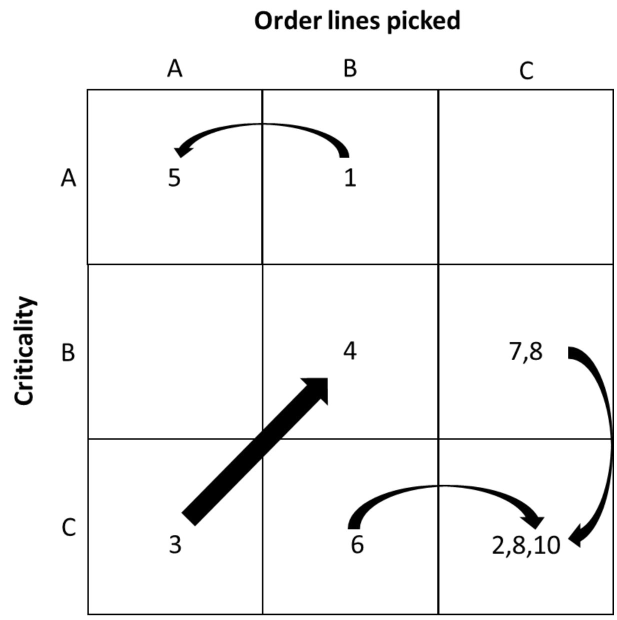

Figure 7. Joint criteria matrix based on Flores & Whybark (1986), displaying first how the different items have been classified on the left, and describing an example of how the items classified as AB, BC and AC can be re-evaluated to only end up with AA, BB and CC classes

In regards to the ABC-analysis Xiao et al. (2011) mention that companies are starting to base their ABC-analysis on the cross-selling effect. Items are reallocated in the matrix based on its effect on other items. As soon as companies start to take this cross-selling effect into account the company will end up with an ABC-analysis result that looks very different from the regular one, as several items that have not been classified as A-items now are moved into this class (Xiao et al., 2011).

According to Ravinder & Misra (2016) it is important that the managers' perception and the company's prerequisites are reflected in how the different criteria are weighted. Weighing the different criteria is not easy and decision managers need to counterbalance one criteria against another, to minimize the risk of ending up with lower productivity as an example (Ravinder & Misra, 2016). But, the aggregated information that the management is basing its decisions on is in turn usually based upon information that is incomplete or almost non-existent, making it very uncertain (Bhattacharya et al., 2007). When management end up in a situation with very limited information they usually are dealing with highly seasonal items and misinterpreted information, which will result in obsolete stock that will never be sold (Bhattacharya et al., 2007).

3.6 Warehouse Reallocation

Reallocation is a warehouse management strategy that entails reallocating goods from one location to another with the overall aim of improving productivity and the allocation of products (Pazour & Carlo, 2014). Hou et al. (2010) states that besides improved productivity, reallocating products also improves space utilization and could increase the number of empty storage locations. Relating to the aim of reallocation, Pazour and Carlo (2014) claims that aspects that could be affected by the reallocation is travel distance, time and speed. The travel speed in particular could be affected as the material handling equipment might change as a result of the reallocation. Pazour and Carlo (2014) further states that due to the kind of benefits connected with reallocating products, this strategy could be of particular importance for warehouses with a large number of SKUs. Gu et al. (2007) claims that warehouse functions such as receiving, storage and picking could all be affected positively by reallocations.

The reason for reallocating products could be to handle demand changes due to seasonality, the product life cycle or because of uncertainty related to incoming shipments (Gu et al., 2007). Gu et al. (2007) claims that the reallocation should be performed in such a way that high-volume products are located close to the inbound/outbound doors and the low-volume products further away. In addition, reallocations should only be made when the time-savings, due to an increased productivity, exceeds the required reallocation time of the actual reallocation (Gu et al., 2007). Gu et al. (2007) further states that variables to consider before making reallocations are which products to reallocate, where to move them and how to schedule the actual reallocation.

Apart from many different variables to consider, there are also different ways to execute the actual reallocations, Pazour and Carlo (2014) describes two categories: firstly reallocating a single product to another empty location and secondly exchanging location of two or more products. The first category is simple and only require an empty location to reallocate the product to. The second category, on the other hand, entails the use of intermediary storage locations since you have to move one product to reallocate another product to that location. Reallocating products in this way requires double-handling, defined as multiple moves before the product is stored at its final position, which is generally avoided since it results in additional material handling (Pazour & Carlo, 2014). However, Pazour and Carlo (2014) claims that in some cases double-handling will be beneficial since it will have a lower or equal travel distance as compared to a direct move of a product to its final locations. Regarding the issue of when to execute the reallocation, Pazour and Carlo (2014) presents examples of strategies such as using idle time to make reallocations or to rearrange stored goods while picking. However, how often reallocations should be performed depends on the demand profile of the product and thus reallocations can be performed on a daily to yearly basis (Pazour & Carlo, 2014).

3.7 Literature Summary

Traditionally, reallocation decisions are based on the expertise of individual warehouse managers, potentially making the decisions inconsistent (Hou et al, 2010). According to Hou et al. (2010), having a systematic approach to reallocation will save time and effort and make the reallocation process more effective and efficient. Decisions regarding reallocation can, as previously stated, be founded on several input variables and the most commonly mentioned are presented in Table 1 below. Table 1 describes the summarized result of the literature study and constitute the collected data that will be brought into the analysis of this Master's thesis. In the analysis, these suggested input variables will be combined with and compared to the input variables that was discovered during the collection of empirical data. Together they will make the foundation of the resulting set of input variables that should be used in a reallocation decision.

Table 1. The input variables mentioned in literature that directly or indirectly affects the reallocation decision and the related productivity outcome.

Input variable	Affects	Mentioned in literature by
Demand, demand changes & variability	- Allocation - Item classification - Operations - Reallocation	Accorsi et al. (2014), Boylan et al. (2008), Chan & Chan (2011), Chen et al. (2011), de Koster et al. (2007), Flores & Whybark (1986), Gu et al. (2007), Hatefi & Torabi (2015), Pazour & Carlo (2015), Ravinder & Misra (2016), van Kampen et al. (2012)
Assignment strategy	- Operations - Productivity - Quality	Accorsi et al. (2014), Chan & Chan (2011), de Koster et al. (2007), Flores & Whybark (1986), Gu et al. (2007), Gu et al. (2010), Guerriero et al. (2015), Pazour & Carlo (2015)
Order lines picked	- Allocation - Item classification - Reallocation	Accorsi et al. (2014), Bhattarchaya et al. (2007), Boylan et al. (2008), de Koster et al. (2007), Flores & Whybark (1986), Gu et al. (2007), Hou et al. (2010), Pazour & Carlo (2015)
Locations	- Productivity - Reallocation	Chan & Chan (2011), Dallari et al. (2009), Gu et al. (2007), Guerriero et al. (2015), Hou et al. (2010)
Picking process	- Allocation - Productivity - Quality	Chan & Chan (2011), Dallari et al. (2009), de Koster et al. (2007), Gu et al. (2007), Gu et al. (2010)
Item characteristics	- Allocation - Item classification - Operations - Productivity	Bhattarchaya et al. (2007), Boylan et al. (2008), Chan & Chan (2011), Guerriero et al. (2015), Pazour & Carlo (2015)
Cross-selling effect	- Item classification - Productivity	de Koster et al. (2007), Flores & Whybark (1986), Guerriero et al. (2015)
Seasonality	- Demand - Reallocation	Chen et al. (2011), Gu et al. (2007), Pazour & Carlo (2015)
Inbound order quantity and frequency	- Item classification - Operations - Reallocation	Accorsi et al. (2014), Gu et al. (2007), Pazour & Carlo (2015)
Reallocation cost	- Reallocation	Chen et al. (2011), Gu et al. (2007), Pazour & Carlo (2015)
Reallocation travel distance	- Reallocation	Chen et al. (2011), Gu et al. (2007), Pazour & Carlo (2015)
Routing method	- Allocation - Productivity - Travel distance	Chan & Chan (2011), de Koster et al. (2007), Roodbergen (2001)
Material handling equipment	- Productivity	Gu et al. (2007), Pazour & Carlo (2015)

New products	- Demand - Item classification - Operations - Reallocation	Gu et al. (2007), Pazour & Carlo (2015)
Travel distance and time	- Productivity - Reallocation	Chan & Chan (2011), Pazour & Carlo (2015)
Consolidated put aways	- Operations	Gu et al. (2007)
Customer forecast	- Operations	Gu et al. (2007)
Needed locations	- Reallocation	Gu et al. (2007)
Reallocation time	- Reallocation	Chen et al. (2011)
Remaining inventory level	- Reallocation	Hou et al. (2010)
Remaining inventory level	- Reallocation	Hou et al. (2010)

4 Empirical findings

In this section the empirical data gathered through interviews and observations will be presented. Firstly, a general presentation of DB Schenker and SLOG will be performed, continuing with a description of SLOG operations, storage assignment, warehouse routing, material handling equipment and reallocations at SLOG. In Chapter 4.7 describing reallocations at SLOG a summarizing table of input variables affecting the reallocation decision will be presented and constitute the second part of the analysis foundation. Before the analysis starts, the three customers of SLOG that are the focus of the study will be presented.

4.1 DB SCHENKER

DB Schenker is a world leading logistics service provider that transport and stores goods all over the globe and supports companies through contract logistics and supply chain management. With 64 000 employees in 2000 locations and warehouses in over 50 countries, DB Schenker has the possibility to offer customer tailored logistics solutions worldwide (DB Schenker, 2017).

The aim of DB Schenker is to be the leader within integrated transportation and logistics by 2020 (DB Schenker, 2017). DB Schenker is going to achieve this through "Successfulness" and a strategy concerning all three dimensions of sustainability; economic, social and environmental. The end goal of their strategy is to fulfill customer expectations through innovation and high-quality services, becoming the top employer within their industry and setting the standard for carbon and energy efficiency as well as emission reduction.

Within Sweden, DB Schenker offers transportation on land, rail, sea and air as well as complete warehouse and logistic services. In 2015, DB Schenker Sweden had 3500 employees and a turnover of 13 billion SEK (DB Schenker, 2017). The goal of the company is to be in the forefront within sustainability, particularly in the environmental dimension.

4.2 Schenker Logistics AB

SLOG is the 3PL specialist within the DB Schenker group and delivers complete logistics solutions based on the customer needs and expectations. SLOG was founded in its current form in 2002/2003 and the headquarter is situated in Landvetter, Gothenburg, since 2011. SLOG has warehouses in four cities in Sweden; Stockholm, Nässjö, Jönköping and Gothenburg. The total number of employees at SLOG is 500 people and the yearly revenue is 600 million SEK (Kolderup-Finstad, 2016). Services provided ranges from warehousing and distribution services to consolidation and value adding services such as quality checks and repackaging (DB Schenker, 2017). Developing these services is something that SLOG is continuously working with in order to reach the main aim of improving performance and quality while keeping costs down.

A couple of years back, the overall goal of SLOG was to have a 10 % profit and a 10 % growth rate, since then SLOG has worked with their strategies but the main focus is still to be profitable on a low-level. SLOG will not take on a customer that is not earning them a profit simply to win a customer for another part of the DB Schenker group. The main goal however, is to continuously improve operations so that the cost for the customer can remain stable and ensure that SLOG can stay competitive. In addition, a stated ambition is that no customer should have to leave due to too low service levels.

In the Landvetter DC, there are currently around 200 employees of which 40 is office staff. The size of the warehouse is around 49 000 m^2 including a mezzanine of 8 000 m^2 with a clear ceiling height of 11.7 m (Kolderup-Finstad, 2016). Furthermore, the facility has 44 gates for receiving and shipping to achieve the needed flexibility in operations. Finally, the Landvetter DC currently have nine customers of varying size and demand patterns, most of which are within consumer/retail-fashion industry.

4.3 Productivity at SLOG

At SLOG, productivity is measured as order lines picked per man-hour and is the sole parameter used for the ABC-analysis of SKUs within a class. The order lines productivity measure is used since it is affected by all design decisions in the warehouse, ranging from the physical dimensions of the building and what type of racking is being used to the chosen material handling equipment, allocating strategy, picking processes and warehouse routing method. Productivity at SLOG is defined in this way not only since it is affected by many parameters, but also since it is easy to use and measure. In addition, it is easy for Locationers and Order Pickers to relate to the productivity measurement since it is directly connected to their individual performance and a change in operations can directly be seen and understood by the employees. Order lines picked per man-hour is published individually for each SLOG customer and is used to monitor the performance over time as well as measuring the effect of improvement implementations.

4.4 Storage assignment strategies at SLOG

SLOG is currently using three different storage assignment methods: class-based, random and dedicated storage. Each of the customers of SLOG are managed individually and each receive the most appropriate storage assignment method for its specific characteristics regarding demand patterns and products.

The class-based strategy is used for the entire SLOG warehouse in the sense that each customer has its own storage area, but apart from this class-based storage is only used for the larger customers that have many types of SKUs. The smaller customers generally don’t have enough order volumes to make it worthwhile to systematically organize their products into different classes. The SKUs of the larger customers are divided into different classes based on item characteristics such as size, weight, product type or who the end customer is. The rationale for using these types of classes is to ease the overall management of that customer but also to increase space utilization, productivity, and enable good pallet order building. Most often the classes are created on SLOGs own initiative but in other cases it is a customer requirement that makes SLOG setting up a new class. An example of such a requirement could be that the customer only wants to have a specific product type on each shipped pallet. Using class-based storage assignment in this way, effectively divides the warehouse and customers into different pick zones, each of which contain a specific product class. SLOG is thus able to use different storage assignment and picking methods as well as material handling equipment within each pick zone. The main reason for this is that SLOG believes that using the most suitable strategies and equipment based on the item characteristics, will minimize the travelling distance and result in the highest productivity.

Within a class or pick zone, SLOG implements either dedicated or random storage assignment. The determining factor in the choice between these two assignments methods are the portion of the assortment that is recurring. More specifically, if the greater part of the SKUs within a class are recurrent, it is deemed space efficient to use a dedicated storage since SLOG then can dimension the required space for each item and simply restock those locations when incoming shipments are received. Another aspect that would make dedicated storage the preferred choice is if there is a large cross-selling effect. If using a dedicated storage, SLOG could more easily place these products together, increasing the productivity. Dedicated storage is also used at SLOG to enable efficient restocking from bulk storage by having the bulk storage directly above the picking location to be restocked.

Random storage is on the other hand preferred if the main product assortment is not recurring and instead varies over time due to for instance fashion trends, which could entail frequent new product releases. Varying inbound quantities, product seasonality or demand connected to weather are additional factors that will make SLOG consider using random storage assignment, as these types of uncertainties and variation in demand makes the space requirements for each SKU hard to determine beforehand. For the same reason, SLOG uses random storage for handling product returns for a certain customer.

4.5 Warehouse Routing at SLOG

Warehouse routing is something that SLOG is continuously working with to ensure that the method used is the most efficient for the customer at hand. When deciding the routing method to use, SLOG is considering several different factors to achieve the main aim of minimal travelling distance and increased productivity. SLOG has to consider factors as what type of racking system that they have, the actual layout of the racking and the type of material handling equipment to be used. An additional factor that is considered before determining the warehouse routing method is the issue of queues. Queues are an issue that arise as soon as too many pickers are at the same location at the same time. An example where this can occur is if all high-volume movers are located close to the inbound/outbound doors. At SLOG both the volumes and the variety of items sold are very large, forcing SLOG pickers to traverse the aisle every time, leading to the decision to use the S-shape method. As a S-shaped routing method is used despite the chosen allocation strategy, it is mainly the vertical travel distance that affects the productivity, see also Chapter 4.7 Warehouse reallocation at SLOG. However, even though the WMS recommends a S-shape picking route, SLOG allows their order pickers to choose the most suitable routing method based on the context. Amongst others, this context could include aspects as queues and blocking of locations.

4.6 Material handling equipment at SLOG

At SLOG many different kinds of material handling equipment is used due to factors such as equipment performance, item characteristics, the configuration of racking system etc. At the DC in Landvetter pallet jacks, push carts, counterbalance forklifts, reach trucks, narrow aisle forklifts and high-level order pickers are being used, see Table 2. Overall, SLOG tries to choose the most suitable material handling equipment based on the factors above to achieve the maximum productivity for inbound and outbound orders.

One reason for using different types of material handling equipment is the racking system that is being used in the particular zone. For instance, if narrow aisle racks have been chosen to be the most suitable, only a narrow aisle forklift is able to drive in those particular aisles. In other words, the available space in an aisle is one determining factor for which equipment to use. Another factor that affects the choice is the height of the rack. If the position you need to visit is on a low-level it might suffice with a push cart while a higher location might require a high-level material handling equipment instead.

Other aspects that have an effect on the choice of material handling equipment during inbound or outbound orders is the size of the demanded items. If the demanded items are small and the total order volume is low, a push cart could be suitable to use. However, SLOG mention that if an order is large or if a full pallet is ordered, a forklift would be more appropriate in terms of productivity.

At the DC in Landvetter, the most frequently used material handling equipment is the high-level order picker and the reach truck. The high-level order picker is most common when storing or picking boxes or other smaller SKUs and the reach truck is most often used when storing or retrieving full pallets. Narrow aisle forklifts on the other hand are used for both small SKUs as well as full pallets. The pallet jack and push cart is mainly used at the mezzanine due to space limitations and the fact that the racks are low there. The pallet jack however, is also used in the receiving/loading area and the push cart is used in picking of boxes and small items in some pick zones not on the mezzanine. The counterbalance forklift is only used on the mezzanine and outside the actual warehouse when loading and unloading trailers.

Each type of material handling equipment has different performance in terms of reachable height, load capacity and speed. The vertical and horizontal operating speeds affects the productivity when picking and is shown in Table 2.

Table 2. The material handling equipment being used at SLOG and its horizontal and vertical speed, Bohlin (2017)

Material handling equipment	Horizontal speed (m/s)	Vertical speed (m/s)
Pallet jack	0,6	0
Push cart	0,6	0,2
Counterbalance forklift	1,11	0,5
Reach truck	0,97	0,55
Narrow aisle forklift	0,7625	0,525
High-level order picker	0,625	0,2

4.7 Warehouse reallocation at SLOG

Reallocation decisions at SLOG is currently being made in a non-standardized manner and are consequently seen as a possible area for improvement. Most often the decision to move an item is based solely on the experience of the Locationer, but in some cases statistical information is gathered from the WMS to ease the decision making. However, it is ultimately the Locationer for each customer that decides what and where to move an item as well as when to schedule the move. Apart from deciding if and where to move a product, the Locationer is responsible for maximizing the productivity and allocate incoming goods. The Locationer works at one specific customer and could also work as an Order Picker. At some customers however, the allocation and reallocation process is a full time job due to for instance the size of the customer or the number of required reallocations.

Today, there are many different reasons for reallocating an item at SLOG, ranging from making room for incoming shipments to plain productivity reasons. Currently reallocations are being done by moving low inventory and/or slow-moving articles to smaller or less accessible locations and also by consolidating different items on one pallet. Another reason for moving products is if a manager know that a certain product will have a temporary but large demand increase. The product can then be moved to a hot spot where it can more easily be picked. SLOG management believes that a reallocation should only be made when it increases the productivity and this view is shared by many of the Locationers. The main issue is that SLOG management do not presently know exactly which input variables that should be considered before a reallocation is being made. They are consequently worried that the current operations might result in unnecessary work and time being spent on moving the wrong items to the wrong location. The input variables that are currently being considered at each customer at SLOG is presented in Table 3. As can be seen, different combinations of input variables are used at each customer.

Table 3. The input variables currently being considered in a reallocation decision at SLOG are displayed in the table below, the columns display each individual customer at SLOG Landvetter

Input variables \ Customer	A	B	C	D	E	F	G	H	I
Remaining inventory level	x	x		x	x	x	x		
Size	x		x		x		x	x	x
Needed space	x	x		x			x		
Order lines picked				x	x	x		x	
Seasonality			x	x	x				x
Shape		x			x		x	x	
Weight	x				x			x	
Demand pattern		x						x	
Quantity picked		x						x	
Reallocation time		x	x						
Cross-selling effect								x	
Inbound order quantity and frequency				x					

Apart from the input parameters shown in Table 3 there are some additional issues that are of a more general nature, reflecting how SLOG evaluate its reallocations and consequently its effect on the productivity. These additional issues are relevant for all customers at SLOG.

Generally, the Locationers does not receive information from the customer regarding forecasted demand, but knows from experience how to handle the seasonality and what types of SKUs that are typically fast-moving items. They do get information on incoming shipments regarding estimated time of arrival, a general description of what it contains and in what quantities. Shipment specific information is helpful when allocating products but it is expressed that additional information regarding forecasted demand would be beneficial when handling seasonality and demand variations. Regarding new products, it would be especially good to have access to demand forecasts from customers as these products have no previous sales data and are consequently hard to classify. At the moment, new products are assumed to be fast-moving and are allocated to accessible locations if possible. Using order lines picked as performance measurement also raises the question of what should define an A-product at SLOG. Only using order lines picked could make Locationers disregard other important aspects such as quantity picked or remaining inventory. It is currently not clear to SLOG if order lines picked is enough to classify a SKU.

Another issue is to what locations to reallocate products. More specifically, SLOG does not think that a traditional ABC-arranged warehouse, where each class of products are placed together, is appropriate. If all high-volume movers were located close together SLOG see the risk of order pickers having to wait to access the same location, thus creating queues which are reducing the productivity of the warehouse. Instead SLOG wants to distribute the high-volume movers along the aisles on an easily accessible height. SLOG firmly believes and openly states that the additional time required to traverse the whole aisle is negligible when compared to the time saved not needing to raise the material handling equipment and waiting for other order pickers to access a location.

A related topic is then how the different types of travelling distances, in metres, are believed to affect the productivity of the picking route. SLOG consider the movement along the aisle (y-movement) to be of less importance than the between aisle movement (x-movement) and vertical movement (z-movement), see Figure 8, for an example and explanation of how the different axes are oriented in relation to the most optimal location. The most optimal location is the location in the warehouse where a pick can be completed the fastest according to the warehouse improvement specialist, which is different depending on the customer context. As SLOG consider the y-movement to be of less importance, they would rather have the order pickers traverse the whole aisle than going into an additional aisle, which would add another full length of an aisle to the travelling distance. That a full length of an aisle is added is due to that SLOG is using a S-shape routing method, every aisle that is entered will be traversed in full. This is to some degree contradicted by the researchers' observations as the order pickers sometimes uses the aisle along the x-axis to exit an aisle before having to traverse the entire aisle, see Figure 8. To summarize, the core of this issue is that SLOG does not see travelling distances along the different dimensions as having an equal effect on the productivity, preferring to minimize the vertical and between aisle movement at the cost of longer travelling distance along the aisles. The situation can however differ depending on how the SKUs are picked. An example can be made by comparing multiple picks and the picking of one full pallet. While picking multiple items, it is probable that the full aisle would have to be traversed and thus, SLOG sees no problem with the along aisle travelling distance. In the case of a full pallet pick however, travelling distance along all dimensions are important as the order picker visits only one location and goes directly from that location to the outbound area instead of applying the S-shape picking route.

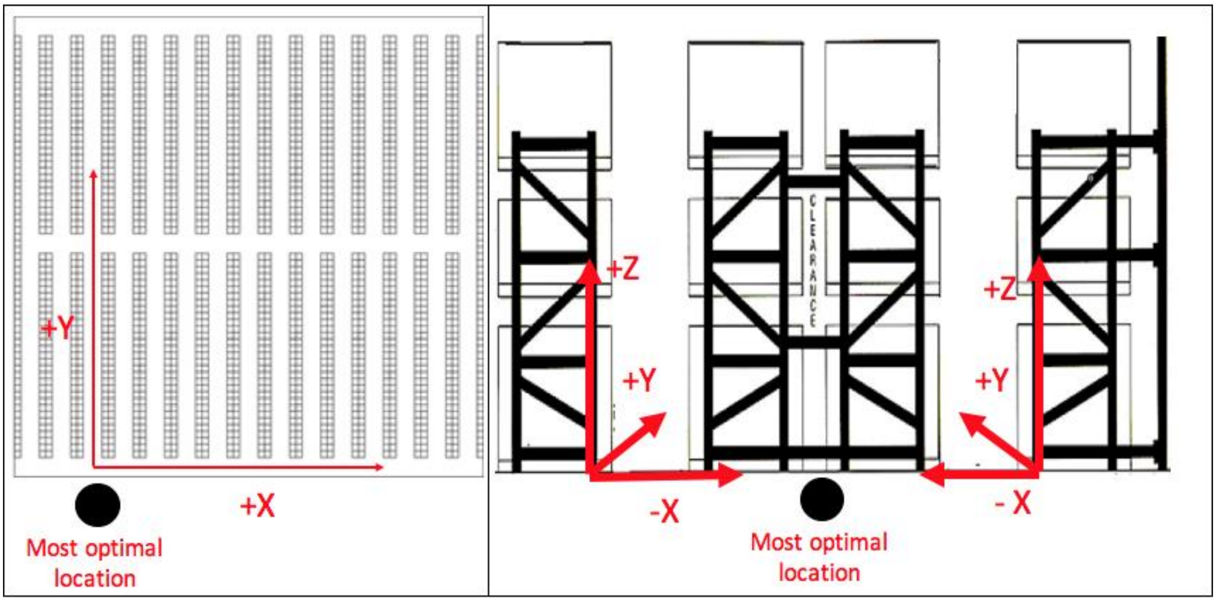

Figure 8. Display the orientation of the axis (x, y, z) and an example of how the sign of each of them differ in reference to the most optimal location, which is the location in the warehouse where a pick can be completed the fastest according to the Warehouse Improvement Specialist. The most optimal location will differ at different customers due to context.

The final issue that was identified was the remaining lifetime of a product, that is, how long the product is expected to remain in storage. The remaining lifetime is a factor affecting the productivity outcome from a reallocation. If the remaining lifetime is long, there is a longer period of time to regain the timeloss of the physical reallocation and if the lifetime is short it is consequently harder to achieve this. The same issue is connected to if the allocation strategy used is random or dedicated. If the random strategy is used, there will be no restocking of the SKU at that specific location, making the remaining lifetime only dependent on the remaining inventory and the quantity picked per visit. If on the other hand, the dedicated strategy is applied there will be some restocking from put aways and buffer during the remaining lifetime of the SKU at that specific location and therefore it is easier to earn back the time used for a reallocation. The remaining lifetime of a SKU is thus especially important if the reallocated product is a high-volume mover being reallocated to a more accessible location.

Table 4 describes the summarized empirical findings and constitute the collected data that will be brought into the analysis of this Master's thesis. In the analysis, these suggested input variables will be combined with and compared to the input variables that were discovered during the literature study. Together they will make the foundation of the resulting set of input variables that should be used in a reallocation decision.

Table 4. The input variables mentioned in the interviews that directly or indirectly affects the reallocation decision and the related productivity outcome.

Input variable	Affects
Remaining inventory level	Reallocation
Size	Allocation, item classification, material handling equipment, reallocation
Order lines picked	Allocation, item classification, productivity, reallocation
Seasonality	Allocation, demand, inbound order quantity and frequency, reallocation
Needed locations	Reallocation
Shape	Allocation, item classification, material handling equipment, reallocation
Quantity picked	Allocation, material handling equipment, productivity, reallocation, travel distance
Reallocation time	Productivity, reallocation
Weight	Allocation, item classification, material handling equipment, reallocation
Demand, demand change & variability	Allocation, reallocation
Locations	Allocation, material handling equipment, productivity, reallocation
Picking process	Productivity, travel distance
Assignment strategy	Allocation, productivity, reallocation, restocking efficiency, travel distance
Cross-selling effect	Allocation, productivity, reallocation
Inbound order quantity and frequency	Allocation, operations, reallocation
New products	Allocation, item classification, productivity
Routing method	Productivity, travel distance
Travel distance	Productivity
Customer forecast	Allocation, item classification, productivity, reallocation
Material handling equipment	Productivity, routing method, travel distance, travel time
Queues	Allocation, productivity, reallocation
Remaining SKU lifetime	Productivity, reallocation

4.8 SLOG customer presentations

In this section the customers of SLOG will be described. Only the customers where detailed investigations were made will be described in detail, while the remaining customers will be briefly presented in Table 5 and Table 6 at the end of the chapter.

4.8.1 Customer D

Customer D is a large customer of SLOG and have a wide assortment of clothing products. They also have branded goods that belongs to a specific end consumer. The types of clothing ranges from winter garments to shorts and t-shirts, making a large portion of the SKUs seasonal. The seasonality causes large daily demand variations for different SKUs, but on an aggregated level Customer D receive and ship large volumes on a daily basis. The staffing of Customer D varies daily.

The assignment method used at Customer D is class-based in combination with random storage and the classes are firstly divided based on end consumer and subsequently by order volumes and size of location (for instance boxes or full pallets). When an item is received and needs to be put away, the WMS suggests a location based on information given by the Locationer regarding height and size of the goods. It is also possible for the Locationer to manually allocate an item to a specific location. The type of storage used is pallet racks, regular shelves, floor space and also shelves on the mezzanine. In the racks, they only pick on shelves up to a certain height, all storage above that is buffer locations, except for on the mezzanine where they pick on all levels of the racks. The material handling equipment is primarily high-level order pickers and reach trucks, but on the mezzanine only pushcarts are being used. The goods stored at the mezzanine is belonging to certain end customers and are moved up by a reach truck and to later be stored with the help of a counterweight forklift or by pushcarts.

When making reallocation decision, the Locationer at Customer D uses a systematic approach based on experience and data gathered from the WMS regarding order line frequency, last pick date, product entry date and remaining inventory. If the order line frequency is too low or the last pick date is too far back in time the product is moved away to a less accessible location to make room for an incoming, probably faster moving product. If the remaining quantity is low and the item is in a large location intended for large order volume SKU it is moved to a smaller location to free up space. Generally, there is enough space at Customer D but they continuously end up with the wrong type of locations, due to changes in inbound order patterns, which forces the Locationer to reallocate items. The changes in inbound order patterns display itself by that the customer has changed its order pattern from full pallets to smaller and more frequent order quantities, which can result in that Customer D has to move up to 70 items in a day to free up space for incoming SKUs.

4.8.2 Customer G

Customer G is a small customer of SLOG Landvetter and sells clothing to end customers. Most the customer SKUs are new items with a large seasonality but they also have a small recurring assortment. Even though there is a large seasonality, which in turn causes large demand variation, the demand from year to year is relatively stable. Usually it is enough to look at the previous year’s demand statistics on an aggregated level, based on product type, to get a good view of the current demand. At Customer G, both inbound and outbound volumes vary due to its seasonal products. Hence, Customer G currently have a variable staffing to cope with demand peaks, but normally there is a maximum of six people working at Customer G. Since the products at Customer G are relatively small and light, they are easy to pick and as a result, Customer G can achieve a fairly high productivity.

Due to the seasonality and the size of the customer, Customer G has a random storage that is not class-based, as there is simply not enough order volumes nor enough number of SKUs to make it worthwhile spending time on organizing the SKUs into classes. As with Customer D, when an item is received and should be put away, the Locationer feeds the WMS information about height and size of the SKU and the WMS then suggests a suitable location. The suggestion can be overridden by the Locationer, who might choose to allocate the item manually. The type of racking used at Customer G is ordinary racks and floor storage and the material handling equipment used is high-level order pickers and reach trucks.

Reallocations is not a big issue at Customer G, the Locationer tries to reallocate items once a week and the motive is to use the space more efficiently. The Locationer traverse the aisles, looking for SKUs with a low remaining inventory and moving them to smaller locations. In addition, they sometimes get a report from SLOG management containing a list of frequently sold goods that should be moved to a location that is easier to pick from, the reason is then to increase the productivity. To make the reallocation as efficient as possible, the Locationer tries to move several items at a time, as a move requires some time spent at the computer and making several moves at the same time is thus more time efficient.

4.8.3 Customer H

Customer H is another small customer of SLOG Landvetter, which only occupy one aisle in the warehouse where they store their products. Customer H is a stable customer of SLOG and have no real seasonality and small demand variation over time. They get weekly, high-volume inbound deliveries while their outbound deliveries are daily and smaller in size. From time to time there are some new product releases and older products are being phased out but generally their products have a long shelf life of at least six months. Since the workload is relatively even and the customer is small there is not many order pickers at this customer.

The assignment strategy used at Customer H is dedicated storage due to the stability in product assortment and the low variability in demand. The Locationer can therefore more easily can decide where to put an item based on the demand pattern and item characteristics. When allocating a new item, the Locationer takes a range of parameters into consideration, including order line frequency, size, weight and quantity. In addition, the Locationer has arranged some bays based on the cross-selling effect, increasing the productivity by allocating the affected SKUs near each other. Other similar arrangements have been created based on order line frequency and the shape of the products. The type of storage at Customer H is racks and the material handling equipment used is high-level order pickers and reach trucks.

When picking, the order pickers pick several orders simultaneously and then sorts the picked products into different boxes belonging to the respective orders. It is not seen as worthwhile to sort the products directly when picking as they believe that they can pick more per picking tour if they sort it afterwards. It was however noted by the Warehouse Improvement Specialist that there might be an increased risk of making more errors as the goods are handled twice.

The only reallocations that are currently being made at Customer H are due to that the Locationer realizes that the demand for a certain product will be unusually high. The Locationer then moves the whole pallet close to the outbound doors and picks from that location instead.

4.8.4 Overview of customer characteristics

The different customers at SLOG have many different characteristics and in order to achieve a comprehensive understanding of them all two tables are used to describe the different customers at SLOG. Table 5. describe the demand characteristics of all customers and Table 6 describe all the storage characteristics. These two tables were used to distinguish the three customers that covered the full spectra of dedicated storage, locations with small order volumes to class-based storage with large order volumes used in the productivity effect of a reallocation decision.

Table 5. The demand characteristics of all SLOG customers

Characteristic \ Customers	A	B	C	D	E	F	G	H	I
Demand variation	- Large - Very seasonal	- Large	- Large	- Large - Seasonal	- Large	- Medium	- Large	- Low	- N/A
Inbound deliveries	- Half year	- Daily	- Infrequent	- Daily	- Daily	- Weekly	- Weekly	- Weekly	- Infrequent
Inbound volumes	- High	- High	- High	- High	- High	- Low	- Low-High	- High	- Very low
Outbound deliveries	- Daily (season) - Infrequent (off season)	- Daily	- Daily	- Daily	- Daily	- Daily	- Daily	- Daily	- Infrequent
Outbound volumes	- High (season) - Low (off season)	- Low-High	- Low	- High	- High during season	- Low	- Low- High	- Low	- Very low
Forecasting information	- Season start and end	- No	- No	- No	- No	- No	- No	- No	- Yes, also regarding eta
Returning assortment	- No	- Small base assortment	- Small base assortment	- Small base assortment	- Small base assortment	- Yes	- Small base assortment	- Small base assortment	- Yes, mostly

Table 6. The storage characteristics of all SLOG customers

Characteristic \ Customer	A	B	C	D	E	F	G	H	I
Type of storage	- Mostly floor storage - Some racks	- Racks	- Racks	- Racks	- Flow rack - Racks	- Racks	- Floor storage (hangers) - Racks	- Racks	- Racks
Assignment strategy	- Random	- Random	- Random	- Class-based (random)	- Class-based (random, dedicated)	- Random	- Random	- Dedicated	- Random
Allocation system used	- Judgement	- Judgement - Script	- Script	- Judgement - Script	- Judgement - Script	- Judgement - Script	- Judgement - Script	- Judgement	- Script
What is a good location	- N/A	- Floor is bad - No need to reach or bend	- Close to i/o doors - Floor is worst	- Floor location	- Where you do not need to reach or bend	- In level with forklift	- Where you do not need to reach or bend	- Where you do not need to reach or bend	- Close to i/o doors - Floor is worst
Enough space	- Yes	- Yes	- Yes	- No	- No - Yes	- Yes	- Yes	- Yes	- Yes
Material handling equipment	- Pushcart	- Narrow aisle forklift	- Narrow aisle forklift	- High-level order picker - Reach truck	- High level order picker - Narrow aisle forklift - Push cart - Reach truck	- Reach truck	- High level order picker - Reach truck	- High-level order picker - Reach truck	- Reach truck
Reallocation decisions	- Judgemental	- Judgemental	- Judgemental	- Judgemental - Statistical	- Judgemental - Statistical	- Judgemental - Statistical	- Judgemental	- N/A	- N/A

4.9 System X

The ABC-analysis tool System X is an IT-system that was created to deal with the issue of ABC-classified storage allocations. SLOG had the opportunity to test an early demo version of System X and the Locationer who tested it was very positive to the benefits it could bring the company. The final result of System X is a heatmap of the chosen warehouse section, aisle or even rack. The presentation below of System X is based on the first version of System X and will not contain future developments.

4.9.1 Required import information

IT-systems can sometimes require a lot of information. Warehouse workers thus need to gather and create a lot of different reports to be able to feed the system with all the required data. In the case of System X it requires two separate reports. The first is a complete list of all the items that should be classified and its respective location. The second report is supposed to cover the sales data and needs to include the date an item was picked, the Purchase order number, the SKU name and the quantity picked. When importing files to System X there are some restrictions: one is that the first file must be imported as an Excel file, another is that the second file has to be a csv file. However, a restriction is the number of order lines that can be entered, which is limited to 150,000 order lines according to Schenker Asia Pacific. It would be possible to import larger files but then it has to be imported from their end and not by a daily operator.

4.9.2 Calculations in System X

The calculations that are made in System X are used to create the most optimal ABC-classification based on the imported order lines picked for each SKU. The calculations in System X are not based on the normal Pareto curve (70-20-10) by itself, instead the developers have decided to apply the method of triangle to determine the optimal ABC-classification.

The method of triangle, unlike the regular Pareto approach, does not have a fixed interval for each ABC-class (Bond, 2015). The method of triangle uses two different axes: one showing the SKU contribution and one that display the percentage of the total SKUs being included, see Figure 9. (Bond, 2015). When the percentage split is completed, two lines are drawn from the bottom left to the top right: one green and one red, as an example see Figure 9.. The green line represents the contribution percentage of each SKU and the red line represent the number of included SKUs as a percentage of the total number of SKUs, see Figure 9. These two lines have a fixed start and end, which means that the green line can only be moved along the Y-axis and the red line can only be moved along the X-axis. Each of these lines represent a Pareto curve and in the method of triangle these lines are moved back and forth until the two lines intersect at the dotted line in point (Xp, Yp) and the optimal Pareto curve can be drawn. The optimal Pareto curve is represented by the blue line in Figure 9, which has to be symmetrical around the dotted line between the top left and bottom right. The optimal Pareto curve will vary depending on the input variables. When this optimal Pareto curve is drawn, two 45 degree lines are drawn from each breakpoint: one for the green and one for the red Pareto curve. The intersection points, location fl(x) and fn(x), are then used to determine the border between each of the classes: A, B and C.

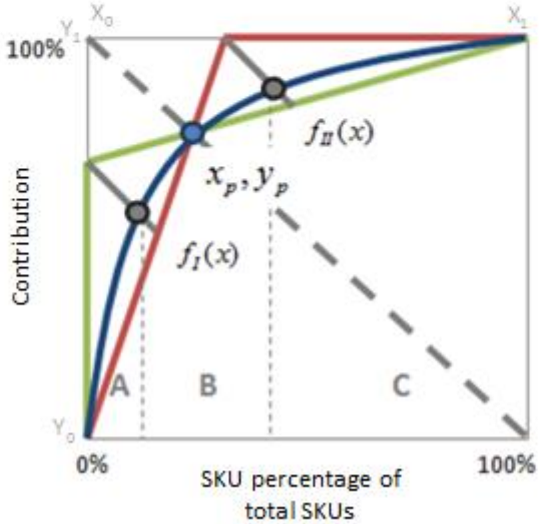

Figure 9. Display the end result of the method of triangle being used in System X to determine the border line of the ABC-classes

Furthermore, System X is using the Pareto curve to determine the Gini-coefficient. The Gini-coefficient is used to explain the variations in the imported warehouse data. The result of its calculations is a number between zero and one, the closer the result is to zero the smaller the variations in the data. Schenker Asia Pacific argue that if the Gini-coefficient is below 0.6 there are very small improvements that can be achieved by moving items in the warehouse. If the result on the other hand is close to one there are large improvement potential in the warehouse.

4.9.3 Aisle based or Row based warehouse structure

When creating the heatmap in System X it can be based on two different warehouse structures. Either the warehouse locations are based on: an aisle structure or a row structure. The aisle structure is displayed in Figure 10, and means that the numbering of the locations are alternating from left to right, resulting in that all odd numbers are on the left side of the aisle and all the even numbers are on the right. In a row based structure on the other hand, each bay on either side of the aisle has the same bay number but different row number, see Figure 10. Which one of the two structures that are chosen as the foundation of the heatmap should be based on the actual warehouse structure of the warehouse. Choosing the incorrect warehouse structure in System X will result in a heatmap that does not correctly display the reality.

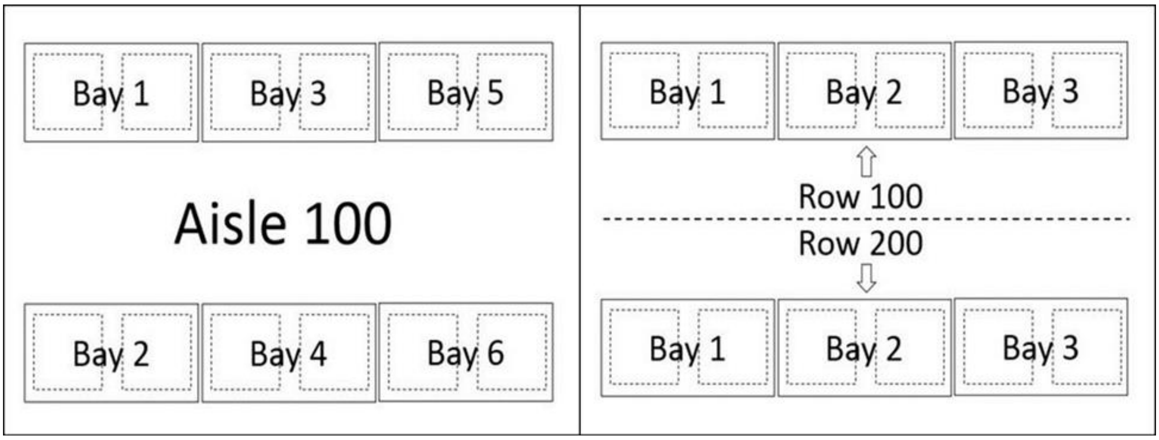

Figure 10. Display the difference between an Aisle based and a Row based setup

4.9.4 Location input and set up

In order for System X to create a heatmap it is important that the location input is accurate. Having incorrect location codes in System X will result in a heatmap that is not a visual representation of the actual warehouse. In order to ensure that the imported data is accurate, System X will inspect the imported spreadsheets to find the column containing the location code. When System X has identified the location code column it will take a complete location code and display it as in Table 7 below. Table 7 below is just a visual representation of the location code that was imported and based on this, the user in steps have to select the characters that represent: aisle, bay, location and level. After this data is entered a heatmap of the warehouse can be created.

Table 7. Display how System X read the location that it found in the imported information

Aisle		**Bay**		**Level**		**Position**
BF	-	024	-	64	-	22

4.9.5 ABC-analysis display

The ABC-analysis display is the result screen of the System X calculations. The display contains a Pareto curve, Figure 11., and a table, Table 8., summarizing the data that has been imported and how it was classified. As can be seen in the Figure 11. the Pareto curve does not exactly match the (70-20-10) rule, since the Pareto distribution in System X is based on the method of triangle as mentioned in section 4.8.2. However, the Figure 11 clearly display the cumulative order line distribution between the three classes: A, B and C.

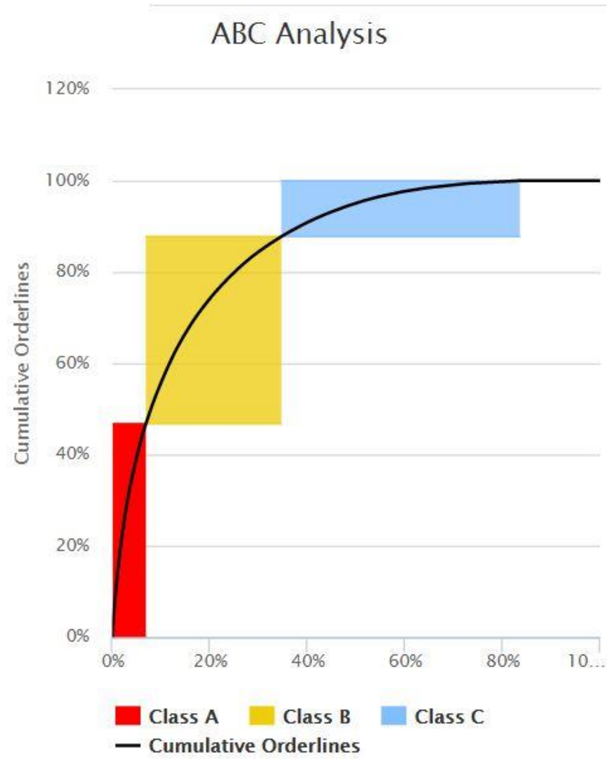

Figure 11. Display the result of the ABC-analysis on the Pareto curve that has been created in System X and the size of each class

The other part of the screen is a summary of the class characteristics, see Table 8. Here all the information about the SKU classification can be found. The first column display the four classes used in the SKU classification. These four classes are always the same no matter the number of products that are imported. Important to mention is that the D class, which is not displayed in Figure 11 above, is included and represent the items that has not been sold during the imported period. The second column display the number of SKUs that ended up in each class, and the third column display the SKU class percentage of the total SKUs and is displayed on the x-axis in Figure 11 above. The fourth column display the spread of order lines picked for each item. In Table 8., which is our example, display a large spread between and within the four classes. The fifth and sixth column display the No. of order lines and order lines % respectively for the class in total. The seventh column is a little bit different as it calculates the ratio between the SKUs% and the order line %. What that means is that in our example in Table 8., for every C item that the company picks the company will pick four B-items and 28 A-items. The last two columns are just there to display how many location there are in each class and their distribution.

Table 8. The result of the ABC-analysis performed in System X and each column demonstrate the distribution split between the ABC-classes

Class	No. of SKUs	SKU%	Order line frequency	No. of order lines	Order line %	SKU% to Order line% ratio	No. of Locations	Locations %
A	64	6,9%	56-443 per 4 months	7643	46,7%	1:7	64	6,9%
B	259	27,8%	11-58 per 4 months	6706	41,0%	1:1	259	27,8%
C	456	48,9%	1-11 per 4 months	2002	12,2%	4:1	456	48,9%
D (no movem ents)	153	16,4%	0 per 4 months	0	0%		153	16,4%
Empty location							0	0,0%
Total	932	100%		16351	100,0%		932	100,0%

4.9.6 Order profile

The order profile tab of System X is fairly simply constructed, it only contains one type of data which is the summary of how many order lines per order that was picked. In the example in the table in Figure 12. it is displayed that, for the actual customer, most customer orders only contain one order line per order. That an order only contains one order line per order implies that the picker has to travel to only one location to complete an order. In Figure 12, which is a graphical representation of the table, the percentage split between order sizes is displayed.

Orderlines per order	Orders	Fraction of orders
1	3 868	67,2%
2	771	13,4%
3	367	6,4%
4	149	2,6%
5	132	2,3%
6	86	1,5%
7	62	1,1%
8	49	0,9%
9	34	0,6%
10	19	0,3%
More than 10	222	3,9
Total	5 759	100%

Figure 12. Is a representation of the order profile of the SKUs that were imported into System X

4.9.7 Order volume analysis

The volume analysis in System X is a set of graphs that summarizes and display the order patterns for a chosen customer. The data is founded, as the graphs above, on the two imported Excel documents for the chosen period. The volume analysis display four different graphs each of which providing a different interpretation of the same data. Figure 13a has divided the entire period into days and then summarized the total order lines for each day and represented it in a line chart. In Figure 13b the data is aggregated into order lines per weekday, Figure 13c per month and Figure 13d is displaying the total order lines per day and month.

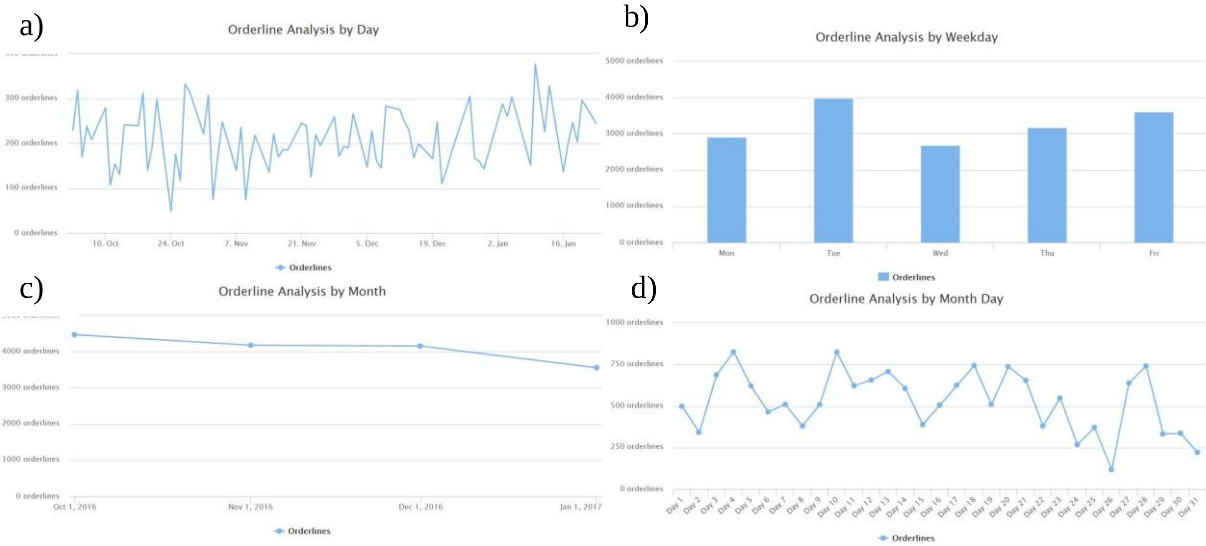

Figure 13a-d. Shows four different graphs of the order patterns of the imported SKUs, based on daily, weekly and monthly aggregation

4.9.8 Heatmap

The final tab of System X is the actual heatmap itself. The aim is to display where the different SKU class items are located in the racks of the warehouse. Each SKU class has received a specific colour: A = red, B = yellow, C = light blue and D = black. The last SKU class D contains items that have no movement at all during the chosen period. As can be seen in Figure 14. a row based warehouse has been chosen to display the actual heatmap. The white line display the aisle itself and each SKU is represented by the coloured dots. Each dot illustrates a specific location in the warehouse and the level is represented by each row of dots. The closer the row is to the aisle (white line divider) the closer to the floor the SKU is located, which means that the actual heatmap produced by System X only display where the different SKUs are located and its class. Finally, the vertical blue lines are used to display the width of each bay. Each bay has to have the same width and it is thus based on the bay with the most locations in that particular aisle. If a bay does not have the same amount of locations as the widest aisle the rest of the bay width is greyed out.

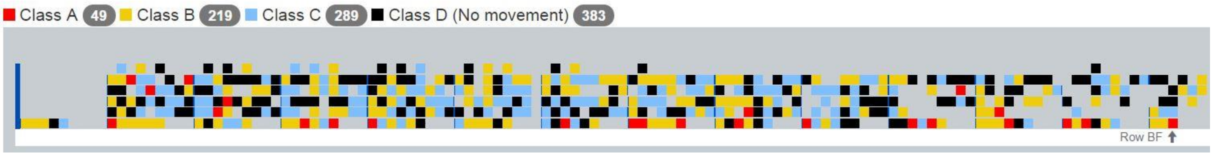

Figure 14. Is the heatmap of the imported SKUs and their respective location in the rack

4.9.9 Download SKU ABC

The last function of System X is the ability to review the SKU classes and each individual items ranking within each class in an Excel sheet. The Excel sheet is just a simple summary of the location, the SKU, which class it has been assigned and lastly the rank that it has within this class.

5 Analysis

The analysis chapter will have its foundation in the two presented tables of input variables that affect a reallocation decision, see Table 1 and Table 4. Furthermore, a collected view of the mentioned input variables can be seen in Table 9. After analysing the input variables an evaluation of System X and its potential areas of use will be given.

Table 9. Displays the possible input variables collected from literature and empirical findings that directly or indirectly affects reallocation and its productivity outcome.

Input variable	Mentioned in
Assignment strategy	Empirical findings, literature
Consolidated put aways	Literature
Cross-selling effect	Empirical findings, literature
Demand, demand change & variability	Empirical findings, literature
Customer forecast	Empirical findings, literature
Inbound order quantity and frequency	Empirical findings, literature
Item characteristics	Literature
Locations	Empirical findings, literature
Material handling equipment	Empirical findings, literature
Needed locations	Empirical findings, literature
New products	Empirical findings, literature
Order lines picked	Empirical findings, literature
Picking process	Empirical findings, literature
Quantity picked	Empirical findings
Queues	Empirical findings
Reallocation cost	Literature
Reallocation time	Empirical findings, literature
Reallocation travel distance	Literature
Remaining inventory level	Empirical findings, literature
Remaining SKU lifetime	Empirical findings
Routing method	Empirical findings, literature
Seasonality	Empirical findings, literature
Shape	Empirical findings
Size	Empirical findings

Travel distance	Empirical findings
Travel distance and time	Literature
Weight	Empirical findings

5.1 Input variables and their possible effects

Both literature and empirical findings support the notion that reallocation of products should only be made as long as the productivity gains outweighs the required efforts of the actual reallocation. More precisely, the time to move a product, including the needed administrative work, must be less than the time savings due to the productivity increase. On the other hand, empirical findings and literature do differ in terms of where to move a fast-moving SKU. Literature suggests that the SKUs with high demand should be placed close to the inbound/outbound doors to minimize the travel distance while the empirical findings raises the risks for queues if many fast-moving products are reallocated to a small area. Instead it is suggested that the SKUs should be spread along the aisle to minimize the risk of such queues. However, literature and the empirical findings are in agreement on that there are many potential input variables that could have an effect on the reallocation decision. The different input variables brought up in literature and empirical findings are displayed in Table 9 and is presented and analysed below.

Order lines picked and **Quantity picked** are two closely related input variables that literature discuss, in terms of demand and demand variation, which are a direct consequence of the demand for a certain SKU. The demand could in turn be affected by aspects such as sales offerings and seasonality. The literature also states that the demand affects the allocation of products in a warehouse. Typically, the literature suggests that high-demand products initially should be stored or reallocated to locations that are easily accessible for order pickers, preferably close to the inbound/outbound doors to minimize the travel distance of the picking route. The demand in terms of order lines picked and quantity picked could furthermore be used as a basis for an ABC-analysis and a following ABC-classification of SKUs. The result of the ABC-classification is that high-volume movers will be classified as A-products, making it easier for the Locationer to assign these products to the most suitable location, which in turn makes the picking process more efficient.

The empirical findings show that these input variables can be used as a basis for reallocation decisions as a response to changing demand. Thus constituting a means to determine the SKUs effect on the productivity and a possibility to reallocate high-volume SKUs to more accessible locations. In fact, SLOG uses the order lines picked, not only as an input parameter for reallocations but also as their main performance measurement. Thus, putting even more emphasis on this particular input parameter than the literature does. The quantity picked is however marginalized as an input parameter as SLOG focus on the number of stops at each picking location. As in the literature, the empirical findings show that demand-related input parameters could be used as a basis for an ABC-classification of SKUs. Again, emphasis is put on the first parameter as it is used as the main criteria for ABC-classification, both at SLOG, but also in the ABC-analysis tool System X.

According to literature, **Locations**, or more precisely, the travel distance to locations in terms of both horizontal and vertical distance affects the picking productivity. In other words, the further away the location is from the most optimal pick location, the longer time the picking will take. The most optimal pick location is, according to literature, the location in the warehouse closest to the inbound/outbound doors. Vertical movement is, according to material handling equipment specifications and interviews, generally slower than horizontal movement, see Table 2. Thus, making the height of the location relatively more influential on order picking productivity than the horizontal dimensions. Literature also states that the height of the location limits the choice of material handling equipment as all material handling equipment cannot be raised sufficiently high. In addition, empirical findings show that the size and load limit of the location is a determining factor for what SKUs to store where, as the SKUs could be too large or too heavy for a specific warehouse location. As this aspect affects where to store products it directly affects the allocation and reallocation decisions in the warehouse and consequently its productivity.

Remaining inventory level is a possible input variable for reallocation decisions, both according to literature and empirical findings. Most Locationers at SLOG uses the remaining inventory level as an indicator for what products to move to smaller locations, to free up space in the racks for high-volume goods. If no more restocking is going to be done for a specific product, the remaining inventory level is the determining factor for the remaining lifetime of the SKU.

The choice of **Material handling equipment** is affecting the productivity to a great degree, this is clearly stated both in literature and in the empirical findings of this study. Different material handling equipment have different capabilities in terms of horizontal and vertical speed as well as height capability and load-capacity. The characteristics of the equipment used when picking and storing goods affects how fast the task can be completed. While the literature and empirical findings show that the effect on productivity is determined by the material handling equipment characteristics, the empirical findings also raised item characteristics and type of racking system used as a basis for the choice of material handling equipment. Both literature and empirical findings show that if the most appropriate material handling equipment is chosen, it will decrease the need to visit the same location multiple times as a result of not having enough space on or improper material handling equipment. The material handling equipment capabilities and performance in terms of horizontal and vertical speed is not currently considered per se in the reallocation decision.

The **Reallocation time** is the time required for the actual movement of the SKU from one location to another and includes the needed administrative time connected to the reallocation. Reallocation time is mentioned in literature as part of the reallocation cost, meaning required time and work for the reallocation. Both literature and interviewees states that the reallocation should only be made if the time savings gained from a productivity increase outweighs the required reallocation time. In this way, the reallocation time is an input variable that also serves as an evaluation parameter for the reallocation decision. Even though the reallocation time is being considered at SLOG they currently don't have a way of ensuring that the productivity outcome from a reallocation is larger than the time incurred.

The following two input variables are connected to the **Assignment strategy** used at a warehouse. Literature states that the assignment strategy is the most influential factor on picking productivity and that it also influences the warehouse storage capacity and space utilization. At SLOG the choice of assignment strategy is class-based with a random or dedicated storage strategy within each class. The choice is primarily based on demand patterns and inbound order patterns. The two input variables that are connected to, and dependent on, if dedicated or random storage assignment is used are remaining SKU lifetime and number of put aways within the remaining lifetime and these will be described next.

The **Remaining SKU lifetime** means how long the SKU is expected to remain in storage, either based on the remaining inventory and the average pick rate or as a fixed time before the remaining inventory will be scrapped. The remaining lifetime is only brought up during the interviews in this study and has not been mentioned as a potential input variable in the reviewed literature. In a dedicated storage setting the remaining lifetime of a SKU can be relatively long, as it is continuously restocked in the warehouse. The remaining lifetime is then based on the remaining inventory level and the period of time that new inbound shipments containing the product will be received. In a random storage setting on the other hand, the remaining lifetime of a SKU at a certain location is simply based on the remaining inventory level. It is possible that new shipments containing the product will be received but it will then not be stored at the same location as is the case in a dedicated storage setting. Consequently, the remaining lifetime of a SKU at a specific location is generally much shorter when a random storage is applied. Shorter remaining lifetime affects the productivity outcome, of a reallocation, in terms of having a shorter time to make up for the required reallocation time when moving a SKU. It is thus easier to achieve a productivity increase when reallocating a SKU within a dedicated storage than a random storage, if the remaining lifetime is considered in the evaluation of the reallocation decision.

The second input variable connected to dedicated and random storage is the number of **Put aways within the remaining lifetime** of a SKU, which is naturally connected to the remaining lifetime of the SKU. The number of put aways is a factor in a dedicated storage setting alone as the random storages has no restocking of products to the same location. Put aways require time and work and are dependent on the travel distance to the location in which to store the SKU. Thus, the reallocation of a frequently restocked SKU can increase the overall performance of the warehouse. Literature states that if it is possible to gain knowledge of what SKUs are included in an incoming shipment it would enable the Locationer to consolidate put aways and choosing the most appropriate material handling equipment. Both literature and empirical findings show that this would help to decrease the total number of put away trips, increasing the efficiency of the warehouse.

Reallocation movement (x, y, z) means the distance in three dimensions between the initial and final position of a reallocated product. The **x-movement** is between aisles, the **y-movement** is along aisles and the **z-movement** is vertical movement, see Figure 8. In the literature, the distance that a SKU has been moved is claimed to affect picking productivity as the travel distance, travel time and even travel speed is potentially affected by the reallocation movement. The x- and y-movement thus affects the travel distance which in turn affects the travel time. The z-movement instead affects the vertical travel distance and consequently also affects the travel time and speed as it potentially influences the choice of material handling equipment due to height capabilities. At SLOG emphasis is put on the vertical and between aisles movement of a product, marginalizing the along aisle movement, as it is claimed that the order pickers most often are traversing the whole aisle due to the used routing method: S-shape. Since SLOG believes that the x- and z-movement have the largest effect on productivity, SLOG attempts to place SKUs with a high demand as close to the floor as possible, while simultaneously trying to minimize the number of aisles entered. The approach applied by SLOG is in contrast with the literature claim that the most preferable locations for high demand products is simply locations close to the inbound/outbound doors.

Full pallet pick means that the SKU is only being picked and stored as full pallets. Given this situation, each dimension of the reallocation movement is guaranteed to affect the travel distance and time and hence the productivity outcome of the reallocation decision. This as the order picker is going to travel directly to the pick location and then directly to the inbound/outbound doors. Literature states that if a SKU is picked in full pallets this affects both the classification of products and the assignment strategy. The former is also supported by the empirical findings as some customers at SLOG has a full pallet storage section. In the literature, it is also claimed that what is ultimately determining if a product is picked in full pallets or not, is the size of the order quantities and if the customer wants to receive a complete pallet.

Inbound order quantity and frequency is a combined input variable that is ultimately based on the demand and the expected demand of the end customers, which describes how often and in how large volumes shipments are received. In the literature, order quantity and frequency is described as a very influential input variable that could potentially affect the overall design of the warehouse and how the 3PL constructs its different customer solutions. More specifically, changing inbound quantities and frequencies could cause earlier design decisions such as the size of locations to be ineffective. Furthermore, literature claims that the inbound order quantity and frequency can affect the choice of allocation strategy, which is confirmed in the empirical findings, as SLOG chooses a random storage strategy if the order volumes and frequency are too unstable. The empirical findings further show that lower inbound quantities and higher frequencies increases the need of reallocations, since this could result in a lack of suitable locations to store incoming goods. In addition, this could be seen as a confirmation of the literature claim regarding earlier design decisions.

The physical characteristics of SKUs such as **Weight**, **Size**, and **Shape** is the most commonly used input variable when making a reallocation decision, according to the empirical findings. These physical attributes are used since it affects in which locations the SKUs can be stored as the locations might have load capacity limits or be too small for certain SKUs. Empirical findings also shows that a class-based allocation strategy, based on these input variables, can increase the productivity as well as space utilization and simultaneously preserving a good building order of pallets. In addition, the physical characteristics can influence the choice of material handling equipment as not all equipment can manage all types of SKUs. In the literature, these three input variables are described to affect the SKU classification, the choice of assignment strategy, where SKUs can be stored and also how the 3PL constructs its customer solutions.

Needed locations is an input variable that must be taken into consideration if space is scarce and there is a shortage situation on certain locations. That there is a need for locations might result in that the Locationer has to reallocate products to be able to receive new products. That is, even though a reallocation might not result in a productivity increase by itself, the Locationer would nonetheless have to execute the reallocation to make room for incoming goods. The need of locations thus increase the need for reallocations and overrides the productivity parameter. The empirical findings show that some of the Locationers at SLOG have this situation and the need for locations is used as a highly influential input parameter. The reason for this need of locations is stated to be changing inbound order patterns in terms of reduced inbound order quantity and increased frequency. The literature adds other possible reasons for changing inbound order patterns such as new product releases, seasonality and the product life cycle which also could contribute to an increased location and reallocation need.

Seasonality has a large effect on a wide range of aspects such as how the 3PL constructs its customer solutions, the complexity and demand variability as well as the ABC-classification of SKUs. In addition to these aspects, literature further states that the need for reallocations could be increased due to demand changes, resulting from seasonality, which also could affect the ABC-analysis. Empirical findings show that a high seasonality could argue for the implementation of a random storage assignment strategy, as is done at SLOG. It is also stated that handling seasonality would be eased by having access to the customer forecasted demand. Having access to the customers forecast of a SKU would enable the Locationer to allocate and reallocate SKUs to the most appropriate location before they actually arrive in the warehouse.

Another input variable that affects the ABC-classification is the release of **New products**. Literature states that new products change the end customer demand and creates overall demand variability when they are released, reducing efficiency and effectiveness of the implemented warehouse solution of the customers. The empirical findings on the other hand highlighted that new products cannot be classified based on order lines picked as there is no available demand statistics. Consequently, the Locationers don't know if the product is going to be frequently picked or not. In this situation it would be beneficial if there was a demand forecast available to use as a basis when allocating new products. In the current situations, Locationers simply assume that new products will be picked more frequently than the average pick rate and tries to allocate new products to accessible locations and if needed, SKUs are reallocated. In this way, new products drive reallocations while simultaneously making the resulting productivity unsure.

As previously stated in regards to earlier input parameters, a **Customer forecast** regarding demand or incoming shipments, would enable warehouses to better cope with seasonality, demand changes and new product releases. In addition, literature states that if such a forecast where available it would enable the receiving function to choose the most appropriate material handling equipment for put aways and to consolidate put aways, increasing the efficiency of warehouse operations. Literature also claims that the forecast could help to lower the uncertainty in regards to incoming shipments and therefore it would also lower the need for reallocations. The empirical findings points to other aspects and shows that a forecast could affect the ABC-classification of products, making it more accurate, especially in regards to new products. Generally the Locationers at SLOG do not receive a forecast but it is claimed that it would help them doing the initial allocation right the first time, lowering the need of subsequent reallocations.

The **Picking process** and **Routing method** both have an effect on the productivity of a warehouse, according to literature and empirical findings. Batch picking, defined in literature as picking the quantity of a product equal to several orders at the same time, could affect the productivity positively as the number of visits are lower than when discrete picking is used (picking one order at a time). Both literature and the empirical findings describes the effects of batch picking in this way and further states that the productivity increase can vary depending on how the products are sorted into different orders after being picked. The use of batch picking would however potentially decrease the productivity increase resulting from reallocations as it could lower the number of stops being made at locations containing SKUs that are present in multiple orders. The choice of picking process and routing method are interlinked and affects each other. Depending on which routing method is used, the chosen picking process will perform differently. In the case of SLOG, only the S-shape routing method is applied since their strategy is to spread the high-volume movers along the complete aisle. According to literature however, the routing method affects the travel distance to a great degree as well as the allocation of products and should be evaluated for each unique situation.

The **Cross-selling effect** could, if considered in the allocation decision, increase the productivity of the warehouse if SKUs that are frequently picked together are also located close to each other, thus decreasing the picking time. The result of the cross selling effect is stated in literature as well as shown in the empirical findings. Literature also claims that the cross-selling effect could influence the ABC-analysis in terms of number of SKUs classified as A-products, this as low-volume SKUs could be classified as A-products if they have a large effect on the other SKUs. If the cross-selling effect is taken into consideration, this input variable could increase the number of reallocations being made since SKUs that affect each other should be reallocated close to each other.

5.1.1 Division of variables into input variables and wildcards

From the above analysis it is clear that different input variables affect the reallocation decision and its productivity outcome in different ways. Some input variables are directly affecting the productivity outcome of a reallocation decision while other input variables have a less distinctive effect on the reallocation decision that is more difficult to describe and quantify. Therefore, the identified input variables have been divided into two categories: "Input variables" and "Wildcards", see Table 10 and Table 11.

The first category is simply named Input variables since they are directly affecting the potential productivity increase of the reallocation and are either known to the Locationer, easy to measure and are readily available through the WMS. As such, they are incorporated in the Excel model to provide a solid foundation for the reallocation decisions. The second category named Wildcards are not as easy to handle. The wildcards are input parameters that influences the productivity outcome of a reallocation as well as the need of the reallocation. Many of the wildcards makes the reallocation decision more complex and increases the uncertainty of the productivity outcome from a reallocation. Furthermore, its effect is hard to quantify and consequently it is up to the Locationer to apply these to the reallocation decision after the initial productivity calculations have been made. It is also possible that the wildcards will make the productivity aspect irrelevant, as is the case with the need of locations wildcard. The concluded effects of each input parameter and wildcard is displayed in Table 10 and Table 11 that also show their effects according to literature and the empirical findings.

It has been noted that the reallocation decision can be very complex when trying to incorporate both input variables and wildcards, as they affect both the need of a reallocation and the productivity of the warehouse differently. The identified input variables and wildcards thus constitute a guide for what variables that should be considered in a reallocation decision.

The input variables contain information about the SKU that must be included in the reallocation decision to be able to understand and quantify the productivity outcome. The wildcards are instead additional aspects which have a more complex effect on the reallocation decision that still needs to be considered before reallocating a SKU.

Table 10. Display the resulting input variables that should be considered in a reallocation decision. These input variables are also included in the Excel model

Input variables	Explanation	According to literature affects	According to empirical findings affects	Concluded effect on
Order lines picked per day	Average number of order lines picked per day for the SKU	- Allocation - Item classification - Operations - Reallocation	- Allocation - Item classification - Productivity - Reallocation	- Item classification - Productivity - What products to reallocate - Where to allocate and reallocate SKUs - Reallocation decision
Quantity picked per day	Average quantity picked per day for the SKU	- Allocation - Item classification - Operations - Reallocation	- Allocation - Material handling equipment - Productivity - Reallocation - Travel distance	- Item classification - Where to allocate and reallocate SKUs - Reallocation decision
Locations	Location code for SKU	- Productivity - Reallocation	- Allocation - Material handling equipment - Productivity - Reallocation	- Productivity - Where SKUs can be physically allocated and reallocated - Reallocation decision
Remaining inventory level	The current inventory level of the SKU	- Reallocation	- Reallocation	- Remaining SKU lifetime - Reallocation decision
Material handling equipment	Type of material handling equipment used for picking the SKU	- Productivity	- Productivity - Routing method - Travel distance - Travel time	- Productivity - Reallocation decision
Reallocation time	The average required time in minutes to reallocate a SKU, incl. administrative time	- Reallocation	- Productivity - Reallocation	- Productivity - Reallocation decision
Assignment strategy	If random or dedicated storage is used	- Operations - Productivity - Quality	- Allocation - Productivity - Reallocation - Restocking efficiency - Travel distance	- How to calculate productivity outcome of a reallocation decision - Productivity - Reallocation decision

Remaining SKU lifetime	The remaining lifetime in months for the SKU		- Productivity - Reallocation	- The time available to earn back the reallocation time - What SKUs to reallocate - Reallocation decision
Number of put aways within remaining SKU lifetime	Number of expected put aways within the remaining SKU lifetime	- Operations	- Operations - Productivity	- Total operations outcome - Reallocation decision
Reallocation movement (x, y, z)	The length of the movement along the x-, y- and z-axis in meters	- Productivity - Reallocation	- Material handling equipment - Productivity - Reallocation	- Productivity - Reallocation decision
Full pallet pick	If the SKU is picked in full pallets or not	- Allocation - Item classification - Operations	- Allocations - Item classification - Productivity	- All dimensions of travel are affecting productivity - Item classification - Reallocation decision

Table 11. Display the wildcards that should be considered after deciding the productivity outcome of a potential reallocation as these could affect the result and need of the reallocation.

Wildcards	Explanation	According to literature affects	According to empirical findings affects	Concluded effect on
Inbound order quantity and frequency	The volume of the inbound orders and its frequency	- Item classification - Operations - Reallocation	- Allocation - Operations - Reallocation	- Choice of assignment strategy - Item classification - Reallocation need
Weight, size, shape	The physical attributes of the products	- Allocation - Item classification - Operations	- Allocation - Item classification - Material handling equipment - Reallocation	- Item classification - Where SKUs can be physically allocated and reallocated
Needed locations	If there is a shortage of locations	- Reallocation	- Reallocation	- Reallocation need

Seasonality	The seasonality of the SKUs	- Demand - Reallocation	- Allocation - Demand - Inbound order quantity and frequency - Reallocation	- Choice of assignment strategy - Item classification - Reallocation need - What SKUs to reallocate
New products	If the product is new, generally without known demand	- Demand - Item classification - Operations - Reallocation	- Allocation - Item classification - Productivity	- Item classification not possible - Productivity - Reallocation need - Where to allocate products
Customer forecast	If there is a demand forecast provided by the customer	- Operations	- Allocation - Item classification - Productivity - Reallocation	- Allocation - Item classification - Productivity - Reallocation need
Picking process	If the picking technique is batch picking or discrete picking	- Allocation - Productivity - Quality	- Productivity - Travel distance	- Productivity - The number of stops required when picking
Routing method	What type of routing method is being used	- Allocation - Productivity - Travel distance	- Productivity - Travel distance	- Productivity
Cross-selling effect	If the demand of a SKU implies demand of other SKUs	- Item classification - Productivity	- Allocation - Productivity - Reallocation	- Item classification - Productivity - Where to allocate and reallocate SKUs

5.2 Evaluation of System X

In the following sections the potential areas of use with System X will be discussed and different limitations in the system will be presented.

5.2.1 Possible areas of use with System X

System X can be used for several different purposes as it provides valuable SKU information in its different display screens, see Chapter 4.9. Starting with the first result display in System X, where the cumulative order lines of each ABC-class is displayed in a Pareto curve and the order line background in each class is described in a table, see Figure 11 and Table 8. Knowing the order lines that are picked in each class is helpful for a warehouse Locationer as it provides important background information in the reallocation decision. That System X is founding its calculations solely on order lines picked is in line with several authors mentioning this as one of the most common foundation criteria for an ABC-analysis. The larger the differences in order lines frequency the larger the effect of an ABC-classification in a dedicated warehouse. In a random warehouse on the other hand, the effect is not as large as the SKUs are not refilled at the same location. Therefore, a Locationer in a dedicated warehouse can use this screen to get an understanding of the productivity differences of reallocating SKUs from different classes. In addition, this result screen in System X can be used to see the number of locations that are occupied by slow-moving items. According to Gu et al. (2007) a need for reallocation is created as soon as a SKU becomes slow-moving. Knowing the number of SKUs that are not selling provides the Locationer with an action list of items that should be reallocated to give room for new incoming SKUs. How the SKUs are stored in the warehouse have an effect on the warehouse performance and thus being able to act on this information provides large benefits for the Locationer.

The second result screen in System X, which contain the order profile, does not include that much information but can be useful to the Locationer and the Warehouse Planner. Both the Warehouse Planner and the Locationer use the order volume data in their daily operations to evaluate how the orders of a customer should be picked. Consequently, this simple data about how many order lines there are on an order can display if the company is using the correct picking method; discrete or batch picking, or not. The less order lines that are on an order the more reason to use batch picking instead of discrete picking as it reduces the number of trips back and forth to the starting area. Not applying the correct picking method to the specific context consequently affect the warehouse performance of the company.

The third result screen in System X regarding the volume analysis is another good presentation of the imported data that can be used to determine how the order volumes varies per month, but also per day in each month. Investigating sales trends and changes in demand is important according to Gu et al. (2010) as the earlier design decisions could become inefficient. Therefore, statistically knowing how large the order volumes are for a specific customer at any given day of the week can be of high importance for a company as SLOG, where they have large seasonality customers and the main part of the workforce is temporary staff. In addition, order volumes are telling the warehouse planner a lot about the number of completed restocks that are needed on an average Tuesday, the more outbound orders the more restocks are needed. Having large order volumes on some days also provides the opportunity for the Warehouse Planner to allocate inbound orders to low-volume order days. Better scheduling of incoming orders can create an opportunity of consolidated put aways, which reduces the number of visits an employee has to make to that location to put away the goods and thus increasing its productivity according to the literature. Furthermore, having the information of the warehouse workload presents an opportunity to be proactive in the staffing of different tasks. It is also very important when a company as SLOG is trying to trim its warehouse operations to run with as a low number of workers as possible. Lastly, the volume analysis provides a good overview of how the sales trend of the customer is developing and if System X is run for a single SKU the sales trend of the particular SKU can be determined.

The final screen of System X is the actual heatmap, where the user easily can see where the different SKUs are located and how they are classified. Being able to attain a visualisation of the actual warehouse on a daily basis can be of great use to the Locationer, as it is possible to optimize the warehouse daily and ensure that the SKUs evaluated for a reallocation are classified as A- or C-products, in accordance to the ABC-analysis, to gain the largest effect of the reallocation. Having this map therefore reduces the risk of reallocating SKUs that are believed to be high-volume movers, when they might not be. Being able to act on the SKUs that are providing the largest effect on the company productivity is in line with the literature that states that focus should be on the items where the largest productivity effect can be achieved. The actual heatmap also provide the Locationer with the opportunity to perform an ABC-analysis, horizontally and vertically, as the Locationer easily can see where the SKUs are located the Locationer can understand what reallocations are needed to achieve the most optimal warehouse allocations, in the specific customer context. The most optimal appearance of the heatmap will depend on the material handling equipment used at the specific customer. For example, if a regular push cart is used for the picking process it will have a different vertical performance than a high level order picker and thus affect the optimal heatmap. Important to consider is however that System X does not suggest how the SKUs should be reallocated, that has to be determined by the Locationer. In this final screen the possibility to download the actual ABC-analysis of System X exists, which include the SKUs, its class and how it was ranked in the class itself. The Locationer can thus track the development of the SKU and determine if it is becoming more or less popular. Demand information is beneficial as the Locationer can move a SKU to a more appropriate location as soon as the SKU is starting to become more popular and does not have to base its reallocation solely on judgment.

5.2.2 Limitations in System X

System X is an IT-system and like all systems it has its limitations. Starting with the import process of System X it can be fairly complicated unless the user is very familiar with Excel, as almost every imported Excel file has some errors. One error that occur almost every import attempt is that the user forget to remove buffer locations. Not removing the buffer locations, all buffered SKU quantity have the same location code within a specific area, will create an error as System X does not allow a location to have two different inbound shipments with the same SKU, in the same location. To avoid this error the user must remove all the buffer locations before the file can be imported into System X. Another limitation with System X is that all locations in the imported file must have the exact same naming convention. In a warehouse system as the one at SLOG it is common that the warehouse has different location naming conventions depending on the customer at hand, which results in a need of manual refinement of the exported data from the WMS system. Having different naming conventions creates more work for the employees and thus reduces their productivity and according to literature IT-systems are needed to deal with this issue. Performing this manual refinement takes time and even more time if the user is not familiar with Excel. During the testing sessions, it was further noted that System X had major difficulties with location codes that did not have corresponding naming conventions, where the last character in the location code was a letter and not a digit. Importing a file with some location codes with different naming conventions in them made the system crash directly.

These limitations can be solved by creating custom reports in the WMS so that the user can export the correct files directly. A larger limitation however, is the number of order lines that System X can process at the same time. According to the developers the system can handle up to 150 000 order lines, which can be considered enough, but the largest customers of SLOG has more than 160 000 order lines a month. One could of course reduce the imported data to only include half a month worth of sales. However, by reducing the time frame of the ABC-analysis it will respond more quickly to large variations in sales volumes and constant high-volume movers can be surpassed by short-term high-volume sales SKUs. Consequently, SKUs that are sold in very large volumes in a short time frame can skew the result of each ABC-classification. The issue with the imported order lines limit results in that the largest customers, with the largest potential for improvement, cannot be processed in full. In order for System X to process these large volume customers the user has to divide the sales data into specific areas of the warehouse. Not having a systematic approach to a reallocation decision makes the reallocation process less efficient and hence more time consuming, according to the literature. Having to divide customers into specific areas takes time and the Locationer has to switch between screens, as the Locationer does not have all information available at the same time. Furthermore, as the customer SKUs are divided into different sections the SKU will be classified as A, B or C within its area. If only slow moving items are imported it implies that some of them will be classified as A-products even though they barely have any sales, which can result in a reallocation of a SKU where no productivity increase can be achieved.

The foundation of the ABC-analysis in System X is based only on the order lines picked for each item, which is one of the most common according to literature. Only considering one variable in an ABC-classification can be the most suitable for a company, but as mentioned in literature it can be of value to evaluate more than one variable in the ABC-analysis to ensure that all criteria of the customer SKUs are covered in the analysis. Additionally, considering more than one variable might drastically change the end result, but also the complexity of the ABC-analysis according to literature. Not considering the cross-selling effect, as an example, at some customers can have a large effect on the productivity of the warehouse, according to the empirical findings. Being limited to the order lines picked can also be an issue for some customers at SLOG, where the order lines are low but the quantity per order line picked is very large. Not being able to pick all items at once creates a need for a revisit to the same location and thus should have been counted as two order lines.

In regards to the time it takes to import the data into System X it is clearly affected by the amount of sales data for the customer. If the sales data is around 60 000 order lines it takes up to 1.5 minutes to complete one document import, which is a lot of wasted time in an area where time is of the essence. The larger the sales data the slower the rest of the steps of System X will become as well. In the trials performed by the researchers it could take up to one minute to change between different screens, which increases the total time it takes the user to finalize all process steps of System X and create the final heatmap. In the most extreme case when the data got close to 150 0000 order lines, system overload was achieved and the system crashed. Having system overload when not even reaching the maximum level indicates that the actual system capacity is lower than 150 000 order lines.

5.2.3 How System X should be used at SLOG

System X was presented as an ABC-analysis tool and from the analysis several different areas of use were discussed, but the effect will differ depending on for which customers it is applied. The result will differ as the SKU lifetime at the given location will be different depending on which storage assignment that is applied. In the random storage allocation a SKU will only be located in a particular spot until the entire inventory, in that location, is picked. Consequently, if System X is applied to a customer that applies a random storage allocation the heatmap will vary daily as high-volume SKU locations will become empty at a high rate. Therefore, creating a heatmap of a random storage assignment with large order volumes becomes redundant, as the items will not be restocked at the same location. In a dedicated storage assignment on the other hand System X can be of greater use as items are restocked at the same location for a longer period of time. Consequently, the Locationer can optimize the warehouse both horizontally and vertically based on the resulting heatmap, without having a heatmap that changes continuously.

To achieve the most benefits of System X it should be run on a daily basis, to ensure that the Locationer attain a standardized procedure for reallocation decisions. By using System X that evaluates the data consistently every time, a company can assure that the decisions taken by the Locationer become more standardized and less based on judgment. Removing some of the Locationers judgment, ensures a more systematic approach which in turn reduces the complexity according to literature. Having a systematic approach with the needed data for a reallocation decision in two displays, instead of numerous different ones, increase the number of reallocation decisions a Locationer can evaluate on a daily basis. Evaluating the data on a daily basis also increase the possibility of the Locationer to reallocate SKUs as soon as the trend of a SKU changes.

However, as the ABC-analysis in System X is based on the order lines picked for the imported period, it classifies SKUs that are brand new and have no sales as D products. That the SKUs without any sales are classified as D is due to that System X is not able to predict future sales, which in turn means that if the customer has large seasonality and short life cycle SKUs, System X will not display an accurate heatmap of all SKUs. For customers with high seasonality the Locationer still has to perform a manual evaluation, using his judgment, of each reallocation.

In terms of importing sales data into System X and processing speed, System X does not perform that well. Together with the numerous limitations of the system makes the system hard to utilize efficiently, especially when considering larger customers. Having to manually refine data and divide customer sales into different areas reduces the efficiency of the entire system as it is not an automatic approach. The manual approach results in a situation where System X becomes hard to apply for very large customers, even though it is for these customers where reallocations due to an ABC-classification could have the largest effect on the productivity.

Based on the argumentation above, SLOG should consider the different characteristics of the different customers before starting to use System X. System X can be a good decision support system if the context of the customer suits the system. The customers where SLOG has the largest potential and most easily can apply System X on a daily basis is for customers that:

- Have a dedicated storage assignment
- Have order volumes below 60 000 order lines per month
- Have low variation in demand
- Have long life cycles
- Have location codes without alternating naming conventions

6 Development of Excel model

Based on the reasoning regarding different input variables in the analysis, see Table 10, the input variables that directly affect the productivity of the warehouse and are measurable, were included. Based on these variables an Excel model was created to be able to simulate what a potential reallocation of a SKU could result in. The Excel model is just a prototype of how SLOG should evaluate a potential reallocation and act as a decision support system in the daily operations. The model created does not consider SKUs with no sales, which includes new products, as it is not possible to calculate its effect on SLOG productivity and remaining lifetime etc.

6.1 How the Excel model is to be applied

The Excel model that was developed can be used as a standalone prototype where the user manually enter SKUs considered for a reallocation or in combination with another IT-system that suggests SKUs to be reallocated. If the system is used as a standalone prototype the user can potentially drive up and down an aisle and evaluate SKU reallocations as the aisle is being traversed. However, if the system is used in combination with another IT-system like System X a faster evaluation can be made. In this Master's thesis the Excel model was applied on the final heatmap of each of the three customers, to determine what potential productivity increase that could be achieved by reallocating different SKUs. The benefits of combining these two are that the heatmap removes the need to actually traverse an aisle to determine what SKUs to reallocate and the Excel model then is able to evaluate the potential productivity effect of the reallocation before the SKUs are reallocated. Consequently, the heatmap and the Excel model was used in parallel to attain the benefits of the two.

6.2 Input variables

In order for the Excel model to provide SLOG with a potential productivity increase by the reallocation of a SKU, data has to be imported into the model. The imported data has to cover all the input variables, see Table 10. The information that the required input variables contain, are all the necessary data needed to determine if the reallocation will increase the productivity of the warehouse or not. However, even though a productivity increase could not be achieved, the wildcards can override the result and justify a move. In order to gather the input variables needed, the user has to import data about the SKUs and then manually enter some additional data to cover all aspects of the reallocation decision.

Firstly, the user has to import two different documents containing information about each SKU. The first Excel spreadsheet to be imported should include SKU name, location and inventory level, which provides the Excel model with the physical location of each SKU in the warehouse, but also the inventory level at its specific location. The reason for importing data about the inventory levels is that it will later be used to determine the actual time a SKU will block a location for another SKU. The second Excel spreadsheet the user needs to import contains the sales data for the chosen period. The spreadsheet should contain the pick date, purchase order number, SKU name and the pick quantity and thus contain all the sales information of each SKU. From this spreadsheet one can determine the actual sales pattern of a SKU. The more frequently an item is picked in a period, the larger number of physical visits the order picker has to make to that location. Consequently, the larger number of stops an order picker has to make far away from the most optimal pick location the lower the productivity. Therefore, this data is needed to determine if a productivity increase, by reallocation, can be achieved or not.

Thirdly, the user must insert information about its material handling equipment. The data that is needed is the information about the horizontal and vertical speed of the material handling equipment. The needed data can then be used to determine the time difference, for the order picker to travel to different locations and heights.

The final information that is needed will be manually inserted when the user clicks the button Enter SKU to be reallocated, in the Excel model. When the user clicks this button a userform is opened, see Figure 15, asking for additional information about the specific SKU and picking situation. Information that needs to be manually entered into this userform is: which SKU to be reallocated, what location that the SKU should be moved from, if the assignment strategy applied is dedicated or random, if the SKU is picked as a full pallet, the reallocation time and the horizontal and vertical movement of the SKU. In addition, if the assignment strategy applied is dedicated, the user must enter the remaining lifetime of the SKU and the number of inbound shipments that will occur, see Figure 16.

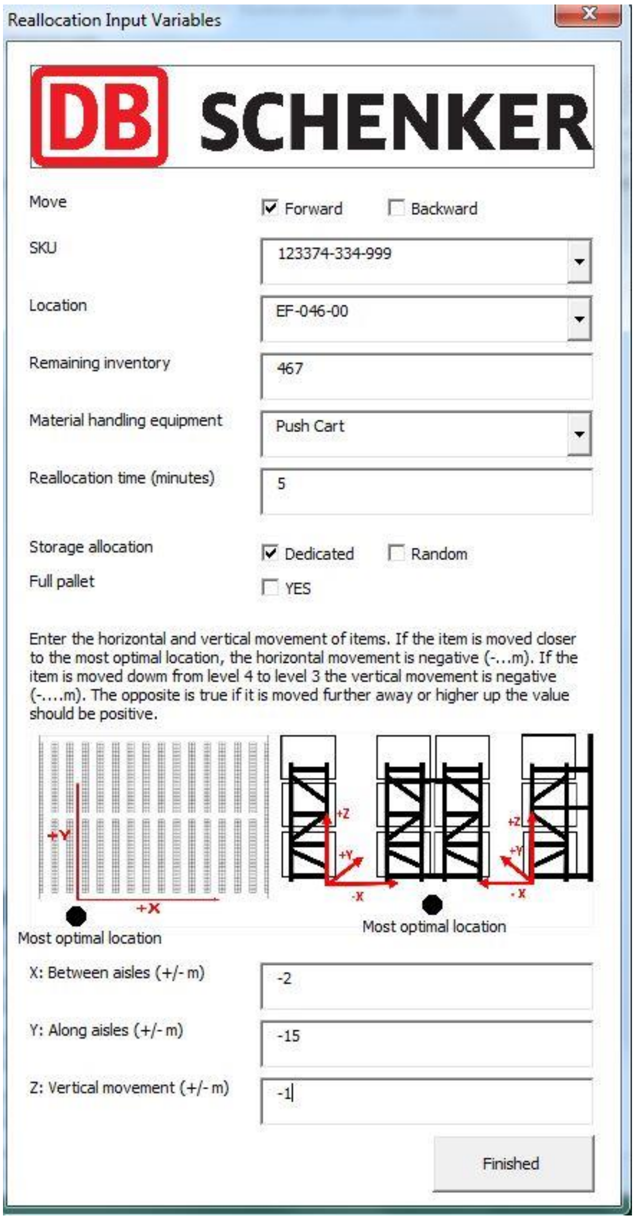

Figure 15. Display the userform that will open after the user clicks the button Enter SKU to be reallocated and an example entry

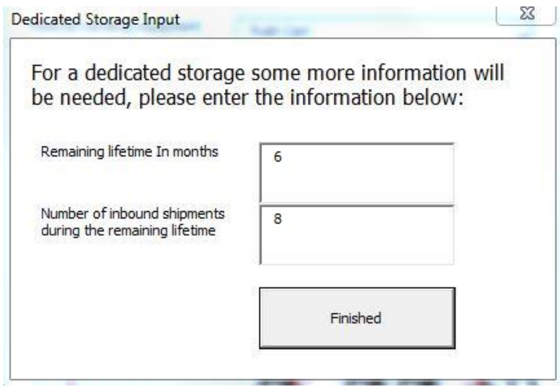

Figure 16. Display the additional userform, with information that needs to be entered, if the user has chosen a dedicated storage assignment

6.3 Calculations in Excel model

The calculations that are made in the Excel model are based on the actual situation that the SKU is in and if it is reallocated to a location closer to or further away from the most optimal pick location. Depending on where the SKU is reallocated to, the possible material handling equipment and the resulting travelling duration might change. The same is valid for the case of random and dedicated storage assignment. In the model three different calculations are made. The first calculation considers the case of a random storage assignment, the second consider the dedicated storage assignment and lastly a case covering moving away an item to make room for an incoming average SKU. Two variables that are used in all three cases will be described first and then each of the three cases will be described individually. After all the necessary information is entered regarding the SKU to be reallocated the Excel model uses the calculations below to calculate the productivity outcome of the reallocation. An example of what the result can look like is presented in Figure 17.

Time difference by shorter or longer transportation

This variable is built up by the horizontal and vertical reallocation movement. That is, if an item is moved further away from the most optimal location the horizontal movement between aisles (X), the horizontal movement along aisles (Y) and the vertical movement (Z) will be positive. If the SKU is moved closer to the most optimal location the opposite is true. Knowing the (X, Y, Z) movement and the material handling speed in the respective direction results in a positive or negative time difference, as compared with the initial position, thus increasing or reducing the productivity, see calculation below:

$$T_{max} = \frac{X+Y}{a} + \frac{Z}{b}$$

$a = horizontal\ material\ handling\ speed$
$b = vertical\ material\ handling\ speed$

This complete time saving by the calculation above is only valid if it is an one order line order that is picked separately or a full pallet order. If the order picker on the other hand is traversing one or several aisles, picking multiple SKUs at the same time, the time difference by the calculation above only represent the maximum time difference that can be achieved by the reallocation. In this case only the vertical difference can be guaranteed and you end up with the following formula:

$$T_{min} = \frac{Z}{b}$$

$b = vertical\ material\ handling\ speed$

Remaining days in inventory

The remaining days in inventory variable is based on the number of units that are left in the chosen location and the actual sales quantity per day for the chosen SKU.

$$R_{days} = \frac{Remaining\ inventory\ at\ location}{Sales\ qty\ per\ day\ for\ the\ chosen\ location}$$

Dedicated storage assignment

In a dedicated storage assignment the different SKUs are located in one fixed location and the remaining inventory is replenished to that location. Consequently, if a SKU is reallocated, it is not only the actual inventory at the location that will provide a potential productivity increase or reduction. In the dedicated storage assignment the remaining lifetime of the actual SKUs also has an effect and needs to be considered in the calculations. The remaining lifetime of a SKU cannot be gathered through a direct import and this data has to be manually entered by the user. When this information is entered it is possible to calculate the potential productivity effect of the remaining inventory and the remaining lifetime of the item, see calculations below.

1. Max productivity effect$_{\text{during } R_{days}} = T_{max} \times R_{days} \times c$
2. Max productivity effect $_{\text{entire lifetime}} = c \times d \times T_{max} + e \times R_{days}$
3. $Max\ productivity\ effect_{total} = Max$ productivity effect$_{\text{during } R_{days}} +$ Max productivity effect $_{\text{entire lifetime}} - f$

$c = SKU\ orderlines\ per\ day$
$d = Remaining\ lifetime\ of\ a\ SKU$
$e = number\ of\ inbound\ or\ outbound\ orders\ per\ day$
$f = Reallocation\ time$

To attain the minimum productivity effect T_{max} is changed to T_{min}.

Random storage assignment

The random storage assignment is constructed in such a way that a SKU can be stored at several different locations at the same time and no replenishment is performed, as the order picker will pick from another location as soon as the inventory at the chosen location is zero. Therefore, the Excel model for the random storage assignment is not as complicated as for the dedicated storage assignment, since the remaining lifetime of a SKU should not be included as the SKU will be assigned a different location for every inbound delivery. In the random storage assignment, the only variables needed are: the SKU order lines per day, the time difference by reallocation, the remaining inventory lifetime and the reallocation time. When these variables are determined the Excel model can provide the user with an estimated productivity effect by reallocation, positive or negative depending on the physical movement. The estimated productivity effect is generated by the following formula:

$$Max\ productivity\ effect_{estimated} = T_{max} \times R_{days} \times c \text{ - f}$$

$c = SKU\ orderlines\ per\ day$
$f = Reallocation\ time$

To attain the minimum productivity effect T_{max} is changed to T_{min}.

Move away

In the last Excel model case the Locationer is moving a SKU further away from the most optimal location to free up that location for an incoming item. In this specific situation you cannot calculate the productivity effect in the same manner as in the above two cases, since a productivity increase will not be achieved when moving an item further away from the most optimal location. In order to achieve a potential productivity increase the Excel model is constructed to compare the productivity reduction of moving away a SKU to the productivity increase achieved by moving forward an average SKU. The reasoning for moving forward an average SKU and not the most frequently picked SKU is that it ensures a more realistic productivity effect and not a hypothetical maximum, hence the average effect is achieved and constitutes the most probable outcome. Therefore, the calculations used in the case Move away consists of two separate calculations. However, the first calculation will be consistent with the Random or Dedicated calculations above, the calculations used will be based on the chosen storage assignment. The second calculation is partly the same as for the Random and Dedicated above, the differences are that average order lines per day for all SKUs was used and that the number of inbound orders are changed to one inbound delivery on average per month. Calculation 2 is as follows:

Calculation 2, Dedicated:

1. Max productivity $\text{effect}_{\text{during } R_{days}} = T_{max} \times R_{days} \times g$
2. Max productivity effect $_{\text{entire lifetime}} = g \times d \times T_{max} + h \times T_{max}$
3. $Max\ productivity\ effect_{total} = -(Max$ productivity $\text{effect}_{\text{during } R_{days}} +$ Max productivity effect $_{\text{entire lifetime}}) - f$

$f = Reallocation\ time$
$g = Avg. orderlines\ orderlines\ per\ day\ all\ SKUs$
$h = Remaining\ lifetime\ in\ months$

To attain the minimum productivity effect T_{max} is changed to T_{min}

Calculation 2, Random:

1. $Max \text{ productivity effect}_{\text{during } R_{days}} = -(T_{max} \times R_{days} \times g)$

By merging calculation 1 and calculation 2 a potential productivity effect can be determined

Enter SKU to be reallocated

Update SKU list and Location Codes

Input variable	Unit	Values
SKU		123374-334-999
Location		EF-046-00
Total orderlines picked per time period		169
orderlines picked/day	ord/day	8,45
Remaining inventory level	qty	467
Material handling equipment		Push Cart
horizontal speed	m/s	0,6
vertical speed	m/s	0,2
X	(+/- m)	-2
Y	(+/- m)	-15
Z	(+/- m)	-1
Reallocation time	s	5
Number of inbound orders during lifetime	qty	8
Remaining life time in stock	months	6

Result variable	Unit	Min	Max
Savings	s	-5	-33,33
Days left in inventory	days		132
Reminvdays	days		10,67
Total Savings per day	s/day	-42,25	-281,67
Total Savings rem lifetime	s/day	-5 617,00	-37 446,67
Total Savings per lifetime	s/day	-6 067,99	-40 453,26
Total Savings Entire Lifetime	min	96,13	669,22
Potential Productivity increase	min		
Swap Back			

Figure 17. Display the final result of the Excel model, which is divided in input variable and result variable to clearly distinguish the result from the user inserted information.

6.4 Productivity effect of a reallocation in the three different types of customers with the aid of System X and Excel model

To determine how the productivity of the warehouse is affected by a reallocation decision, each of three customers Customer D, Customer G and Customer H were evaluated. Each of these three customers had different characteristics in terms of storage assignment and sales volumes, see below.

- Customer D: high-volume and class-based
- Customer G: medium-volume and random storage
- Customer H: low-volume and dedicated storage

Each of these three customers were chosen to cover the three different storage assignments used at SLOG, but also to cover the full range of demand/order patterns. The three customers will then be evaluated based on three different reallocation tests:

- Reallocation test 1: reallocating an item only vertically
- Reallocation test 2: reallocating an item both vertically and horizontally
- Reallocation test 3: moving away an item both horizontally and vertically

To determine the potential productivity effect of a reallocation decision the Excel model created was used to simulate the actual reallocation. The calculations that were used are presented in the Chapter 6.3. For each customer, the result of the reallocation tests is presented and discussed below while the detailed information regarding what products are reallocated, locations and reallocation distance is presented in Appendix B.

Dedicated storage assignment

The dedicated storage assignment at Customer H constitutes a situation where the potential productivity increase of a reallocation could last for the entire lifetime of the product, as the SKU will be restocked at the new location, instead of the current location. In the test performed, a remaining six months lifetime was used and a total of six inbound orders. The reason for using six months and six inbound orders were that it was said to be the minimum lifetime of a SKU at Customer H. In addition, that the SKUs are not allocated randomly, as in the random storage assignment, present the opportunity to reallocate all high-volume SKUs close to the most optimal location and remove the need to traverse large parts of the aisles. In the first reallocation test, where a reallocation only was performed vertically, a potential productivity increase was actually achieved. The potential productivity increase was not that large, only 0.1order lines per man-hour, but it still constitutes an improvement. That a productivity increase was achieved in this case even for small vertical movements has much to do with the remaining lifetime of an item.

In reallocation test 2, the effect of a reallocation were much larger, this is due to the fact that the aisles are 75m long and the SKU can be moved long distances horizontally. The much higher productivity increase is also depending on the remaining lifetime of the SKU and thus much shorter distance has to be travelled for a long period of time. The results of the tests used the same average remaining lifetime for all SKUs. Consequently, if the exact productivity effect of a reallocation is to be determined, each SKU lifetime has to be evaluated individually. To be able to determine the remaining lifetime of a SKU it could be necessary to ask the customers for assistance in the determination. Important to mention is that all items were moved forward closer to the midpoint of the rack and every reallocation resulted in a productivity increase. This implies that if an item is moved either only vertically as in reallocation test 1 or vertically and horizontally as in reallocation test 2, it will increase the productivity of the warehouse. The size of the productivity effect due to the reallocation can however be very small, see Table 12.

In reallocation test 3, where the low-volume SKUs were reallocated further away from the most optimal location the largest productivity increase was achieved. The productivity increase, as can be seen in Table 12, was almost three times as high as the productivity effect of moving forward a SKU. The productivity effect from moving away a SKU is much larger than from moving forward a SKU due to that the slow-moving items in highly accessible locations blocks that specific location for a long period of time, preventing a more frequently picked SKU to be allocated there. Additionally, as the SKU with an average pick frequency has a much larger productivity than the very slow-moving SKU, the effect of moving away the slow-moving SKU becomes very large.

Table 12. Describe the achieved time savings in minutes for each of the three reallocation tests for Customer H and the actual productivity effect (order lines per man-hour)

Reallocation result Customer H	Total minimum saving in minutes	Total maximum saving in minutes	Minimum productivity increase	Maximum productivity increase
Reallocation test 1	185	185	0,1	0,1
Reallocation test 2	71	3455	0,05	2,0
Reallocation test 3	−1328	12594	−0,8	7,4

Random storage assignment

The second customer, Customer G, applies a random storage assignment with products located fairly close to the ground, reducing the potential effect of a vertical reallocation. In reallocation test 1, where the SKU is only reallocated vertically the results displayed clearly that no productivity effect was achieved by this type of reallocation. By reallocating the SKU only vertically the potential productivity effect was actually a reduction by 0,3 order lines per man-hour, see Table 13. For a relatively small customer as Customer G, this does not have a large effect on the total performance as there are not that many people working there. However, if the customer is larger, with more order pickers, this can result in a large reduction in total order lines picked.

In reallocation test 2, the results were a little bit different. The SKUs that were reallocated both horizontally and vertically actually resulted in a potential productivity increase of 0.2 order lines per man-hour, see Table 13. The productivity increase of 0.2 has to be considered a small as the SKUs on average were moved 30 meters horizontally. The reason for Customer G not to have a larger possible productivity increase is partly due to the fact that the SKUs all had very high order volumes, that the remaining inventory was very low but also that the time the SKU would occupy the specific location was very short, reducing the total effect of the reallocation drastically.

For the final test, reallocation test 3, where SKUs are moved away from the most optimal location, the result was a potential productivity increase of 2.5 order lines picked per man-hour. At Customer G, this way of reallocating SKUs is however not that common. The Locationer at Customer G only move away SKUs once a week if it is needed. However, when the C-items located closest to the most optimal location were moved further away from the most optimal location, the difference between the maximum and minimum productivity increase was not that large. The productivity difference amounted to 3 order lines per man-hour. For a customer with similar order volumes as Customer G, 3 order lines per man-hour does not give a large total productivity effect. However, if the customer would have the same type of products but larger volumes the 3 order lines would result in a larger total productivity effect.

Table 13. Describe the achieved time savings in minutes for each of the three reallocation tests for Customer G and the actual productivity effect (order lines per man-hour)

Reallocation result Customer G	Total minimum saving in minutes	Total maximum saving in minutes	Minimum productivity increase	Maximum productivity increase
Reallocation test 1	−42	−42	−0,3	−0,3
Reallocation test 2	−72	27	−0,5	0,2
Reallocation test 3	−144	706	-0,5	2,5

Class-based storage assignment

For the class-based storage assignment at SLOG, with an S-shape routing method, it was mentioned during the interviews that only the vertical reallocations would have an effect on the productivity of the warehouse. This as the order picker would traverse the entire aisle for every batch order. However, during the evaluation of SLOGs largest customer, Customer D, no productivity increase was achieved when the researchers only reallocated items vertically, reallocation test 1, see Table 14. The evaluation showed that all SKUs that were evaluated actually lowered the productivity of the warehouse between -0.2 to -0.8 order lines per man-hour, for the remaining lifetime of the SKU, at the particular location.

For the reallocation test 2, when a reallocation of a SKU was done both horizontally and vertically, the result were different. In this test the minimum productivity increase was negative, which is consistent with reallocation test 1, as the minimum productivity only considers the vertical reallocation of a SKU. But, by including the horizontal movement of the SKU a potential productivity increase was actually achieved. The productivity increase was however only 0.04 order lines per man-hour, which for large customer as Customer D is small for the number of SKUs that were reallocated, see Table 14. That the potential productivity increase was not that large is due to the fact that the high-volume SKU locations are emptied very fast, as they are picked in such high frequency. The result implies that when a high-volume mover is reallocated in a random storage assignment it will not occupy that new location for a long time and the productivity effect becomes very small, see Table 14.

The type of reallocation made in reallocation test 3, where a SKU is moved to a location far away from the most optimal location, is being made daily at the largest customer at SLOG, Customer D. By evaluating several SKUs classified as C-products the potential productivity increase, of placing an average SKU in that location, could be achieved. In the case of Customer D the span between minimum productivity increase and the maximum productivity increase was very large, it amounted to 10 order lines per man-hour. Having a large difference in the potential productivity effect is a result of that the C-products that are moved away have significantly less order lines per day in comparison to the average SKU. Low-volume sales SKUs enables the Locationer to move the SKU far away from the most optimal location and thus attain a larger productivity effect.

By investigating the results, see Table 14, it can be determined that large volume customers with a random storage assignment cannot achieve a productivity increase by just moving a SKU vertically. There are more factors that affect the outcome, as the horizontal movement and SKU characteristics for example, which implies that each SKU needs to be evaluated individually to ensure a productivity increase. Furthermore, for this type of customer a maximum productivity increase is always achieved when moving away low-volume SKUs, classified as C-products.

Table 14. Describe the savings in minutes achieved for each of the three reallocation tests for Customer D and the actual productivity effect (order lines per man-hour)

Reallocation result Customer D	Total minimum saving in minutes	Total maximum saving in minutes	Minimum productivity increase	Maximum productivity increase
Reallocation test 1	−28	−28	−0,2	−0,2
Reallocation test 2	−73	8	−0,4	0,04
Reallocation test 3	−140	1615	−0,8	9,2

7 Discussion and recommendations

In this chapter general questions by the researchers are raised and how these will affect SLOG and its business will be presented. Furthermore, different recommendations on solutions and improvement suggestions are mentioned.

7.1 Choice of routing method and the importance of different travelling dimensions

When making the choice of routing method, SLOG claims to take many different aspects into consideration such as: the type and layout of the racking system they have and what type of material handling equipment is being used. They also state that the order pickers themselves can influence the picking route. In the choice of routing method SLOG strives to create a customer specific solution that is uniquely adapted for each customer. As the aim is to create the most productive solution for each customer it is noteworthy that SLOG applies the S-shape routing method for all its customers. Especially given the shifting characteristics of the customers regarding demand, inbound and outbound shipments, item characteristics etc. which should result in different routing methods for different customers. As the literature study and empirical findings both show that the choice of routing method directly affects the picking productivity there might be some potential gains from re-evaluating the choice of routing method. During this study, the researchers have noted that many Locationers simply states that they always traverse the whole aisle, as is done when using the S-shape routing method, the researchers have however also observed that this is sometimes not the case. Instead, the order pickers use the aisle along the x-axis to exit an aisle before its end, as it seems to be more efficient than traversing the whole aisle even though there are no products to be picked in the second half of the aisle. In conclusion, the researchers recommend that SLOG at least re-evaluate its choice of routing method, to potentially increase the productivity of certain customers. A concrete example is to rearrange the products to store the non- or very slow-moving products to the second part of the aisle and simply apply the S-shape (or the most suitable routing method) to the first half of the aisle where high-volume moving products should be stored. Changing the strategy should enable enough space to mitigate the risk of picking queues that SLOG has raised as a reason for spreading the high-volume movers along the whole aisles.

While SLOG also aims to minimize the movement along the z- and x-axis at the cost of increased travel distance along the y-axis this Master's thesis shows that there should be some benefits from reallocating products along the y-axis as well. Even though there is some uncertainty as to how large the potential productivity increase could be by doing so, the reallocation of products along the y-axis is recommended based on the developed Excel model. It is recommended that SLOG re-evaluates its current situation and executes reallocations, in accordance with the Excel model suggestions, for one of their customers to observe the change in productivity.

In relation to SLOGs concern with the relative importance of movement along the x-, y-, and z-axis respectively it is possible to apply the previously presented idea of rearranging the aisles in a front end picking zone. If x- and z-movement is still judged to be more important despite the result of this study, the second half of the aisles closest to the inbound/outbound doors could be included in the picking area.

The above discussion is only deemed applicable to storage areas that uses a dedicated assignment strategy as this study clearly show that reallocations in a random storage should generally not be done at all. The reallocations should not be performed since the remaining lifetime of products in a random storage results in a saving that does not cover the required time to reallocate the product. However, if the remaining inventory level is high enough and the average pick quantity is low enough, it could still be possible to increase the productivity by reallocating a product in a random storage. On the other hand, this seems to very rarely be the case. In a dedicated storage, the remaining lifetime is much longer due to that the SKU is restocked for a time, making it generally worthwhile to reallocate a product. In conclusion, it is recommended that reallocations are made in a dedicated storage but not in a random storage.

7.2 Future suggestions for System X

After the evaluation of, the according to Schenker Asia Pacific completed IT-system, System X several limitations were found. These limitations should not be found in a completed IT-system according to the researchers and creates concerns for the implementation of such a system. In order for SLOG to implement System X these limitations need to be resolved so that SLOG does not have to change its current operations to fit into the system. Consequently, the researchers do not consider System X to be a finished product, it has some functionality that provides good information, but the only information that is actually new to SLOG is the resulting heatmap. Therefore, it can be of interest for SLOG to get in contact with Schenker Asia Pacific and resolve the current limitations of the system and present areas of improvement, to ensure that SLOG gain from a system implementation. The overall concept of System X is very good as it displays where the SKUs are located, but it has to become easier to use. After the evaluation the system, neither of the researchers was under the impression that System X was intuitive and easy to apply. That System X was not easy to apply could be a result of the fact that SLOG has different location codes for different customers, but variations in the naming convention should not cause the system crash. The researchers also believe that it could be of interest for Schenker Asia Pacific to look at the Excel model that was created to get inspiration to how System X could be improved in the future. This as the combination of the Excel model and the heatmap could act as a good decision support system for reallocations worldwide.

7.3 Sustainability

When making a decision to implement a new information system or perform a change in operations to improve productivity, sustainability as a whole is not being considered in detail at SLOG. It is the researcher's understanding that the cost or monetary gain that is the determining factor. The social aspect is also important and is considered in the implementation decision, while the possible environmental effect is not considered to influence the implementation decision to a great degree. The reason for this is not that SLOG don’t care but that they have a hard time seeing the environmental effects of many of these improvement suggestions. In the case of reallocation, the only possible environmental outcome would be that in total, the use of material handling equipment might to some extent but as these are either electrical or manual, they already have a small environmental effect. It is however the researcher's belief that improvement changes should be evaluated in all aspects of sustainability, if for no other reason than to create an awareness of the importance of a sustainable operation of companies.

Regarding reallocation, SLOG and the researchers agree upon that there might be some positive social effects of decreased stress, since the reallocation moves the item to a more accessible location and thus increases the overall productivity. On the other hand it is the experience of SLOG that employees generally don’t cope well with change, not even if the implemented change is solely for their benefit. In this way, there might also be some negative effects of implementing a structured reallocation scheme.

Finally, the monetary aspect is, as already stated, the determining factor when SLOG decides if an implementation should be made or not. How large the productivity increase has to be depends mostly on the customer contract timeframe. If the contract is about to expire it might not be worthwhile to implement a large change in the operations. On the other hand, an increased productivity or lowered costs could possibly make a customer that is about to leave to change its mind. Generally though, if SLOG believes that an idea will have a positive outcome, it is implemented. However, no follow up is currently being made of individual implementations, making it difficult for SLOG to quantify the effect on sustainability as a whole.

In conclusion, sustainability is not constituting a large aspect of consideration when evaluating possible implementations to increase productivity. Especially the environmental aspect is not considered an important evaluation parameter of implementations. However, the researchers do understand that it might be difficult to see relevant effects on environmental sustainability when implementing changes of operations on such a low-level as reallocation of products within a warehouse.

7.4 Reliability, replicability and applicability of the Master's thesis

The results in this Master's thesis originates from nine different customers at SLOG, Landvetter, who all have different characteristics. By originally evaluating a wide selection of customers and then making an additional selection to end up with a smaller range of customers, covering the three different storage assignment strategies and the full range of demand/order volume patterns, the Master's thesis ensures that the results can be reliable. In addition, as the result cover a wide spectra of customer characteristics the results of this thesis are applicable for a wider range of companies and customers and not only to the specific customers of SLOG Landvetter.

The calculated productivity effect of a reallocation decision in this report is founded on information from the WMS about the products and the actual speed of the material handling equipment. The information given by the WMS has been evaluated and considered reliable by SLOG and is thus considered trustworthy and could easily be collected again at a later date, adding to the replicability of the study. In regards to the speed of the material handling equipment it was provided to the researchers by SLOG themselves, who had measured the speed of each material handling equipment and compared it with the manufacturer's specifications and can thus also be considered reliable. However, the actual effect of the reallocation decision will be dependent on the type of picking method, type of orders and the routing method applied, which results in that the maximum and the minimum productivity effect varies greatly. Consequently, the only productivity effect that can be guaranteed is the minimum productivity effect. However, as the reasoning behind the calculations are clearly described in the report makes it easy to replicate and since the information behind the results are reliable, the productivity effect can be considered so as well.

Determining the actual effect of a reallocation decision is also dependent on how far the SKU is reallocated. The further the SKU is reallocated the larger the productivity effect. In order to ensure that the results of the report were realistic SKUs were only reallocated to locations where queues would not be created. Consequently, A-products were moved closer to the most optimal location but still spread along the aisles to remove the risk of queues. The distance used is based on the researcher's own judgment in combination with the Warehouse Improvement Specialist to ensure its validity. How far forward a SKU can be reallocated will however depend on the material handling equipment and the routing and picking method that is applied for the customer at hand. The queues are not included as a wildcard as the occurrence of queues and its effect cannot be determined beforehand in a very seasonal business as the one at SLOG.

In the Move away calculations, where a location is made available to an incoming SKU, the possible productivity increase is depending on the original location and characteristics of the SKU that is being reallocated. In this calculation it is impossible to determine what item that will be allocated to this location, when it is available, as incoming SKUs are unknown beforehand. Therefore, an average SKU was moved forward to get a result representing the lowest productivity effect that could be achieved by a reallocation. SLOG argue that the new SKU that would end up in this location, in general, would have a demand above the average SKU. The potential productivity effect by the Move away calculation can thus be considered low, but by using the average SKU demand the results can be guaranteed.

Variables that directly or indirectly affect the productivity outcome of a reallocation decision are based on interviews with employees at SLOG and literature. In order for these results to be replicated, similar people needs to be interviewed and similar articles needs to be read. However, if other people are interviewed with the same interview template, see Appendix A, at other companies the result might differ slightly, but as the original selection was nine different companies with different characteristics the results should be trustworthy.

The Excel model that was created is a prototype of how the productivity effect can be determined before a reallocation decision. Using Excel VBA ensures that the calculations are performed consistently every time, which provides results that can be replicated directly. However, the Excel model is only a prototype as the import of information is not automatic and it would need further improvements to be implemented at SLOG. As the Excel model is basing its decisions on the number of meters in each direction that the SKU is reallocated and not using the location coordinates of the old and new location the results are not exact and the distance a SKU is moved can be judged differently.

8 Conclusion

The purpose of this Master's thesis has been twofold. One part had its focus on determining the input variables that should be considered in a reallocation decision in accordance with an ABC-analysis, with the purpose of increasing the productivity. The second part was to evaluate System X, to understand for what type of customers it can be used and if SLOG should implement it or not.

Reallocating SKUs in the warehouse can have a significant impact on the productivity of the warehouse, but the actual effect is not today known at SLOG and in literature as the effect is depending on several different variables. However, even though several variables are mentioned by different authors, none have described how these variables actually affect the productivity of the picking process. Together with the fact that System X is a Schenker created ABC-analysis tool to support a reallocation decision this Master's thesis was initiated to create a decision support for these reallocations.

The construction of the Master's thesis is built upon four different research questions, with the aim of breaking down the purpose into manageable investigation areas. In order to answer the first two research questions several interviews were held at SLOG, with knowledgeable people, and literature within the field was studied to gather all the different variables that are considered in a reallocation decision and how they actually affect the productivity of the picking process. The first research question regarding variables that are commonly used at SLOG and in theory resulted in that many different variables were considered. It was found that these input variables could be divided into two different categories: one directly affecting the productivity and one indirectly affecting the productivity, see Table 10 and Table 11. In regards to the second research question about how the productivity is affected by a reallocation of a SKU an Excel model was created based on the input variables that directly affect the productivity of the picking process. From the calculations in the Excel model it could be determined that in a dedicated storage all A-products reallocated to a more accessible location will result in a productivity increase even if very small. For the Random and Class-based storage on the other hand a potential productivity increase can be achieved if the SKU is reallocated both horizontally and vertically. However, this is highly dependent on the demand volume of the SKU and the number of SKUs left at the location. In regards to moving away a C-product to a less accessible location a potential productivity increase can be achieved if the SKUs are not only reallocated vertically but also reallocated further away from the most optimal location horizontally. The third research question focuses on the different variables that System X uses in its ABC-classification. After thorough investigations of the system it was concluded that System X solely focuses on the order lines picked per SKU and does not consider any other variables in its results. The final research question was regarding how the results could be used at different customers. As System X solely focus on order lines picked and has limitations in its calculation capacity it is not suitable for customers that have a random storage assignment, order volumes above 60 000 order lines per month, large seasonalities, short lifecycles and do not have location codes with alternating naming conventions. System X does however provide several different results for customers that do not have the criteria above, that can create a basis for a reallocation decision. The heatmap, can for those customers where it is applicable, visually present where the SKU is located and its ABC-classification. Based on this heatmap together with the other results provided by System X a decision to reallocate a SKU can be achieved.

Based on the information above the two parts of the purpose can be answered. The first part regarding the input variables that should be considered in a reallocation decision in accordance with the ABC-analysis, with the purpose of increasing the productivity can be found in Table 10. These were the input variables found to directly affect the productivity of the picking process. In terms of for which customers System X can be used and if SLOG should implement it or not, the conclusion of this study is that System X has too many limitations to date and should not be implemented. However, the intention of System X is good and SLOG should approach Schenker Asia Pacific and present the improvement suggestions mentioned in the report. If the improvement suggestions are corrected System X can be a good decision support system for SLOG to use in its daily operations.

References

Articles

Accorsi, R., Manzini, R. & Maranesi, F. 2014, A decision-support system for the design and management of warehousing systems, Computers in Industry, vol. 65, no. 1, pp. 175.

Bhattacharya, A., Sarkar, B. & Mukherjee, S.K. 2007, Distance-based consensus method for ABC analysis, International Journal of Production Research, vol. 45, no. 15, pp. 3405-3420.

Boylan, J.E., Syntetos, A.A. & Karakostas, G.C. 2008, Classification for Forecasting and Stock Control: A Case Study, The Journal of the Operational Research Society, vol. 59, no. 4, pp. 473-481.

Chan, H.K. & Chan, F.T.S. 2011, Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage, Expert Systems With Applications, vol. 38, no. 3, pp. 2686-2700.

Chen, L., Langevin, A. & Riopel, D. 2011, A tabu search algorithm for the relocation problem in a warehousing system, International Journal of Production Economics, vol. 129, no. 1, pp. 147-156.

Dallari, F., Marchet, G. & Melacini, M. 2009, Design of order picking system, The International Journal of Advanced Manufacturing Technology, vol. 42, no. 1, pp. 1-12.

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, vol. 182, no. 2, pp. 481-501.

Dotoli, M., Epicoco, N., Falagario, M., Costantino, N. & Turchiano, B. 2015, An integrated approach for warehouse analysis and optimization: A case study, Computers in Industry, vol. 70, pp. 56-69.

Flores, B.E. & Whybark, D.C. 1986, Multiple Criteria ABC Analysis, *Emerald Group Publishing*, Limited, Bradford.

Gu, J., Goetschalckx, M. & McGinnis, L.F. 2007, Research on warehouse operation: A comprehensive review, *European Journal of Operational Research*, vol. 177, no. 1, pp. 1-21.

Gu, J., Goetschalckx, M. & McGinnis, L.F. 2010, Research on warehouse design and performance evaluation: A comprehensive review, *European Journal of Operational Research*, vol. 203, no. 3, pp. 539-549.

Guerriero, F., Pisacane, O. & Rende, F. 2015, Comparing heuristics for the product allocation problem in multi-level warehouses under compatibility constraints, *Applied Mathematical Modelling*, vol. 39, no. 23-24, pp. 7375-7389.

Hatefi, S.M. & Torabi, S.A. 2015, A Common Weight Linear Optimization Approach for Multicriteria ABC Inventory Classification, *Advances in Decision Sciences*, vol. 2015, pp. 1-11.

Hertz, S. & Alfredsson, M. 2003, "Strategic development of third party logistics providers", *Industrial Marketing Management*, vol. 32, no. 2, pp. 139-149.

Hou, J., Wu, Y. & Yang, Y. 2010, A model for storage arrangement and re-allocation for storage management operations, *International Journal of Computer Integrated Manufacturing*, vol. 23, no. 4, pp. 369-390.

Hult, G. T. M., Ketchen, D. J. & Arrfelt, M. 2007. Strategic Supply Chain Management: Improving Performance through a Culture of Competitiveness and Knowledge Development. *Strategic Management Journal,* 28**,** 1035-1052.

Javalgi, R. G., Dixit, A. & Scherer, R. F. 2009. Outsourcing to emerging markets: Theoretical perspectives and policy implications. *Journal of International Management,* 15**,** 156-168.

Jenkins, G.P. & Wright, D.S. 1998, "Managing Inflexible Supply Chains", *The International Journal of Logistics Management,* vol. 9, no. 2, pp. 83-90.

Kakabadse, A. & Kakabadse, N. 2005. Outsourcing: Current and future trends. *Thunderbird International Business Review*, 47, 183-204.

Pazour, J.A. & Carlo, H.J. 2015, Warehouse reshuffling: Insights and optimization, *Transportation Research Part E: Logistics and Transportation Review*, vol. 73, pp. 207-226.

Ravinder, H.V. & Misra, R.B. 2016, ABC Analysis For Inventory Management: Bridging The Gap Between Research And Classroom, *American Journal of Business Education (Online)*, vol. 9, no. 1, pp. 1.

Roodbergen, K.J, 2001. Layout and Routing Methods for Warehouses (No. EPS-2001-004-LIS). *ERIM Ph.D. Series Research in Management*. Erasmus University Rotterdam.

van Kampen, T.J., Akkerman, R. & Pieter van Donk, D. 2012, SKU classification: a literature review and conceptual framework, *International Journal of Operations & Production Management*, vol. 32, no. 7, pp. 850-876.

Xiao, Y., Zhang, R. & Kaku, I. 2011, A new approach of inventory classification based on loss profit, *Expert Systems With Applications*, vol. 38, no. 8, pp. 9382-9391.

Books

Bryman, A. & Bell, E. 2015, Business research methods, *4.th edn, Oxford Univ. Press*, Oxford.

Gillham, B. & Ebook Central (2007), Research interviewing: the range of techniques, *Open University Press*, New York;Maidenhead.

Jacobsen, D.I., Sandin, G. & Hellström, C. 2002, Vad, hur och varför: om metodval i företagsekonomi och andra samhällsvetenskapliga ämnen, *Studentlitteratur*, Lund.

Yin, R.K. 2009, Case study research: design and methods, 4.th edn, SAGE, London.

Master theses

Frankin, S. & Johannesson, K. 2013, Analyzing warehouse operations in a 3PL company - Mapping of processes and identification of key time drivers, *Chalmers University of Technology*, Göteborg.

Jösok, A. & Gärdefors, K 2015, Analysing the impact of size, complexity and cut-off time on waste time for outbound processes in a 3PL company - Designing a calculation tool to support labour scheduling, *Chalmers University of Technology*, Göteborg.

Presentations

Kolderup-Finstad, Nikolai, Oral presentation of Schenker Logistics, 2016-02-18

Schenker AG, 2012, Material flow planning – Materials handling techniques and equipment. *Presentation presented at Corporate Contract Logistics / SCM Conference in Essen*, May 2012

Bohlin, F, (2017), Material Equipment Performance, Schenker Logistics AB, Solution Design

Websites

Bond (2015), https://bondarenkoivan.wordpress.com/2015/01/21/method-of-triangle-in-abc-analysis/ (2017-03-15), provided by Schenker Asia Pacific

DB Schenker (2017), www.dbschenker.com (2017-03-15

Unicarrier, (2017), https://unicarrierseurope.com/products, (2017-02-24)

Gigant, (2017), http://www.gigant.se/, (2017-02-26)

Appendix A - Interview Templates

A1. Interview questions for the responsible person of each customer

- **What customer are you responsible for?**
- **What is your responsibility for those customers?**
  - What is your current title?
  - How long have you been at this job?
- **How would you describe the inbound/outbound order patterns of the customer?**
- **What type of storage allocation do you use? Dedicate/random?**
- **What different types of products do you store?**
  - **Do the A-locations differ depending on specific characteristics as weight for example?**
    - Weight?
    - Size?
  - **Which locations are considered A-locations?**
  - **How many A-locations do you have compared to B and C?**
  - **Do you have enough space?**
- **What type of IT-systems do you currently use?**
  - Excel, script, judgment?
- **What are the most critical locations today?**
- **How many products are being moved each day?**
- **What characteristics are you looking at when allocating an item?**
- **How often do you reallocate an item?**
  - **Do you ever consider the remaining inventory level of the item being reallocated?**
    - Total number of picks?
    - Picks per day?
    - Timesavings per level?
- **What is the time difference in travel between going up one level and going to the next rack?**

A2. Interview questions Warehouse Manager and Warehouse Improvement Specialist

Employee background

- **How long have you been working at SLOG?**
  - Have you worked at another company than SLOG?
- **How long have you been at your current position?**
- **Have you had many different positions within SLOG?**

Company presentation

- **Who are SLOG?**
  - When was the company founded?
  - What is the aim of SLOG?
- **The relation to DB Schenker?**
  - Is SLOG run separately from DB Schenker?
  - Where is the headquarter located?
  - What is the aim of DB Schenker?
- **How many employees are currently employed at SLOG Landvetter?**
  - How many blue collar/white collar?
- **Dimensions of the warehouse?**

Receiving

- **What information do you get with the inbound orders?**
- **When do you get the information regarding the inbound orders?**
- **What information is contained in the SKU name?**
- **How does it differ from the information contained in the SKU name of the customer?**
- **What type of workers are there at the receiving function?**

Assignment strategy

- **What strategies are being used**
- **Why those strategies**
- **What type of customers does the strategies used fit**

Warehouse routing

- **What routing methods are being used**
  - Why those methods?
  - For which customers characteristics do these routing methods work?

Material handling equipment

- **What type of material handling equipment is used at different customers?**

  - Why those material handling equipments?
  - What type of racking is appropriate for each type of material handling equipment?
  - What performance does the different equipment have?

Reallocation decision

- **How are the reallocations being made today?**
  - What do you consider before a reallocation decision is made?

Customers

- **Could you describe the customers of SLOG Landvetter in terms of:**
  - General presentation?
  - Number of employees?
  - Size of the customer in terms of order lines picked per day?
  - Type of products?
  - Type of storage used (floor storage, racking, flow racks, etc.)?
  - What levels are picked from/considered buffer?
  - Inbound flows (frequency, volume)?
  - **Reception:**
    - How are the products received?
    - How are the products being allocated in detail (script, judgemental)?
  - **Outbound flows**
    - Frequency?
    - Volume?
  - **Sales information:**
    - Demand forecasting?
    - Inbound information?
    - Type of shelf life of a product?
  - **Storage assignment:**
    - How are the zones divided?
    - How are the zones handled (individually or together)?
    - What assignment strategy is being applied?
  - Warehouse routing method used?
  - Material handling equipment used?

Sustainability

- **In the evaluation of a tool such as System X, how is sustainability considered?**
- **Social:**

    - **How would an improved productivity affect staffing and consequently the morale?**
        - How is the morale affected when implementing general improvements, such as a system implementation?
        - Is the morale affected differently concerning SLOG employees and hired workers?
- **Cost:**
    - **How large does the productivity increase have to be for you to consider an improvement implementation?**
- **Environmental:**
    - **Do you have an environmental sustainability policy and is it weighted against the productivity gains of the implementation?**

Appendix B – Detailed result of the reallocation tests

In this appendix, detailed information regarding the reallocation tests of the three chosen customers are presented. For each customer, an optimal vertical level was decided based on the information gathered during the interviews. Each product was moved to its optimal level in all three tests, the rationale being that since a move is being made closer to or further away from the most optimal location it would still be preferred to place the SKU at a convenient height. The number of SKUs being moved varies depending on the situation at each individual customer. For instance, if many SKUs already are located at a suitable location few SKUs will be reallocated in the test.

In reallocation test 2, where high-volume movers are reallocated closer to the most optimal location, the reallocation distance along the y-axis is set differently for each reallocated SKU. The distance will differ amongst the customers to effectively spread the high-volume movers along the aisle to avoid the risk of queues. The reallocated SKUs are high-volume movers that are originally located in the second half of the aisle.

In reallocation test 3, where low-volume movers are reallocated further away from the most optimal location, the reallocation distance along the y-axis is set to half the aisle length. This as all products can’t physically fit in the same small area. Reallocating the SKUs in this way will spread the products in the second half of the aisle.

Table 15. Customer D - Reallocation test 1

A-product	**Location**	**z-axis**	**Remaining inventory level**	**Result min (min)**
113043-943-129	EC-021-00	−1	3	−4,9
113037-926-406	EC-123-20	−0,5	80	−3,4
123398-940-346	EC-161-30	−0,5	39	−4,1
123398-940-347	EC-167-00	−1	29	−3,5
102001-900-405	EC-277-40	−1	32	−3,8
121258-541-406	EC-293-40	−1	10	−4,6
102158-900-406	EF-293-60	−2	24	−3,8
			SUM	**−28,0**

Table 16. Customer D - Reallocation test 2

A-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
119362-580-409	EC-619-30	−0,5	−38	58	−7	4
119364-580-407	EC-607-20	0	−37	71	−8	6
119369-540-347	EC-601-30	−0,5	−36	27	−7	14
119288-540-406	EC-579-20	0	−30	8	−8	−2
122799-900-407	EC-569-30	−0,5	−30	1	−5	−5
104262-540-407	EC-559-10	−0,5	−28	1	−7	−7
113715-940-344	EC-491-10	−0,5	−24	9	−7	−3
102145-900-345	EC-491-00	−1	−24	3	−7	−1
104119-940-504	EC-485-20	0	−23	1	−8	−7
103042-940-347	EC-425-10	−0,5	−20	39	−6	10
103047-540-344	EA-292-20	−2	0	10	−4	−4
				SUM	**−73**	**8**

Table 17. Customer D - Reallocation test 3

C-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
113043-943-124	EC-001-00	−1	75	4	−9	32
113033-941-406	EC-005-10	−0,5	75	1	−8	15
106505-900-323	EC-003-60	−2	75	7	−20	139
106591-930-404	EC-009-60	−2	75	10	−26	202
106591-930-404	EC-011-60	−2	75	8	−22	160
111705-900-331	EC-013-40	−1	75	5	−10	47
111399-943-410	EC-013-30	−0,5	75	7	−11	149
113045-930-403	EC-013-10	−0,5	75	20	−11	141
113041-943-408	EC-015-10	−0,5	75	20	−17	439
106593-930-409	EC-015-20	0	75	13	−8	289
				SUM	**−140**	**1615**

Table 18. Customer G - Reallocation test 1

A-product	Location	z-axis	Remaining inventory level	Min result (min)
2000001293997	AB-439-05	−0,5	20	−4
312546-1-1-4*	AB-445-07	−1	2	−5
312562-1-1-4*	AB-477-05	−0,5	1	−5
2000001291153	AB-517-05	−0,5	2	−5
2000001292914	AB-529-05	−0,5	5	−5
2000001293331	AB-533-05	−0,5	50	−3
2000001293317	AB-535-05	−0,5	6	−5
2000001293218	AB-553-05	−0,5	3	−5
2000001305577	AB-589-05	−0,5	1	−5
			SUM	**−42**

Table 19. Customer G - Reallocation test 2

A-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
2000001293997	AB-439-05	−0,5	−27,5	20	−4	10
312546-1-1-4*	AB-445-07	−1	−25	2	−5	−4
312562-1-1-4*	AB-477-05	−0,5	−26	1	−5	−4
2000001291153	AB-517-05	−0,5	−30	2	−5	−4
2000001292914	AB-529-05	−0,5	−32	5	−5	−3
2000001293331	AB-533-05	−0,5	−33	50	−3	39
2000001293317	AB-535-05	−0,5	−33	6	−5	−1
2000001293218	AB-553-05	−0,5	−34	3	−5	−2
2000001305577	AB-589-05	−0,5	−37	1	−5	−4
2000001275252	AB-493-03	0	−23	74	−5	16
2000001291160	AB-509-03	0	−28	3	−5	−4
2000001293270	AB-537-03	0	−32	4	−5	−2
2000001293232	AB-545-03	0	−34	1	−5	−4
2000001294178	AB-551-03	0	−35	4	−5	−1
2000001294130	AB-553-03	0	−35	1	−5	−4
				SUM	**−72**	**27**

Table 20. Customer G - Reallocation test 3

C-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
2000001302132	AB-371-05	−0,5	25	21	−11	42
2000001290538	AB-373-03	0	25	2	−8	−2
2000001293720	AB-381-07	−1	25	36	−12	22
2000001286319	AB-383-01	−0,5	25	4	−10	26
2000001295649	AB-383-07	−1	25	1	−8	−4
2000001290040	AB-386-05	−0,5	25	17	−17	134
2000001292662	AB-397-05	−0,5	25	2	−8	−6
2000001293898	AB-399-05	−0,5	25	22	−9	19
2000001302095	AB-403-05	−0,5	25	63	−16	114
2000001293836	AB-403-03	0	25	17	−8	6
2000001293843	AB-405-05	−0,5	25	41	−30	334
2000001297513	AB-407-01	−0,5	25	34	−9	22
				SUM	**−144**	**706**

Table 21. Customer H - Reallocation test 1

A-product	Location	z-axis	Remaining inventory level	Min result (min)
232211	BF-002-53	−1,5	193	6
198330	BF-002-45	−0,5	393	6
242050	BF-002-59	−1,5	219	26
199206V	BF-020-48	−0,5	275	8
7156	BF-040-61	−3	15	37
158735	BF-040-42	−0,5	1688	5
7192	BF-044-62	−3	26	42
7157	BF-046-63	−3	6	32
7424	BF-050-62	−3	20	31
			SUM	**192**

Table 22. Customer H - Reallocation test 2

A-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
520	BF-030-11	0	−8	65	−8	91
1010F	BF-030-13	0	−8	38	−8	126
1510FG	BF-032-11	0	−10	53	−8	67
1539FG	BF-032-12	0	−10	105	−8	41
540	BF-034-13	0	−12	1	−5	77
7264	BF-036-11	0	−14	229	−8	144
1714F	BF-036-13	0	−14	10	−5	148
6250F	BF-038-12	0	−18	106	−8	107
1930F	BF-038-13	0	−18	78	−8	88
7156	BF-040-61	−1,5	−20	15	13	103
6150F	BF-040-11	0	−20	63	−8	410
158735	BF-040-42	−0,5	−20	1688	88	210
1904F	BF-040-13	0	−20	39	−8	131
2733F	BF-042-12	0	−22	38	−8	84
182	BF-042-22	−1	−22	244	14	168
241014	BF-042-13	0	−22	241	−8	199
7192	BF-044-62	−3	−24	26	41	159
2814F	BF-044-12	0	−24	74	−8	145
7157	BF-046-63	−3	−26	6	30	133
1030F	BF-048-12	0	−28	85	−8	146
7464	BF-048-13	0	−28	209	−8	130
1910F	BF-050-11	0	−30	102	−8	147
7424	BF-050-62	−3	−30	20	28	143
1035F	BF-050-13	0	−30	85	−8	289
				SUM	**85**	**3486**

Table 23. Customer H - Reallocation test 3

C-product	Location	z-axis	y-axis	Remaining inventory level	Min result (min)	Max result (min)
6217A	BF-002-62	−1,5	25	7	−137	555
239585	BF-002-24	−1	25	33	−424	2911
241999	BF-004-44	−0,5	25	363	−50	628
169940V	BF-002-54	−1	25	18	−113	732
109096	BF-002-55	−1	25	55	−81	505
199880	BF-002-35	0	25	17	−8	1026
201500	BF-002-26	−1	25	26	−122	792
859366V	BF-002-46	−0,5	25	21	−69	921
231041	BF-002-27	−1	25	8	−161	1068
105385	BF-002-37	0	25	65	−8	598
159180-60	BF-002-47	−0,5	25	20	−148	2093
159015V	BF-002-38	0	25	8	−8	767
				SUM	**−1328**	**12594**