Warehouse Redesign Process: A Case Study at Enics Sweden AB

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ABSTRACT

Nowadays warehousing became one of the most important and critical part in supply chain systems due to the fact that it consumes a considerable part of logistic cost. Designing phase of warehousing system is the most important part in warehousing since most of the strategic and tactical decisions should be taken in this phase. Majority of academic papers are primarily analysis oriented and does not give a systematic method and techniques as a basis for warehouse redesign. So there is a need to develop a structured procedure that can be applied for different type of warehouses. Therefore the purpose of this thesis is to develop a process for redesigning production warehouses, and analyzing major problems during redesign steps. The thesis is designed as a case study, and a mix of quantitative and qualitative methods were used for data collection and data analysis. The methodology focuses around the warehousing process and redesign steps as described in the literature. Results of the thesis develop a seven steps procedure for redesigning of the production warehouse, also different problems and challenges are faced during redesign steps. It was tried to choose the best redesigning method which fit with the characteristics of the warehouse, in order to cover the space reduction of the warehouse with the consideration of existing facilities and reducing of cost. In addition, the performance of the current warehouse system was evaluated based on current design of the warehouse in order to avoid repeating of same mistake in redesign process. Storage assignment policy as one of the redesign steps was discussed and a framework for storage system of the components were suggested. The findings of the thesis to some extent can be applicable to other production warehouses. Further research is suggested for more specific results and new developed redesign methods for all types of warehouses.

KEYWORDS: warehouse design, design process, warehouse problems, warehousing, layout design, performance evaluation
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1. INTRODUCTION

In this section, the background of the research will be presented which will be followed by the problem formulation, purpose and research questions, and limitations of the project and finally outlines of this thesis work.

1.1. Background

Warehouses are one of the most important parts of a logistic system in a company; they contribute about 20% of logistic costs (Koster et al., 2007). Also as Baker and Canessa (2009) mentioned in their paper the capital and operating cost of warehouses in USA is about 22% of logistic costs and it is 25% in Europe. It shows that they are significant from cost perspective and should be well-designed and work with high performance in order to reduce costs as much as possible and improve the efficiency. Although warehouses are related to high cost, a well-managed warehouse system is required and it is the key concept of modern supply chain system and has an important role to lead the company to be successful in these days business world (Baker and Canessa, 2009).

In any warehouse system there is a flow of material including, unloading incoming goods, identifying them, and sorting in shelves. At the same time customer orders come to the warehouse that should be picked, shipped and delivered to the customer (Berg, 1999). In addition there are missions that should be done such as: achieving transportation economies, achieving production economies, providing customers with a mix of products instead of a single product, providing temporary storage of material to be disposed or recycled, providing a buffer location for trans-shipments, etc. So in almost all manufacturing plants a center is needed to sort raw materials, parts and products and it plays a critical role in company’s logistic success (Koster et al., 2007).

A well-managed warehouse system should have easy access to market, good located, sufficient space and reasonable delivery time (Lihui and Hsieh, 2006). It is mandatory to improve the efficiency of warehouse performance in order to reduce the inventory level as much as possible. So to fulfill this goal and have a well performance of the warehouse management there are some key factors in analyzing warehouse performance. Factors like: on time shipments, order picking accuracy, annual work force turn over, inventory capacity by dollar/unit, dock to stock cycle time, and distribution costs as a percentage of sales, etc. (Berg, 1999). Ordered components are planned to ship as soon as possible, and they should be on time and with no damage and of course correct amount (Baker and Canessa, 2009). Between the time, an order from production line comes to the warehouse and the time that it will be delivered, it could happen different kind of errors in accuracy and completeness and as a result time will be lost (Koster et al., 2007).
One of the most important factors that can have direct impact on the performance of the warehouse is the warehouse design. A perfect design of the warehouse with minimizing the warehouse area will reduce travelling time and traveling distance with selecting the best route to pick orders and as a result it will reduce the cost (Lihui and Hsieh, 2006). Because, one of the most time, labor and money consuming activities in almost every warehouse is order picking which is estimated to spend 55% of the total warehouse costs, hence with a good design of the warehouse, this activity will improve, and as a result the performance of the warehouse will improve respectively (Koster et al., 2007). Designing of a warehouse could be based on the order picking system, it could be automated or manual, which each one has its own advantages and disadvantages (Hwang and Cho, 2006). In the process of order picking factors like quantity and lay out design, combination of the orders in a batch, picking route, traveling time and distance, and many other factors are important and all of them depend on the design of the warehouse. If these activities perform well enough they have direct impact on the warehouse performance and decreasing the total cost (Lihui and Hsieh, 2006). Furthermore, over stocking leads to increase inventory and it means money sitting idle. With a well-designed warehouse over stocking that can make costs like warehouse space, utilities, maintenance, damage, lost, insurance, taxes, will be reduced (Krar, 2007). Warehouse design plus storage assignment and picking routing planning directly affect the operation efficiency and space utilization and reduce costs (Lihui and Hsieh, 2006).

1.1.1 Enics Sweden Background

Enics is a young company, founded in 2004. Their main customers are big industrial corporations like ABB and Bombardier, and electronics companies like Elcoteq and Flextronics. Enics was found as a third generation company with a clear focus on industrial and medical business. The company was the 6th Largest EMS (Electronic Manufacturing Services) Company in IE (Industrial Electronics) in 2011. Enics has approximately 3200 employees in eight plants in two continents Asia & Europe. In Västerås plant work around 260 persons. The company has a broad range of products that are produced every year. There are 4000 different products available in the catalogue of the company. With this huge variety of finished good there is a request of huge variety of raw material and component respectively. Each year approximately 5000 different raw materials are unloaded in the company. Therefore a good and effective warehouse designing and managing is required. Today Enics has one main warehouse in the factory for storing incoming goods and feed the production line.
1.2. Problem formulation

Aspects of warehouses design could be layout, order picking policies and equipment choice. Although various researches suggest different methods for warehouse designing; there is still not one accepted methodology especially for redesigning process (Baker and Canessa, 2009). According to Rouwenhorst et al. (2000) during designing process of a warehouse, there are relevant problems that should be solved simultaneously. These problems occur in different levels, strategic level, tactical level and operational level. And each of them can be viewed from three different axes: processes, resources and organization. Problems in strategic level could be like design of process flow and technical capabilities. In tactical level, challenges could be layout design, selection of equipment, and design of the organization. And finally in the operational level fine-turning of the organization policies could be the main concern (Rouwenhorst et al., 2000).

Warehouse design mostly depends on the characteristics of the company and their needs, also type and variety of material should be considered at the same time. Even in those cases that a proposed design procedure can be used; it is not always clear how results can be validated (Rouwenhorst et al., 2000).

According to Bonder et al. (2001) problems of warehouse design are to specify processes during designing systems such as: material handling, sorting, storage, and their relation to each other. The main goal is to minimize capital and operating costs during a limited time period.

There are several challenges during designing a warehouse system including: tighter inventory control, shorter response time, and a greater product variety. On the other hand, new information technologies such as bar coding, and warehouse management systems (WMS), provide new challenges in design process (Gu et al., 2007).

According to Lihui and Hsieh (2006), there are four major directions in warehouse design problems including: warehouse layout, storage assignment policy, picker routing, and zoning, which the first two ones are the overall design problems and the last two are specific design sub problems.

This project was come out of Enics Sweden AB. There is a main warehouse inside the factory for incoming goods. Finished goods are shipped out once or twice per day directly from packing area. So there is no need for storing finished goods. The major problem of the company today is the huge space of the warehouse that the huge part of it is not used. It cause waste of space, transportation and of course wastes of money. Enics aim is reducing this area more than 60% in order to reduce cost and centralize the warehouse and also improve the efficiency of it. They also need to evaluate the performance of the warehouse and present performance evaluation metrics to compare the current level of performance with the improved one. There is also another problem; this warehouse is in one side of the factory, but the production line starts from the other
side of it. In order to feed better those stations at the beginning of the production line, there is a small warehouse on that side only to feed those stations. Hence the problem of the current design is with wasting of huge amount of space and money the operation of the warehouse is not efficient. Feeding different production line stations is with delay, and order picking process is weak because there is no policy for material storage. With the new design, the management expects to centralized the warehouse and keep it efficient enough that can feed the whole production line with one centralized warehouse in a shorter time with high performance efficiency and at the same time save money and reduce wastes.

1.3. **Aim and Research questions**

The purpose of this thesis is to develop a process for redesigning production warehouse, and analyzing important factors that influence this redesigning process. Analysis is performed through the comparison of current warehouse layout design, with redesigned one based on reducing the space of warehouse, in order to see the impact on storage capacity, cost and performance. In order to carry out this analysis the following research questions have been formulated:

What is the process of redesigning a warehouse (at Enics)?
What are the major problems during redesign process of a warehouse?
What evaluation metrics should be used in a warehouse redesigning process?

1.4. **Delimitations**

Although inventory management is a broad area and can cover all parts in a supply chain system, this study focuses on redesigning production warehouses and how it effects on the performance of the warehouse. In addition this case study is carried out at Enics Company in Västerås, and their warehouse is just for incoming goods so it will not cover the entire supply chain system of the factory. Since this area is broad with in supply chain system, references were limited to warehouse performance based on layout design, problems during redesign process of a warehouse and factors that have an impact on it. Hence all other factors about the efficiency of the warehouse performance are excluded. Problems that are encountered during the redesign of an incoming good warehouse will be analyzed, and topics like warehouse location problem and external logistics are not addressed. This thesis is limited to suggest the best proposal for redesigning of the warehouse; implementation of the proposal is not included during this limited time. In addition, because most of academic papers are focused on designing of warehouses and not on warehouse redesigning, there is no defined procedure for redesigning
warehouses, and based on type of the warehouse, equipment and other factors it can be
different case by case, which in turn cause another limitation to find the best option for
this specific warehouse.
Since the thesis focuses on redesign, the current storage equipment should be kept and
reused, although new facilities can be suggested to add in the new proposal. Some of
this current equipment is quiet old, but since the new ones are expensive and even
removing them, costs a huge amount of money for the company, Enics prefers to keep
the current facilities. Hence in redesigning the new warehouse these factors cause
limitations and should be considered as well.

1.5. Outline

Chapter 1: The report starts with introduction which introduces topic to the reader, as
well as presents main idea of the research. The problem area is presented which
followed by company’s background where study is performed. Aim and research
Questions and project Limitations are also presented in this chapter. Chapter is finished
with the outline of the project.

Chapter 2: Research method is presented in this chapter. Methodology presents the
research design by which the thesis was carried out. Which method is chose and why.
The methodology chapter explains how the literature review and data collection was
conducted and how the data analysis was performed. Validity and reliability of the
research also discussed at the end of the chapter.

Chapter 3: The theoretical background is presented to the reader in chapter 3; including
necessary literature which is needed for analysis and for getting insights of the topic.
The theoretical background starts with introduction of the warehouse system design,
and continues with the process of warehouse designing, problems, challenges and
important factors during a warehouse design. It will be finished with key indicators in
warehouse performance.

Chapter 4: Results present the data gathered from the company through interviews,
quantitative data collection and measurements, and at the same time, performance
evaluation and problems that are identified in the current state of the warehouse and
during redesign process, will be presented in this chapter.

Chapter 5: This chapter analyses the gathered data with explaining the final proposal
and its specification. The process of redesigning of the warehouse also is presented in
this chapter, as well as solution and suggestions for identified problems and evaluation
metrics, based on frame of references.

Chapter 6: Finally in the last chapter which is conclusion and recommendations, a
summary of the most important elements and recommendations is offered and it
suggests topics for further studies.
2. RESEARCH METHOD

This section presents the design of the research procedure, finding of available literature, different approaches, methods and tools were used, the gathering and analysis of the empirical data, and the consideration of the quality of the study.

2.1. Research Method

There are several ways of doing research such as: experiments, surveys, histories, analysis of archival information and case studies; each of them has own advantages and disadvantages. Case studies are mostly used when how, why or what reference questions are being placed in order to contribute with knowledge of individual or organizational in a relation to a real-life context. Case study method is a way of doing researches to cover contextual conditions and also is covering the logic of design, data collection techniques and specific approach for data analysis. It also can be both single or multiple cases (Yin, 2003).

There are two main reasons that this method is chosen as a case study: first of all, based on research questions the concept of this project is what; what is the process, what is the problems, and what is the evaluation metrics in a warehouse redesigning process. Then during the analysis part it will be answered, why these problems occur and how they can be solved. Second, it was an interest to contribute knowledge gathered from scientific papers and theoretical part to a real-life problem and see how it works in practice in order to have a better approach and logical analysis of warehouse redesign process.

According to Yin (2003) a single embadded case study is when there is a single case that should be studied but with attention to some sub-units and important aspects in order to give better chance for analysis.

The following thesis is designed as single embedded case study based on following reasons: The context is warehouse redesigning process and the case is redesigning of Enics Company in Västerås. Hence the main context is Enics warehouse redesigning and sub-unit aspects are steps of the design, problems and challenges, performance evaluation with consideration of two important factors cost and space.

2.2. Research Process

The study process was divided in three main steps: the first was answering to the question “what” in order to see the current state of the warehouse. What was the process today? What kind of wastes existed, like time, money, and space. What was the methods of arranging and sorting incoming goods, and the current capacity of work
load. All measurements and direct observations were in this step. The second step was going to answer the question “why” in order to find out why the warehouse works like this and not with its maximum potential. The reasons of all wastes that were found in previous step would be analyzed in this section in order to see why wastes and problems were existed. Finally the report was going to answer the concept “how” in order to reach to the decision approach. How the redesign process should be in order to improve the performance, reduce wastes and the most important goal minimize the cost. After analyzing all gathered data, the best proposal would be presented and all research questions would be answered.

At the beginning of the project small literature review was done in order to become familiar to the subject, and it continued during the first two months of doing project. Also a planning report had been done which was helpful to design and structure of the thesis. Reading articles and writing the report went hand by hand with gathering data and analyzing them in order to have discussion and conclusion at the end of report at the right time. Appendix1 shows the time plan of the project. Figure 2-1 represent the research process design of this thesis work.

Figure 2-1: research process design
2.3. Literature Review

According to Yin (2009) one of the most important components of a complete research design is developing a good theoretical framework for the case study as it will result in a good design of the case and data collection. The simple goal of a theory development is having a sufficient blueprint for the study that will give a story to the writer to understand the reasons of acts, events, structures and thoughts (Yin, 2009).

So specially in case study research, theory development is prior essential step for data collection and analyzing. In general for a good theory development some kind of preparing is needed such as: reviewing literatures related to the case, discussing the topic and ideas with others, and asking some challenging questions about the propose of the study and possible results (Yin, 2009).

Literature review should be also generalizing from case study to theory part. There are two different kinds of generalizations, analytic generalization and statistic generalization; understanding the distinction of these two is one of the most important challenges in doing a case study research. Statistical generalization is less relevant to case studies and is most common in doing surveys, and it is a conclusion making a bout a universe from a sample. While in analytic generalization, a previously developed theory is used as a template for comparing with the empirical results from the case study to develop a new approach (Yin, 2009). Hence this study is an analytic generalzition, since the analysis part is a comparison of theory part and empirical results and based on researches that have been done so far for designing and redesigning of warehouses, a new approach is proposed at the end of the study.

According to Creswell (2009) there are seven steps in conducting literature review, and it is planned at early stage of the research. In below thses seven steps in this thesis can be followed:

Step 1- Identifying key words: they can be identified from topic or preliminary reviewing. The key words for seaching literartures in this thesis including: warehouse design, design process, warehouse problems, warehousing, layout design, and performance evaluation.

Step 2- searching in libraries: the literature was searched in books, articles, journals, master and PhD students’ thesis work, and online data bases such as Emerald, Elsevier, Science Direct, Google Scholar, Diva etc.

Step 3- list most relevant articles: by looking the name of the articles and reading the abstract of founded materials, the most relevant ones are listed. In this stage around 45 relevant articles were found.

Step 4- separate those articles are central to the topic: by going through the abstract and intoduction, chapters and conclusion, those literaturs were central to the topic (around 20 articles) was separated.

Step 5- designing literature map: by designing a literature map, a visual picture of the research were taken and provided a useful organizing device for study.
**Step 6- taking draft summaries:** in this step draft summaries were taken from relevant literatures. With this summaries writing process was designed.

**Step 7- writing, finalizing and reviewing the literature:** after summarizing the most important things, the literature was written and reviewed. At the end it is summarized with the major concepts that were found in the literature.

### 2.4. Data Collection

There are two different types of data, quantitative data which are in numerical form and qualitative data that is not in numerical form and could be in text, video, photograph and sound recordings. They are related to each other; all quantitative data are based up on qualitative data and all qualitative data can be described with numbers (Trochim, 2006).

According to Yin (2003) there are six different sources for gathering data: documentations, archival records, interviews, direct observation, participant observation, and physical artifact. Each of these sources has its own strengths and weaknesses. Four following sub sections describe the sources that are used in this thesis; documentation, interview, direct and indirect observations.

#### 2.4.1. Documentation

According to Yin (2009) one of the most common and important sources which plays an explicit role in any data collection is documentation. In case studies the most important use of documents is to admit and add evidence from other sources. These documents could be in form of letters, emails, agendas and minutes of meetings, announcements, reports, and proposals. Using of documents has three main benefits: first, they are helpful to identify correct titles or names in the organization; second, they can provide specific details from other sources; and third, it can be made inferences from documents (Yin, 2009).

Documents that are used for data gathering in this report can be categorized in two different stages:

**Stage 1:** Basic information about the company is gathered through internet, to know a little about the company’s history, goal and other general information.

**Stage 2:** collection of basic data from the company’s database through a software Qlik View about different items were in the warehouse; how long they were there, how often they were used and where they were sorted in the warehouse.

After these data gathered, they were documented and were used for further analysis.
2.4.2. Interview

One of the most important sources of evidence of a case study is interview, because most case studies are about human affairs and behavioural events and a well-designed interview will provide good information about the case. During an interview two aspects should be considered: first following the line of inquiry and second asking actual question which come up during the interview (Yin 2009).

There are three types of interviews that can be used in case studies; first is a focused interview that a person attends the interview as an interviewee for a short period of time to answer specific questions, but it can be open ended. Second one is semi-structured interview that a person attends the interview as an interviewee for a short period of time and the topic and headlines are determined but no specific list of questions are selected. The interview will start with a general question and interviewee’s answers will make next questions and conducts the interview. The third one is a formal survey and it is following both the sampling procedures and the instruments used in regular survey (Yin 2003).

Interviews and discussions with employees of the Enics’ warehouse was one of central sources to gather information for this thesis. Weekly meetings with direct supervisor and everyday discussions and asking questions from involved employees with different job positions within the company such as production manager, purchasing and component manager, and operators played an important role as well. Interviews were taken place in this study were mostly in two types: semi-structured interviews which was with warehouse manager (direct supervisor) and warehouse operators, and some other staff like production manager and purchasing manager, twice with each person during the project which is lasted approximately 1 hour each time per person. In this type of the interview there weren’t specific question prepared before, just the topic was chosen and a framework was designed. The other one was focused interview which took place with three personnel of the warehouse, the responsible person for balancing section, the leader of day shift, and the leader of night shift, and questions were prepared in advance based on the previous knowledge and data gathered. No recording devices were used and answers were written down during the meeting. Questions are available in appendix 2.

2.4.3. Direct Observations

Since this thesis is a case study, it is obvious that it should take place at the case location, so direct observations are an important source for gathering data. Direct observation could be in qualitative or quantitative form and can range from formal to casual data collection activities. It is almost everything that an observer can see around him/herself (Yin, 2009).
According to Yin (2003) observations can involve, meeting, sidewalk activities, factory work and in less formal way can be made throughout a field visit. Direct observations in this project were performed to generate facts and analysis of the current state of the warehouse by being every day at the factory includes; how materials were stored in the warehouse, how often incoming goods come to the warehouse, the process of an order picking, and physically studies in the warehouse process.

2.4.4. Indirect Observations

According to Yin (2003) measurements that is reeding the measure device is known as indirect observations. The measurements have been done in this work is through measuring empty space in each lift and regular shelves for each single shelf or pallet in order to improve the existing storage space. In addition, areas that had the potential to add new shelves or lifts are measured by measuring tape to find out the possibility of adding new shelves.

The first option was to find out if all lifts are full or not; and if they are not full, discover roughly empty percentage of each lift. This job should be done by controlling all levels of each lift one by one. There were two different types of lifts, one type with boxes in each level that materials were inside these boxes, and usually were used for little items like screws or tiny electronic pieces, and the other one without boxes which bigger materials were on each level directly. Lifts without boxes also were used for reserve or buffer materials. For those without boxes, counting the exact percentage of emptiness was not possible, so the empty percentage of each level was guessed by visualizing. With following formulation it became possible to count the empty percentage of both types of lifts;

(1) Formulas for counting the empty percentage for lifts with boxes:

\[ A = \text{number of boxes in each level} \]
\[ B = \text{number of empty boxes in each level} \]
\[ Z = \text{total empty boxes in each lift} = \sum B \]
\[ X = \text{number of empty levels in each lift} = \frac{Z}{A} \]
\[ N = \text{number of levels of each paternoster lift} \]
\[ Y = \text{total percentage of emptiness in each lift} = \frac{X}{N} \times 100 \]

(2) Formulas for counting the empty percentage for lifts without boxes:

\[ A = \text{percentage of emptiness of each level} \]
\[ X = \text{total empty percentage of each lift} = \sum A \]
\[ N = \text{Number of levels of each paternoster lift} \]
\[ Y = \text{total percentage of emptiness of the lift} = \left(\frac{X}{(N \times 100)}\right) \times 100 = \frac{X}{N} \]
2.5. Data Analysis

One of the most difficult aspects of doing case studies is analysing case study evidences. It should be considered that different tools in case study analysis can help as assistant and the investigator is the main analyst which should develop a rich and full explanation and a good description of the case (Yin, 2009).

In this thesis, analysis of data has done for both qualitative and quantitative data. All quantitative collected data were categorized and tabulated in order to be analysed carefully. Qualitative data which are documents, interviews and observation also categorized and helped to understand better the current situation of the warehouse and put the quantitative data in a direction to understand and better analysing.

Having a strategy for analysing data will help to reduce difficulties of analysing process, otherwise the only way that remains, is playing with data. According to Yin (2009) there are four different data analysis strategies: (1) relying on theoretical propositions, (2) developing a case description, (3) using both qualitative and quantitative data, and (4) examining rival explanation.

Two of these four strategies are used in this thesis. First, analyzing of the data is based on answering to the research questions and literature review. In order to answering research questions three concepts, “what”, “why” and “how” should be answered which the study is made up on these three questions. In addition, it is a comparison between reality and literature review. Therefore, one of the strategies used in this thesis is relying on theoretical propositions. The second strategy used in the study is using both quantitative and qualitative data. This strategy is used to analyze indirect observation data (measurements) in relation with direct (qualitative) data gathered from other resources.

After selecting the strategy the next step is selecting a specific analytic technique. Yin (2009) explains 5 different techniques that can be effective in different case studies. These five techniques are: (1) pattern matching, (2) explanation building, (3) time series analysis, (4) logic models, and (5) cross-case synthesis.

The technique that is used in this study is the logic model technique. This technique consists of matching empirically observed events to theoretically predicted events. There are some suggested process steps about warehouse designing in literature that give a procedure for redesigning process of a warehouse but not a unique pattern since designing a warehouse is different case by case and depend on so many local factors. Based on gathered information from literature studies and data collection through the practice, some immediate outcomes was found; it became clear that with reducing the area of the warehouse for more than 60% how many shelves will miss and possible areas to add new shelves also identified. This was some immediate outcomes that gave some idea for designing. Next these immediate outcomes produce some intermediate outcomes; with more careful observations and intent measurements such as calculating all free spaces in shelves and lifts, and also remove scrap materials from warehouse and
as a result improve the existing space of the warehouse, and at the same time considering safety requirements, these intermediate outcomes were found out. In turn after writing down all options and limitations, results of the observations and calculations more precisely, hand by hand with matching theory part’s findings, ultimate outcome is found out and final proposal were suggested.

2.6. Validity and Reliability

A research design should represent a logical set of statements which can be tested through two concepts that are used to establish the quality of case study; validity and reliability. Establishing the validity and reliability of any case study research is important, since these two concepts determine the stability and quality of the obtained data (Riege, 2003)

2.6.1. Validity

“Validity, in qualitative research, refers to whether the findings of a study are true and certain. True, in the sense that research findings accurately reflect the situation, and certain, in the sense that research findings are supported by the evidence” (Guion et al., 2002).

During doing the project, almost every day (5 days per week) for almost three months being at the company helped to see better the performance of the warehouse. Data gathering both in qualitative and quantitative were done through different sources of information such as: interviews, measurements and direct observation. In some cases like measurements of storage emptiness percentage the exact percentage couldn’t have been done; so in such cases the percentage of emptiness just guessed. Then, by selecting all useful data and finding the relationship between these data, research questions were analyzed from multiple perspectives and all possible options were considered. Whenever it was needed, measurements were repeated and more questions were asked in order to be sure that analysis of data perfectly have done. Resources were selected carefully to have the most relevance to the topic and help to understand better the concept. Most of papers for literature review part are conducted to the latest available articles and are found through scientific research engines like Google Scholar, IEEE, Discovery, and DIVA which were published through big scientific publication companies such as ELSEVIER, EMERALD, and SCIENCE DIRECT.
2.6.2. Reliability

Reliability is demonstrating that the operations of a study, such as data collection procedures, can be repeated with the same results (Yin, 2009). In this thesis all listed qualities can be find since all data involve expert opinion on the issues of designing of the warehouse. People who interviewed and selecting of documents and all direct and indirect observations are selected carefully in order to ensure appropriate and reasonable quality on the result. In addition, the reliability of the report depends on the methods and procedures followed and the cited references. The research process which has explaind before in this chapter ensure that data collection can be repeated.
3. Theoretic Framework

This chapter presents necessary literature which is needed for analysis and for getting insights of the topic to readers. The theoretical background starts with introduction of the warehouse design system, and continues with the process of warehouse designing, problems, challenges and important factors during a warehouse design. It will be finished with performance metrics in warehouse redesign process.

3.1. Background

According to Backer and Canessa (2009) today warehouses became a key aspect of any supply chain system and they play an essential role in success and failure of any kind of businesses. Based on the purpose of using warehouses, they can be named differently. When goods move directly from incoming to shipping vehicles without storage, they can be called cross docking points. If activities like pricing and labeling have been done for customers, they will be value added service centers. They are called production postponement points if their main role is configuring or assembling products based on customer demands. In the case that distribution is the main function the term distribution center is commonly used. Finally they are called returned good center if the purpose of usage is to store faulty or end of life goods (Baker and Canessa, 2009).

However in most ordinary warehouses raw materials and finished goods should be received, stored and delivered to the customers after orders are picked. Hence if the main function is buffering and storage the term warehouse is used (Koster et al., 2007). In these days competitive market environment, companies try to achieve high volume production with minimum inventories and deliver products to the customers within short response time through a well-designed logistic system. So warehouse design and performance has very high impact in order to reach to this goal. Warehouses should make a balance between four important factors in marketing: low volume, high variety, frequent delivery, and short response time (Berg and zijm, 1999). Hence continues improvement in design and performance of warehouse systems help companies to be competitive in market (Gu et al., 2007).

JIT (Just In Time) approach as a lean principle become demanded from warehouses in order to have a frequent delivery with lower volumes in a smaller and more sufficient warehouse area (Berg, 1999). The efficiency and effectiveness in any supply chain system is largely determined by the design and performance of warehouses (Rouwenhorst et al., 2000).

Even though the importance of warehouse design and its effect on cost is clear, still there is no comprehensive, defined and accepted method for designing warehouses. Based on this, almost all warehouse designers have their own unique approach (Baker and Canessa, 2009). However there is a need to find such a systematic approach for
warehouse designing in order to be implemented in any different type of warehouses to increase the performance of the warehouse and reduce cost (Rouwenhorst et al., 2000). According to Baker and Canessa (2009) the most important aspect in designing a warehouse is layout, order picking policies, and equipment choice. Hassan (2002) mentioned in his paper that the most important factor in designing a warehouse is its layout design which is the basement of several issues and support the operation of the warehouse mostly in storage assignment policy. Other important issues that are related to the layout design of a warehouse include: the arrangement of different functional departments of the warehouse, determining the number of aisles, number and location of docks, space requirement estimations, the flow pattern designing, and etc. Characteristics of a well-designed layout could be summarized as: maximizing modularity, adaptability, compactness, accessibility, flexibility, space utilization, and reduction of congestion and movement (Hassan, 2002). During designing a warehouse, these operational efficient factors should be taken in account in order to improve the overall warehouse performance (Roodbergen and Vis, 2007).

Between an item is received by the warehouse and be delivered to the customer as an order, some errors in both accuracy and completeness may happen which consume more time. An optimum layout design improve these operation efficiencies and reduce these errors and big part of wastes (Koster et al., 2007).

With this significant impact on customer service level and logistics costs, also with considering the complexity of warehouse operations, the design should be as cost effective as possible. It also should be mentioned that a large extent of warehousing investment cost is at the design phase (Baker and Canessa, 2009).

According to Rouwenhorst et al. (2000), design of a warehouse usually starts from a functional description, continues with technical specification, through equipment selection and layout determination. In each step, minimizing cost and response time and maximizing throughput and storage capacity should be considered. Different purpose of warehouse usage has different requirements. For storage warehouses the storage cost will become more important and should be more efficient for long period storage items in large quantities in a cheap storage system. The main design objective in this case is low investment and operation costs and the main criteria is storage capacity. However, for work-in-process warehouses the objective is fast retrieval from the warehouse since mostly the demand volume is unknown. As a result the design constraints should consider the response time which is the important factor in this case (Rouwenhorst et al., 2000).

All activities inside warehouse system are interrelated to each other and all related on warehouse design. For example the storage assignment policy limit the storage space, and as a result travel distance will be reduced. At the same time order picking cost will be reduced through improving labor performance with a new routing planning. All of
above factors enhance the operating efficiency and space utilization and finally reduce the overall cost (Lihui and Hsieh, 2006).

### 3.2. Warehousing

According to Rouwenhorst et al. (2000), Warehousing could be seen from three different angles:

- **Processes:** there is a flow when products arrive to the warehouse and are taken through numbers of steps or activities until they are shipped out. These activities are called processes.
- **Resources:** all tools, equipment and human resources that are needed to operate in a warehouse system. Example of resources could be: the storage unit, the storage system, order picker auxiliaries, a computer system, personnel, and etc.
- **Organizations:** all procedures and methods such as planning and control which are used in a warehouse system in order to control the flow of process are called organization. An example of this could be definition decisions of the process flow at the design stage (Rouwenhorst et al., 2000).

There are three different types of warehouses: distribution warehouses, production warehouses, and contract warehouses.

- **Distribution warehouses:** a warehouse that collect products from different suppliers and deliver them to the customers. Some times some assembling process also takes place between these receiving and delivering (Berg and Zijm, 1999).
- **Production warehouse:** a warehouse which is used for storage of raw material, work in process products, and/or finished goods for manufacturing or assembling process. Materials can be stored for a long or short period of time (Rouwenhorst et al., 2000).
- **Contract warehouses:** a warehouse that operate on be half of one or more customers is called contract warehouse (Berg and Zijm, 1999).

Based on the type of the warehouse different number of steps are distinguished in warehouse designing process. According to Gu et al. (2010) and Berg and Zijm (1999) there are four major activities in a warehouse: receiving, storage, order picking, and shipping. Berg (1999) described that warehousing with in both warehouses and distribution centers has five main activities: receiving, storage, order picking, accumulation/sorting, and shipping. He separated accumulation and sorting from order picking step and considered it as a separated step.

According to Koster et al. (2007) above these main activities mentioned before, there are also some other activities that warehouses maybe involved such as: value added processing or receiving products and materials from customers and redistribute them to
other customers or back to the original manufacturers. A production warehouse activities include:

- Receiving includes unloading of products from transport vehicles, some quantity and quality inspection will be done, and inventory record will be updated.
- Transfer and put away is transferring the incoming goods to the storage area. In some cases it is needed to unpacking and repackaging from a full pallet to standard size of storage bins based on the warehouse storage standards and then should be moved with forklifts or other carriers to the storage area, and products will be stored in shelves based on storage policies of the warehouse.
- Order picking and selection is the major and most costly activity almost in every warehouses and it involves the process of picking right amount of right materials for an order.
- Accumulation/ sortation is sorting picked items for each order and it become more useful and important for orders that have been picked in batches. Then they should be grouped up on completion of the picked process and packed and stacked on unit loads. They will be sent for shipping.
- Cross docking activity is when received materials are transferred directly to the shipping docks.
- Shipping is delivering the complete order to the customer (Koster et al., 2007).

After different types of warehouses and different activities that they include, there is another concept in warehousing which is directly related to the design of a warehouse and it is warehousing system. “a warehousing system refers to the combination of equipment and operating policies used in item picking or storage/ retrieval environment.” (Berg and Zijm, 1999- page 521).

Three different types of warehousing systems are distinguished: Manual warehousing system, automated warehousing system, automatic warehousing system (Berg and Zijm, 1999)

- Manual warehousing system: an order picker is sent to the storage area for picking orders. It is also called picker to product system.
- Automated warehousing system: it is also called product to picker system. In this system a computer control warehousing activities and it is used for picking small or medium size orders. It is a closed loop and items are held in bins or drawers rotate around this closed loop. Picker has a fixed position and choose the order through computer system and the loop will rotate and brings the material to the picker. It can be used also for other activities such as sorting, packaging and labeling.
- Automatic warehousing system: is a high speed picking of small or medium size items. The difference of automatic warehousing system and automated one is that in automatic system a robot will be replaced with an order picker.
Selecting the type of warehousing system is one of the most important decisions that have to be made in early stage of design phase. Another topic that is important through designing a warehouse is management decisions which are in three levels: strategic level decisions, tactical level decisions, and operational level decisions (Berg, 1999).

- **Strategic decisions** are long term decisions and determine broad policies and plans to use the company’s resources in order to support its long term competitive strategy. Planning and control decisions are in this level which are provided by strategic management concerning long term goals in the supply chain organization and the warehouse design. Strategic decisions face high uncertainties. Planning decisions are based on historical data and solutions will be found by high quality average performance. Control decisions are based on actual data and solutions will be found by high quality performance. The combination techniques are good for solving planning and control problems in the strategic level decisions.

- **The second level is tactical decisions** which help to schedule material and labor efficiently based on strategic decisions that has been taken in previous level. Planning of warehousing system is in this level of decision making with concerning of storage assignment policies. In addition decisions about sequencing, scheduling and routing, layout design and dimensioning of the storage system, and assigning orders to pick batches and grouping aisles in to work zones are in this level.

- **The third level is operational decisions** which are short term decisions and are taken under the operating constraints and based on strategic and tactical decisions that are made in two previous steps. Decisions about inventory management such as types and quantities of storage products and shipment time are in this category and are result in reducing the inventory level and improving warehouse operation efficiency. Other decisions that are taken in this level are: assigning products to storage locations, order picker routing, and sorting/accumulation activity (Berg, 1999).

It should be mentioned that all decisions made in different levels are interrelated to each other and they should be taken based on previous made decisions (Koster et al., 2007)

There are some objectives that should be considered during warehouses redesign and optimization. The most important one is minimizing total cost including both investment and operational cost. Other objectives are: minimizing the average travel distance, the throughput time of an order, and the overall throughput time. At the same time maximizing the use of space, selecting the best equipment, and the accessibility to all items. All decisions that are taken about above objectives are at tactical and
operational levels in different times during warehouse design and operation and based on previous strategic decisions (Rouwenhorst et al., 2000).

3.3. Steps of Warehouse Designing

Before going through steps of designing a warehouse some important points should be mentioned (Baker and Cnessa, 2009): first, design of a warehouse is a high complex activity. Second, different researchers proposed different number of steps in designing warehouses. Third, all steps are interrelated and repetition may be needed in some steps. Fourth, identifying an optimum solution may not be possible since there are different possibilities in each step.

There are different points of view in steps of designing a warehouse, some of them goes through more details while others have more general steps. An example of each point of view will be presented in following.

According to Hassan (2002) the framework of designing a warehouse can be explained in 14 steps as follow:

1. Specifying the type and purpose of the warehouse: the type of the warehouse should be specified in this step in order to gives designers an initial over view of operation levels and requirements.
2. Forecasting and analysis of expected demand: capacity of the warehouse, repairing information, determining inventory levels, equipment, and assignment of items to the storages are forecasted in this step.
3. Establishing operating policies: warehouse operations policies should be considered in early steps of warehouse designing since they has high impact on the design of the layout.
4. Determining inventory levels: it is an operational decision and since has high impacts on warehouse’s size and helps to estimate space requirements should be determined in early stage of design.
5. Class formation: it will help to reduce time and distance for picking items.
6. Departmentalization and the general layout: a warehouse should have several departments in order to run the process flow in the warehouse and have to be identified in this step based on information of first and third steps.
7. Storage partition: storage area is the biggest department in any warehouse and should be partitioned in to picking and reserve areas in order to facilitate operations and reduce movements.
8. Design of material handling, storage, and sortation systems: this step is also an important step and should be considered as a part of layout designing since it is related to aisles, space utilization, storage assignment, and movement in the warehouse.
9. Design of aisles: this step is determining of number, location, orientation, length, and width of aisles with in the warehouse layout design based on the equipment that are going to use in the warehouse.

10. Determining space requirements: estimation of needed space will be determined in this step, and objectives like cost of land, overhead, and scarcity of land may affect this step.

11. Number and location of I/O (Input/Output) points’ determination: this step is determination of number and location of I/O points. It is an important step since it has impacts on storage assignment policy, throughput, picking time and distance, and congestion.

12. Number and location of docks determination: this step is necessary in order to reduce delays and congestion, provide routing flexibility, and more frequent shipping without interference with other departments.

13. Arrangement of storage: arrangement of storage is also an important step in warehouse designing since it has impact on movement time and cost, throughput and congestion.

14. Zone formation: picking area can be divided in to different zones and picker just take items from specified zones. The number, size and composition of these zones should be determined during design of the warehouse in order to reduce picking time and distance (Hassan 2002).

However according to Gu et al. (2010) Warehouse design steps can be more general and be limited to five major steps;

1. The overall warehouse structure determination: it is also called as conceptual design and determines the material flow pattern within the warehouse, the characteristics of each department, and the relationships between departments.

2. Sizing and dimensioning the warehouse and its departments: it determines the size and dimension of the warehouse and also the space allocation among various warehouse departments.

3. The detailed layout determination within each department: it is the most important configuration in designing a warehouse and it includes decisions about aisle configuration in the retrieval area, pallet block-stacking pattern in the reserve storage area, and etc.

4. Warehouse equipment selection: this step is for identifying the warehouse equipment types for storage, transportation, order picking, and sorting as well as appropriate automation level for the warehouse.

5. Operational strategies selection: it is used for determining of how the warehouse will be operated both in storage and order picking. Operation strategies are those decisions that have global effects on other design decisions, and therefore have to be considered in the design phase. Decisions like the choice of different storage methods, whether or not to do zone picking, and the choice of types of
different order picking methods. More detail operational policies, are not considered in design phase (Gu et al., 2010).

Design steps could also be considered from different decision making levels. A design process normally should consider the following objectives: concept, data acquisition, functional and technical specification, selection of means and equipment, layout, and selection of planning and control policies (Rouwenhorst et al., 2000).

Decisions in each step could be situated at a strategic, tactical or operational level. Decisions concerning the process, flow and the level of automation and selection of basic storage systems belong to strategic level. While the dimensioning of these systems and determinations of layout are tactical decisions. Decisions in the operational level are detailed control policies. As mentioned before all decisions taken in each level are related to other level decisions but they are different from time point of view. Strategic decisions are long term, while tactical decisions are medium term and operational decisions are short term decisions. Obviously solutions which are chosen at a higher level provide constraints for lower level design framework (Rouwenhorst et al., 2000).

According to Baker and Canessa (2009), warehouse design is in three main areas: determining the requirements, designing the material handling systems, and developing the layout. Based on these main headlines following designing Steps will be determined: define system requirements, define and obtain data, analyze data, establish unit loads to be used, determine operating procedures and methods, consider equipment types and characteristics, calculate equipment capacities and quantities, define services and ancillary operations, prepare possible layout, evaluate and assess, identify the preferred design. However they believed that the most important step in warehouse designing is the layout design and presents a five steps methodology for layout designing:

- Space requirements planning which is determining the required space for each zone.
- Material flow planning which is the determination of the overall flow pattern.
- Adjacency planning that uses a warehouse activity relationship chart in order to form the input for computer-aided facility layout tools.
- Process location which is dividing of areas by low-bay and high-bay usage.
- Expansion/contraction planning that is Consideration of future changing of the facility (Baker and Canessa, 2009).

There are some important points that should be considered in designing warehouses; as mentioned, warehouse design decisions are strongly related to each other and it is difficult to separate them completely from each other and define a border between them. Therefore, any classification of warehouse designing should not be considered as unique, nor does it mean that any of the decisions should be made independently. In addition, it is important that operational performance measures be considered in the design phase since it is strongly affected by the design decisions, and it can be very
expensive or impossible to change the design when the warehouse is actually built. (Gu et al., 2010)

According to Bodner et al., (2001), even though there are varieties of researches that have been done about how to design a warehouse which some of them discussed above, practitioners use the results of these researches really seldom. Rather, they prefer to rely on their experience and expertise. It has different reasons; the most fundamental one is the lack of a unifying procedure that integrates conceptual design frameworks with models for specific design sub-problems, through the application of common database architecture. Another reason is that, most research results have not been implemented as computational tools in forms that are amenable to use by the practitioner (Bodner et al., 2001).

3.4. Problems and Challenges of Warehouse Design

The overall warehouse design problem is to specify processes which are designed to implement systems such as material handling, sorting, storage, and their relation to each other. The objective function is to minimize capital and operating costs during a limited time period (Bodner et al., 2001).

The warehouse design is a complex activity even in those cases that the proposed design procedure can be used; it is not always clear how results can be validated. Even though different designers describe warehouse design problems from different point of view, but there are two major categories in warehouse designing problems. The first category is about the overall design problem and focuses on the formulation of top-down, iterative, optimization-based approaches. The second one addresses specific design sub-problems, such as: design of a storage system or an order-picking system. (Bodner et al., 2001)

However Lihui and Hsieh (2006) explained more details in these two major categories and defined four directions in warehouse design problems including: warehouse layout, storage assignment policy, picker routing, and zoning, which the first two ones are the overall design problems and the last two are specific design sub problems.

*Warehouse layout design problem*: according to Hassan (2002) designing the layout of a warehouse is a complex task for three main reasons. First there are many different design decisions and most of them are combinatorial problems and finding an optimal solution for solving these problems most of the time is so difficult. Second there are many operations in a warehouse system such as picking and cross docking or factors like physical characteristics of items and material handling that impact travel time, cost, and throughput in a warehouse. All these factors and operations should be considered during a warehouse layout design in order to support the warehouse performance and will make the design process more complicated. Third, those operations and factors mentioned above have interaction with each other that should be accounted for in the
layout design phase (Hassan, 2002). In addition, there are several objectives that need to be maximized during designing the layout of a warehouse including: space utilization, access to products, efficient flows, safe working environment and expansion potential (Baker and Canessa, 2009)

There are two sub-problems in the layout design process which affect the order picking process: the layout of the facility containing the order-picking system and the layout within the order-picking system (Koster et al., 2007)

- The first one is also called the facility layout problem and it is about the location of various departments (receiving, picking, storage, sorting, and shipping). The most important factor that should be considered in solving this problem is the relationship between the departments. The main objective is minimizing the handling cost, which is directly related to travel distance.
- The second sub-problem could be called the internal layout design or aisle configuration problem. The main objective is determination of the number, length and width of blocks and aisles in a picking area. Hence the main goal is to find the best design of the layout to fulfill the requirements with respect to the objective functions

*Warehouse storage assignment problem:* Before any order picking operation to feed the customer, Products have to be put into storage locations. A storage assignment policy is a method to put the products in storage locations (Koster et al., 2007)

It is better to divide the storage area into two separated areas in order to speed up the order picking operation and reduce waste of time and cost and it should be decided in design phase. These two areas are called bulk stock or reserve area and pick stock or forward area. The forward area is smaller than reserve area. Two important factors that should be considered during separating these two areas are the amount of SKU (stock keeping units) that should be placed in each area and the location of them especially in forward area, in order to improve the order pickers’ performance. Sometimes it is better to store some items just in reserve area; especially for huge items or materials that are used less frequent or with high demand quantities (Koster et al., 2007)

According to Koster et al. (2007) there are several storage policies to assign products in storage locations within the forward and reserve areas and five of them are used more frequently: random storage, closest open location storage, dedicated storage, full turnover storage and class based storage.

- In random storage products will be stored randomly in the suitable empty location with equal probability.
- If staff can choose the closest location for storage themselves, the system will be called closest open location storage.
- The third policy gives personnel another possibility to store each product at a fixed location, which is called, dedicated storage.
The policy that distributes products over the storage area according to their turnover is called full-turnover storage. The easiest accessible locations will be devoted to the products that have the highest sales rates.

The last policy is class based storage, which is grouped products into classes, fastest moving products with 15% of total products and 85% of the turnover. This classification is based on Pareto method which is a classical way for dividing items in inventory control system. After that each class will be assigned to a dedicated area of the warehouse, but the storage within each area is random.

Finding the most suitable policy in any warehouse is one the major problems in designing warehouses, and it should be solved in early stages of design phase (Koster et al., 2007).

There is another possibility to classify problems in storage field as below:

- Pallet block-stacking problems such as: storage lane depth, number of lanes for each depth, stack height, pallet placement angle with regards to the aisle, storage clearance between pallets, and length and width of aisles.
- Storage department layout problems such as: door location, aisle orientation, length and width of aisles, and number of aisles.
- AS/RS (Automated Storage/Retrieval System) configuration problems such as: dimension of storage racks, and number of cranes.

These problems affect warehouse performances through construction and maintenance cost, material handling cost, storage capacity, and space and equipment utilization (Gu et al., 2010)

Routing methods problem: The main purpose of routing policies is to reduce time and distance of order picking process through the best possible route. The problem of routing order pickers in a warehouse is similar to travelling salesman problem. The salesman wants to sell products in a specified number of cities; he should go to all cities just one time through the shortest way. It is the same in the warehouse that an order picker should go with a list of orders to picking area and take all the orders through the shortest way (Koster et al., 2007).

This problem can be solved due to some disadvantages of optimal routing in practice. The first important thing that should be mentioned is there is no optimum unique solution for every layout. Secondly, maybe there is an optimal routing solution but it seems illogical to the order pickers and as a result order pickers prefer to find out and choose another route. Third, even a standard optimal algorithm doesn’t consider the aisle congestion. So aisle congestion may be another reason that the optimum routing solution seems illogical and force the picker to select another route maybe longer to avoid the congestion (Koster et al., 2007).

Zoning problem: according to Koster et al. (2007) another possibility to reduce traveling distance in a warehouse and improve the efficiency in designing the
warehouse layout is having several zones and devoting specific people to each zone to pick parts for order from the assigned zone. There are some advantages and disadvantages in zoning of the warehouse which make this problem more important and force the designer to decide either zoning is needed for the specific warehouse or not, in early stage of design phase (Koster et al., 2007). The advantages of zoning are each order picker only needs to move in a small area, traffic congestion will be reduced, and order pickers become more familiar with the item locations in their zones. However there is also a disadvantage of zoning that there is a need to another person to combine received parts from each zone and complete the order list before shipment to the customer (Koster et al., 2007). Even though zoning divides the warehouse into some smaller areas and reduce the total picking time and distance, but inequality of the orders that come to the warehouse, may make some zones more crowded than others which may cause problems there like congestion (Lihui and Hsieh, 2006).

The warehouse design problems can be categorized in five major headlines: overall structure, sizing and dimensioning, equipment selection, operation strategy selection, department layout (Gu et al., 2010). Figure 3-1 presented these five problems and their relationship together.

The overall structure of a warehouse that also can be called conceptual design of a warehouse, determines the functional departments such as number of storage departments, type of using technologies, and the way of assembling the orders. The objective of design in this stage is to meet storage and throughput requirements, and minimize costs, both in investment cost at design level and future operating costs. So departments and their interactions should be clearly defined (Gu et al., 2010).

Warehouse sizing and dimensioning has important impact on cost of construction, inventory holding and replenishment, material handling, and shows the storage capacity of the warehouse (Gu et al., 2010).

There are two different scenarios in inventory controlling in any warehouse for sizing problem; the first scenario is Inventory levels are determined externally, so the warehouse has no direct control over incoming shipments while the second one is the warehouse can directly control the inventory policy. The major difference is that inventory policy and costs should be considered in solving the sizing problem in the second scenario. The warehouse dimensioning problem means capacity into floor space in order to assess construction and operating costs. All departments should compete with each other for space, until an optimum space is found out. So there will be tradeoff points in total warehouse size, the warehouse space among departments, and the dimension of the warehouse and its departments (Gu et al., 2010).

The equipment selection problem is about the level of automation in a warehouse and the type of storage and material handling systems. These decisions can be categorized in strategic level because they affect almost all the other decisions as well as warehouse
investment and performance cost. There are two most important factors in selecting the warehouse equipment: (1) the equipment alternatives identification should be reasonable for a given storage/retrieval requirement; and (2) the selection between these alternatives. The other two problems are discussed before (Gu et al., 2010).

Warehouse design problems can be also discussed from interrelated decision making levels, strategic, tactical, and operational level for long, medium, and short terms respectively. In order to evaluate warehouse design problems, some performance criteria are needed including: investment and operational costs, volume and mix flexibility, throughput, storage capacity, response time, and order fulfillment quality (accuracy). These criterias will be discussed in three different decision making levels (Rouwenhorst et al., 2000)

Strategic level: This process flow can be broken down into two continuous decision problems: one based upon technical capabilities and the other one based on economic considerations dealing with the selection of systems and equipment. The first problem concerns the storage unit, the storage systems and suitable equipment for the products and orders, while not conflict each other. This warehouse design problem concerns both the design of the process flow and the selection of the main warehouse system type. The problem has an input of the products and orders characteristics, while the output specifies combinations of systems that are technically capable products handling and improve the performance (Rouwenhorst et al., 2000)
The second warehouse design problem concerns about economic considerations. The aim of solving this problem is optimizing a possible combination system in order to minimize investment and operational costs. All decisions are taking in this level are related to each other. The following shows some relations between several decisions (Rouwenhorst et al., 2000):

- The number of resources determines warehouse investment costs.
- The warehouse storage capacity is related to the type and dimensions of the storage system.
- The type and dimensions of the resources presents maximum warehouse throughput
- The factors related to the maximum throughput demonstrates warehouse response time

Tactical level: Fields of tactical decisions usually are the dimensions of resources, storage system sizes, number of employees, the determination of a layout and a number of organizational issues (Rouwenhorst et al., 2000)

A bunch of problems occur at the tactical level decision making and should be considered simultaneously. Some of these problems listed below:

- Organizational problems including the picking zones dimensioning, the ABC zoning, replenishment policies and batch sizes, and selection of a storage policy
- Storage systems dimensioning including the forward and reserve areas, also dock areas
- Type and number of material handling equipment
- Establishing a layout of the overall system
- Number of personnel.

The goal of solving all these design problems in tactical level and the same in strategic level is to improve the performance, reduce waste and minimize the cost (Rouwenhorst et al., 2000)

Operational level: Most decisions in operational level concern the assignment of tasks, and scheduling and control of people and equipment such as: the assignment of replenishment tasks to personnel, and the allocation of incoming products to free storage locations. The major difference between decisions taken in this level with two previous levels is that decisions made at this level often can be considered independently (Rouwenhorst et al., 2000).

### 3.5. Performance Evaluation in Warehouses

According to Chan (2003), performance measurement was defined only as the process of quantifying the effectiveness and efficiency of an action. However in modern management system, performance is also evaluated by quantification and accounting.
Warehouse performance evaluation describes the feedback or information on the quality of a proposed design and/or operational policy with respect to meeting customer expectations. In additional, strategic objectives, as well as directly measuring quality and quantity performance of an activity or process and finding areas that have unsatisfactory performance and more importantly, on how to improve it in order to enhance efficiency and quality are the main considerations of warehouse performance evaluation (Chan, 2003).

Performance evaluation is an important action for both warehouse design and operation. This evaluation in warehouse design could be in the areas such as: cost, throughput, space utilization, and services which provide feedback and useful information about how a specific design or operating activity performs in order to meet the requirements, and ways to improve it. In addition, a performance evaluation model is useful in the early stage of the warehouse design to help the designer to evaluate different design alternatives and narrow down the design of the layout or other aspects of warehouse design in order to find the best option. There are different methods for performance evaluation including: benchmarking, analytical models, and simulation models. The one that is used more frequently for warehouse performance evaluation both in academic literature and practice is simulation (Gu et al., 2010).

A system that can evaluate the performance of warehouse design and operation is called Warehouse Management System, or WMS, which is a key part of the supply chain. The main goals of WMS are to control the design process from early stage to the end and give feedback and information in order to improve the design process and result through different factors (Enabling u.d.).

The system will continue evaluation after the design process is finished, during the warehouse operation in order to control the movement and storage of materials within the warehouse and transaction process, including shipping, receiving, put-away and picking. WMS help warehouses to evaluate the performance in design and operation and have several benefits including: reduction of the warehousing costs, improves the efficiency of the order-picking operation, faster inventory turns, increasing the throughput capacity, more efficient use of available warehouse space, enhanced customer service, improved labor productivity, etc. (Berg and Zijm, 1999)

One of the most important indicators to take feedback and information of evaluating of the warehouse performance is customer satisfaction level. Customers could be external customers in distribution center type of the warehouse or internal customer like production line in a production warehouse. Figure 3-2 presents warehouse operation and performance evaluation.
In total seven metrics have been identified as important measures for warehouse performance which are both quantitative and qualitative metrics. The quantitative measures are two factors, cost and resource utilization, and other five are qualitative measures including: quality, flexibility, visibility, trust, and innovativeness (Chan, 2003). Table 3-1 presented these 7 criteria and their sub-criteria of the performance measurements.

It should be mentioned that the main table according to Chan (2003) has more sub-criteria for the whole supply chain, but the one here just shows those sub-criteria that are related to the warehouse performance both in design or operation. In addition, since the case that has been studied is a production warehouse, customers are internal customers which is the production line.
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub criteria</th>
<th>Performance measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Distribution cost</td>
<td>The transportation and handling cost, safety stock cost and duty.</td>
</tr>
<tr>
<td></td>
<td>Inventory cost</td>
<td>The work-in-process and finished goods inventories.</td>
</tr>
<tr>
<td></td>
<td>Warehouse cost</td>
<td>Associated with allocation from one tier to another</td>
</tr>
<tr>
<td></td>
<td>Intangible cost</td>
<td>Quality costs, product adaptation or performance costs and coordination</td>
</tr>
<tr>
<td></td>
<td>Overhead cost</td>
<td>Total current landed costs</td>
</tr>
<tr>
<td>Resource utilization</td>
<td>Labor, machine, capacity, energy</td>
<td>Investigate the percentage of excess or lack of that particular resource within a period</td>
</tr>
<tr>
<td>Quality</td>
<td>Customer dissatisfaction</td>
<td>The number of customer complaints registered</td>
</tr>
<tr>
<td></td>
<td>Customer response time</td>
<td>The amount of time between an order and its corresponding delivery.</td>
</tr>
<tr>
<td></td>
<td>On-time delivery</td>
<td>The percentage of orders delivered on or before the due date</td>
</tr>
<tr>
<td></td>
<td>Fill rate</td>
<td>The proportion of orders that can be filled immediately</td>
</tr>
<tr>
<td></td>
<td>Stock out probability</td>
<td>The instantaneous probability that a requested item is out of stock while number of backorders is the number of items backordered due to stock out</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Labor</td>
<td>The percentage of tasks a worker can perform</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Material handling</td>
<td>The number of existing paths between processing centers and the variety of material which can be transported along those paths without incurring high transition penalties or large changes in performance outcomes</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>The number of products which have alternative sequencing plans without incurring high costs or large changes in performance outcome</td>
</tr>
<tr>
<td></td>
<td>Delivery</td>
<td>The percentage of slack time by which the delivery time can be reduced</td>
</tr>
<tr>
<td>Visibility</td>
<td>Time</td>
<td>Time required from when the designer changes his idea</td>
</tr>
<tr>
<td>Trust</td>
<td>Consistency</td>
<td>The percentage of late or wrong delivery. For late delivery, it is the percentage of time delayed whereas for wrong delivery, it is the percentage of returned goods.</td>
</tr>
<tr>
<td>Innovativeness</td>
<td>New use of technology</td>
<td>The percentage decrease in time necessary for using a new technology</td>
</tr>
</tbody>
</table>
4. RESULTS

This chapter will present the current state of Enics’ warehouse in the way that works today. It also presents the problems encountered from current design of the warehouse and the problems during redesign phase.

4.1. Enics’ Warehouse system

Enics Västerås had a main warehouse inside the factory, which was devoted for raw material and incoming goods to feed the production line. The warehouse included 19 paternoster lifts and rows of regular metal shelves. There was also another small warehouse which fed the machine assembly section. This section was the first station of assembly line and it started from the other side of the factory, the opposite side of the main warehouse. This station had a changeover time between three to four hours based on orders and was designed to feed the first assembly section. This warehouse included two paternoster lifts and numbers of regular metal shelves. More than 99% of materials were kept in these shelves were in the shape of reels in two different sizes. The main warehouse in Enics had three major areas: incoming goods, warehouse, and packing. Normally packing is not one of the parts of a warehouse, but since the raw materials of packing activity were also should be stored in the warehouse, and people who work in the warehouse system were shared between these three areas so packing section was also considered as a part of warehouse system.

4.1.1. Current state of the warehouse

The current area of the warehouse was 1900m² including incoming goods and packing area. In this area there were 19 paternoster lifts and 355 regular metal shelves which mean 710 pallets, since each shelf contained two pallets. Figure 4-1 represents the current area of the warehouse.

![Figure 4-1: current area of the warehouse](image-url)
Paternoster lifts were in different types and different levels, i.e. the height of the levels varies. This difference in level’s height helped Enics to store different items with different volume and size. In table 4-1 the name of each paternoster lift and their capacities is presented.

<table>
<thead>
<tr>
<th>NAME OF LIFTS</th>
<th>VA</th>
<th>VB</th>
<th>VC</th>
<th>VD</th>
<th>VE</th>
<th>VF</th>
<th>VG</th>
<th>VI</th>
<th>VJ</th>
<th>VK</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of levels</td>
<td>76</td>
<td>74</td>
<td>57</td>
<td>72</td>
<td>43</td>
<td>42</td>
<td>55</td>
<td>22</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAME OF LIFTS</th>
<th>VN</th>
<th>VO</th>
<th>VT</th>
<th>H</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of levels</td>
<td>100</td>
<td>40</td>
<td>28</td>
<td>36</td>
<td>36</td>
<td>34</td>
<td>38</td>
<td>38</td>
<td>37</td>
</tr>
</tbody>
</table>

Figures 4-2 and 4-3 show two different types of storages facilities in the warehouse.

Figure 4-2: Regular metal shelves
4.2. Working Process

Working process in Enics Västerås included five major activities; material replenishment, incoming goods, sorting procedure, order picking process, and packing. In next five subsections, explanation of these activities will be given.

4.2.1. Material Replenishment

Enics was an Electronic Manufacturing Services (EMS) company and thus they did not own their own products, which means that the choice of components mostly was managed by customers. This put the company in a very strict place and forced it to improve its logistical approach and partnership with sub-suppliers in order to manage the demand fluctuations and at the same time negotiate the best possible deals.

Purchasing consisted of three different branches a) Strategic procurement that dealt with Source and Selection of suppliers, b) Operational procurement that dealt in material replenishment based on forecasted and un-forecasted demands from customer by utilizing and ERP-system, and c) project purchases for any new or project related procurement that were dealt with prior industrialization of the product for series production.

The components were categorized based on ABC-classification codes:
A category: components that were used more often and had a high volume value
B category: components were medium volume valued in usage frequency and worth
C category: components that were used very seldom or they had a low volume worth

The company used business intelligence software called QlikView, which presented all manner of data and information from the ERP system. It was concerning raw material specifications, such as components with their item number, amount existing in the warehouse, weight, price of them, different suppliers, last date of use, etc. With the help of this reporting tool the purchasing group could track and control the amount of each item number that were existed in the warehouse in order to order the needed component in the right time with the right amount, as well as follow KPI (Key performance indicators) for shortages based on demand.

Lead time of each component depended on the sub-supplier the company had agreed to buy from, some suppliers were domestic and could therefore be scheduled shorter lead time, also the ABC classification had an impact on how much sooner the material was pulled to the warehouse as, A category components were more expensive while C category components had least value.

In the cases that the production or warehousing operators discovered an inconsistency such as stock balance discrepancy, responsible operator might need to communicate with the purchasing group directly in order to expedite the signal for demand.

### 4.2.2 Incoming goods

At the incoming goods area there were five different activities and employees working with incoming goods divided these activities between themselves. First activity was in the shipment area. The responsible person had to count all arrived packages and compare them with the amount in the order and if they matched, the label of the component should be signed. In the second activity, goods would be placed in the queue in order to be registered. As the third activity, the waybill was checked to be matched with the good. If they matched together the package would be unpacked and placed on a carrier, and if not, the responsible person should contact the purchaser, and goods would be moved to the unpack area. The fourth activity was registration of all items in the warehouse system of the company. This registration was a 6 steps procedure;

I. First step was checking the item in order not having any physical damage.
II. If not, the operator would continue with the next step which was amount controlling.
III. If the amount of the item was the same with the order the operator would compare MPN (Manufacturing Part Number) number of the item from different suppliers with the AML (Approved Manufacturing List) number which was registered in the company’s system.
IV. If they matched the item would be registered in the company’s ERP system (Enterprise resource planning).
V. The fifth step was printing out a label with article number, date and place in warehouse.

VI. The last step was inspection of the item in order to become sure that everything was correct.

In the case of any problem in any of these steps, the operator should contact with quality manager, purchaser or component engineer to solve the problem.

After finishing these six steps of item registration, the fifth activity of the incoming goods department was moving items to the warehouse. As mentioned above, there were two warehouses in the company and items could be moved to any of these warehouses.

4.2.3. Sorting Procedure

After the incoming goods registered in the ERP system they would be sent to the warehouse on the rack of pallets. The operator should control some facts like article number, registration date, main storage place, the address copy, and waybill along the goods. One thing that should be mentioned here is if components had been used previously in production, there was a defined place in the warehouse for these components, and the item would be sent to sorting area directly after registration, in order to store at the right area in the shelves. However those components that had not been previously used in production had no defined place in the warehouse. In this case, the incoming section was giving a code to the article and would send it to the sorting part and employees should define a place for the new item.

However, Enics applied no specific sorting system in the warehouse. For each new material that should be sorted, the decision of where the materials should be stored depended on the size of the material; smaller items were sorted in paternoster lifts and bigger ones were sorted with pallets on the regular metal shelves. There was no zone or area that was devoted to special types of materials. The employees only found an empty place based on the size and put the item there and then registered the location in the computer.

A problem that occurred in this process was that sometimes it was forgotten to register the location of the component in the computer; so as a result, when the component needed to be picked from the warehouse, it might not be found, and thus time and resources were needed to find the component. Sometimes the responsible person could go back to the incoming goods section to see the registration history of the item and through that found its place.

Sometimes the received materials even not became sorted; staffs picked orders from these boxes on the ground which also was taking time to find them because they were not registered in the system. In addition, if the defined place for a component was full, employees put the component in the first empty space that was found and registered it in the computer, without checking if already there was another defined place for this specific component or not. As a result, after a while for one component there were
several different locations and none of them were full. After sorting the material, the address copy should be signed and it should be registered in the computer.

4.2.4. Order Picking Process

After sorting process there was order picking process. The materials which were needed from each station in production line would be listed in an order list paper; the coordinator of the line gathered all the order lists and put them in a letter box at the entrance of the warehouse. These orders list could be for routine components that the production line used; for this kind of component they used Canban system. However it also could be a unique order for a new product. The responsible person took the orders from the box and sorted them on a planning board based on the date and time that the order should be delivered to the production line (FIFO principle). Figure 4-4 shows this planning board.

![Figure 4-4: Planning Board](image)

Order pickers took orders and registered them in the computer system and received the printed label for each item in the order list. Each label presented the item number, the main storage of the item, the order list number, the quantity of the item, and also the barcode of the item. Then staffs sorted the labels based on the location of the items, different lifts or shelves, and put them on a trolley and picked them. Then the amount of materials would be controlled and were sorted again for each order list and would be placed together to complete the specific order. Finally they would be delivered to the stations by trollies or material train. The method was used here was “batch order picking” and “pick and sort” procedure. Based on how many items existed in the list and when was the due time for delivery each order, picking process took different time. During this process so many different
problems might happen that caused delay. If staffs could not find the item in the main storage they should came back to the computer and searched for any other possible locations for that specific component. In addition, since there was no specific rule for sorting items, maybe for one order list it was needed to go around the whole warehouse which was time consuming. If any problem happened during order picking process, operator should contact staff from purchasing or emergency delivery part based on type of the problem.

4.2.5 Packing

In front of packing area there were shelves where finished goods were stored there in a queue, and staff of packing section took the products based on FIFO principle. The first thing that should be controlled was the quality of the product and proper documents. Then the amount of product should be registered in to the ERP system. Staffs should control the data and developed picking list and registered serial numbers in to production system. Finally labels would be printed and proper packing materials would be used to seal the product.

There after goods were ready for shipment and delivering to the customer. If the product had some problems in quantity or documents, the goods should be sent back to the responsible group in production line.

Since raw material used for packing area were completely different to the raw material used in production, therefore in the new warehouse design raw materials for packing should be stored close to the packing area in order to save time and money and reduce waste.

4.3. Measurements

The main reason of the warehouse redesigning was decreasing the area from 1900m² to roughly 740m² (more than 60%), and the warehouse would lose 374 pallets. Each shelf was 1.3m in width and 2m in length and contained of two pallets. Each row of shelves was in different column and level. The aisles between two rows of shelves or between shelves and paternoster lifts were 3 meter, which was standard distance in the warehouse system in order to ensure that forklifts could move easily.

The elimination of the warehouse area would be by a wall at one side of the warehouse. After elimination the remaining area is shown in figure 4-5.
Figure 4-5: Remaining area of the warehouse after elimination

With comparing figure 4-1 and 4-5, the limited area and missed shelves can be observed.

Another challenge was the small warehouse on the opposite side of the factory, where the machine assembly was beginning. As mentioned before, management wanted to centralize the warehouse and feed the whole production line from one main warehouse with combining these two warehouses. It included two paternoster lifts with the name of VP with 35 levels and VH with 51 levels.

There were also some small size regular shelves for storing of reels and each shelf was devoted for one specific item number. The number of these shelves was 4150 shelves and usually there was one reel in each shelf. However, roughly 800 of these shelves were empty at the moment that it was counted, which meant 19.3%. Hence around 3330 of them were occupied. Paternoster lifts VH and VP were used as buffer storage for 30% of the reels in the regular shelves. Since those two lifts were not full, there was possibility to store these 30% of the reels in the lifts. In this case, roughly 70% of the reels in the small regular shelves were new materials.

In order to combine this warehouse to the main one, there were two opportunities, first let those two lifts remain there at their current place, and move all the materials to the main warehouse, and store them on regular shelves or in the lifts. The other option was to move those two lifts with all materials inside them to the warehouse and only find storage places for reels from small regular shelves. The first option wasn’t practical because, in order not to move those paternoster lifts, and move just materials inside them, since the number of components were huge, the company needed a huge number of extra shelves or some lifts to cover all the components. These facilities could not be prepared in the limited new area of the warehouse. So the first option was not a good option from both cost and space utilization points of view.

Even though moving these two lifts to the main warehouse cost more than 160,000 Swedish kronor, for following reasons the management accepted the second option.
working with lifts was easier and faster, they took less space, and there was already an empty space in the warehouse that was suitable for putting these two lifts (area number 3 in figure 4-9) and by comparing the price of movement with buying new lifts which cost more than 1 200 000 Swedish kronor, and space utilization by comparing with regular shelves, this option was the best choice, and would help to improve the efficiency of the warehouse.

There were three different options in order to move reels to the main warehouse:
First they could be moved as pallets. As described before for 70% of the materials in the regular shelves, pallets were needed in order to move them to the main warehouse, so:

\[ 70\% \times 3330 = 2331 \text{ reels or small regular shelves} \]

There were boxes which were divided in to 16 parts, and each part could be for one reel and it was equal with one shelf, each pallet also could carry three of these boxes. With below calculation there was a need of 50 pallets, in order to move all materials in small regular shelves to the main warehouse.

\[ 2331 \text{ reels} / 16 \text{ parts} = 146 \text{ boxes} \]
\[ 146 \text{ boxes} / 3 \text{ boxes in each pallet} = 48.6 \text{ pallets} \approx 50 \text{ pallets} \]

The second option was to use the same boxes with 16 parts, but stored them in one lift and one lift could cover all these reels.

The third and best option was buying new generation of material storage which was called cylinder Tower. This option was giving a good opportunity for storing reels since they were easier and faster in use, and they took less space. They would be in the production line close to machine assembly station. The area that was needed for each of them was around 1m² and their height was roughly 2.4m. Each of them had roughly the capacity of 550 reels with different size, and with previous calculation that showed those small shelves consist of 3300 reel approximately; the company needed at least 6 of these towers. In the case of buying and using cylinder Towers, they should be as closest as possible to the machine assembly part in the production line. Figure 4-6 shows these small regular shelves and the reels inside them.

![Figure 4-6: Regular shelves in small warehouse with reels](image)
With formulas in equation (1) which were presented in chapter 2, the empty percentages of those lifts with boxes were found. In the table 4-2 the result is demonstrated.

Table 4-2: Total emptiness percentage of lifts with boxes in levels

<table>
<thead>
<tr>
<th>Name of the lifts</th>
<th>VE</th>
<th>VF</th>
<th>VG</th>
<th>VT</th>
<th>H</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of levels of each lift(N)</td>
<td>43</td>
<td>42</td>
<td>55</td>
<td>28</td>
<td>36</td>
<td>36</td>
<td>34</td>
<td>38</td>
<td>38</td>
<td>37</td>
</tr>
<tr>
<td>number of empty levels in each lift (X)</td>
<td>4.5</td>
<td>21.2</td>
<td>9.9</td>
<td>1</td>
<td>19.5</td>
<td>6.5</td>
<td>5</td>
<td>0.5</td>
<td>12.3</td>
<td>16.8</td>
</tr>
<tr>
<td>Total Percentage of emptiness in each lift (Y)</td>
<td>10.5</td>
<td>50.5</td>
<td>18.0</td>
<td>3.6</td>
<td>54.2</td>
<td>18.1</td>
<td>14.7</td>
<td>1.3</td>
<td>32.4</td>
<td>45.4</td>
</tr>
</tbody>
</table>

However, there was another type of lifts without boxes inside the levels. With formulas in equation (2) from chapter 2 the total emptiness percentage of each lift in this category was counted. Table 4-3 is presented the result of emptiness percentage of lifts without boxes.

Table 4-3: Total emptiness percentage of paternoster lifts without boxes

<table>
<thead>
<tr>
<th>Name of lifts</th>
<th>VI</th>
<th>VJ</th>
<th>VK</th>
<th>VN</th>
<th>VO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of levels of each paternoster lift (N)</td>
<td>22</td>
<td>31</td>
<td>31</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>Total empty percentage of each lift (X)</td>
<td>0</td>
<td>475</td>
<td>695</td>
<td>1550</td>
<td>2250</td>
</tr>
<tr>
<td>Total emptiness Percentage of each lift (Y)</td>
<td>-</td>
<td>15.3</td>
<td>22.3</td>
<td>15.5</td>
<td>56.3</td>
</tr>
</tbody>
</table>

There were four other lifts in the main warehouse, VA, VB, VC, VD; these four lifts were main storage of components and they should be full all the time. Figure 4-7 illustrates two different types of lifts, with boxes and without boxes. Lifts with boxes usually were used for smaller components, while in lifts without boxes bigger materials were placed besides each other.
From tables 4-2 and 4-3 the total empty space from all lifts could be calculated. The emptiness percentages of the lifts are:

VE = 10.5%  VF = 50.5%  VJ = 16.8%  VK = 22.3%

The occupied space in the lift VF is 49.5% which is equal with sum of empty spaces in other three lifts.

49.5% \approx 10.5% + 16.8% + 22.3%

It means that if all material in lift VF will be moved to the three other lifts; there will be one empty paternoster lift with 42 levels.

With the same calculations following results were found out:

If all material in lift W will be moved to four lifts VG, VT, N, and M paternoster lift W with 37 levels will become empty.

If all material in lift H will be moved to three lifts VN, K, and L paternoster lift H with 36 levels will become empty.

So with above results and rearrangement of spaces in paternoster lifts, three lifts, VF, W, and H will become empty and VO also will be half full, while the rest are full.

One of the options to find empty space inside the warehouse was the area that Personnel gathered empty pallets. It was at the incoming goods area. With new design there would be no place to put empty pallets any more. There was a space outside of the warehouse right before the entrance door that had ceiling and if this area became protected with proper wall against rain and snow, it could be a good place for storing empty pallets and boxes.

Another opportunity to find empty space was regular metal shelves. The number of empty pallets on the shelves was discovered by one of the employees who went through all regular shelves one by one and identified those pallets that were empty or consist of
empty boxes, as well as those which were occupied with old or scrap material or after sale products. Results are presented in table 4-4.

Table 4-4: The possible empty pallets on regular metal shelves

<table>
<thead>
<tr>
<th>Status of the pallet</th>
<th>Empty pallets</th>
<th>Pallets with empty boxes</th>
<th>Old or scrap materials or after sale products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number</td>
<td>56</td>
<td>9</td>
<td>56</td>
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Then it was found out those 56 pallets with old material or after sale products could be accumulated in to 44 pallets since these materials were straggly in different pallets. Hence twelve more pallets would become empty also.

In addition, from table 4-4 it could be found out that, currently there were 56 empty pallets on the shelves, and nine pallets that consist of empty boxes. As mentioned before, these nine pallets with empty boxes could be moved to that area outside of the warehouse and be stored with empty pallets. Hence in total from table 4-4, \((56+9+12)\) 77 more empty pallets would be found.

One thing should be considered here is, these numbers of current empty pallets on the shelves and empty spaces in the lifts were at the moment that the observation took place, they changed so often and a place that was empty at that moment, might not be the day after. However, more or less always this amount of empty pallets could be found in the warehouse in different locations. This was one of the weak points of the warehouse performance, that there wasn’t any control on empty pallets and optimization of free spaces. One solution could be that one person per shift always control the materials in the pallets and their location with the computer system and always has the information about locations and amounts of empty spaces.

There were some other shelves that were discovered with the label of LTB (Last Time Buy) material. LTB were those components that were not produced any more by the suppliers, but the company still used them for producing products and they were expensive (A category materials), so the company had to keep the current ones and buy new ones, where ever found them with any price. These materials were stored both in lifts, and in regular metal shelves. The management decided to move parts of the LTB materials to the basement of the factory. Approximately 50% of those that existed on the regular shelves would be moved to the basement. Currently these LTB materials occupied 40 pallets on the shelves, and after moving them to the basement \((50\%\times40)\) 20 pallets would be occupied by them. Hence 20 more pallets would become empty.

There was also another potential to make free pallets. There were some items in the warehouse that they were not used now, they were called Obsolete Material. The last time of usage of these items were varied between 2005 and 2013. These items were anywhere in the main warehouse, the small warehouse, or even shelves in production
line area. Through that software, QlikView, it was possible to identify all of them, but since the consideration was on the main warehouse, so all the information which existed about Obsolete components in the excel file were filtered with only those which were on the regular shelves in the main warehouse. It was discovered that there were 57 pallets on the regular shelves that consisted Obsolete Material; the value of these components were approximately 850,000 Swedish kronor. All pallets should be reviewed one by one in order to find out the possible percentage of these pallets that can become empty. It meant the trade off point between inventory costs and buying new ones should be found. Figure 4-8 is presented part of the excel file of QlikView software with these obsolete materials.

If these 57 pallets with consisting of obsolete material were collected and accumulated, they could be limited in to 36 pallets, which meant 21 more pallets will become empty.

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</tbody>
</table>

Figure 4-8: Obsolete material on the regular shelves

For storage of obsolete and after sale materials which were not used for a long time, pallets could be stored in back shelves far from forward area. However LTB materials which were important and expensive components with considering of their size and shape could be stored in one lift in order to be more centralized and easier to access.

With above measurements all the possible empty places in the current state of the warehouse after decreasing the area could be summarized as below:

- Emptiness percentage of each paternoster lift
- Free space from moving empty pallet and boxes to the outside of the warehouse
- Current empty pallets on the shelves
- Number of empty shelves after accumulation of old, scrap, and after sale products
- Number of empty shelves after moving LTB material to the basement
Number of empty shelves after accumulation of obsolete material

The next step was to find out possible areas for adding extra shelves or lifts. Through reviewing of the warehouse layout and direct observation, with the consideration of some factors such as: the standard size of each shelf (1.3m), standard aisles size (3m), the possible height of shelves in different area (it was depended on the condition of ceiling, if there was any lamp or pipe there), and security and safety of the area (electricity wires and fire fighting equipment), areas that had the possibility to add extra shelves were found. Figure 4-9 with black squares demonstrate those areas that have the potential to add extra shelves or lifts.

In area number 1 there were three different possibilities to add extra shelves; one column with 3 levels, a row of shelves with 4 columns and 3 levels, and also another row of shelves with 3 columns and 3 levels. Since shelves in this area were close to the packing area they could be devoted for storing of packing material. In area number 2 there was a possibility to add a row of shelves with 10 columns, and all could be in 4 levels except one, which should be in 3 levels. In area number 3 there were two options: either to add extra shelves or paternoster lifts. In the case of shelves, it was possible to add 3 rows of shelves, each with 3 columns and 5 levels. In the case of paternoster lift, two lifts could be added in front of each other (face to face), and roughly the distance between these two lifts would be 2 meters. Finally in the area number 4 one row of shelves with 5 columns and 5 levels could be added.

As mentioned before it was better to move those two lifts from small warehouse to the area number 3, so this area would be occupied with these two lifts. Three other areas 1, 2, and 4 would remain to be redesigned with new row of shelves. Based on previous calculations and standard distances and with consideration with safety issues, the total pallets could be added in these three areas were 48 pallets for area number 1, 78 pallets
for area number 2, and 50 pallets for area number 4. Hence in total 176 more pallets could be added in these three areas.

In addition, in the existing row of shelves in area number 2, there were five columns of shelves that consist of three levels which had the potential to be in four levels. If they would be changed from three levels to four levels, 10 more pallets could be added there. The last thing that should be mentioned here is, there were some rooms in the area that was going to eliminate in the new design; they mostly used for education and also personnel’s office. They should be moved to other places in the factory after redesign process.

After all measurements and space utilization four primary proposals were suggested:

- First option: remove all the old lifts and substitute them with regular shelves
- Second option: rearrange the lifts in order to find more space to add new shelves and use the space in a better way
- Third option: remove all old lifts and substitute them with new ones
- Fourth option: keep all the lifts and shelves in the current position and improve the current storage arrangement

The first three options were rejected after discussing with employees and management based on following reasons:

In the first option lifts took less space, had more speed and were more efficient than the regular shelves, and at the same time this approach was a costly activity and needed a huge area. On the other hand, even these lifts were quite old but didn’t break down so often (once or twice per year) and personnel were more satisfied to work with lifts than regular shelves. So this suggestion was rejected.

The second proposal was rejected due to the fact that cost of moving each lift was around 80000 Swedish kronor which in total for 19 lifts would be a huge amount of money for the company to afford. At the same time with observing the layout of the warehouse in figure 4-5, re-arrangement of the lifts wouldn’t give considerable empty space and comparing with the money needed for the movement, it didn’t worth to do that. So from cost and space utilization it was not a good trade-off point.

The third option could be a good solution since new lifts work faster and wouldn’t break down. However, since the price of buying a new lift and removing the old one in total cost roughly 700 000 Swedish kronor, it was not the best solution from cost point of view and at the moment the company couldn’t afford this huge amount of money. Hence, this option also was rejected by the management.

The only choice remained was to keep all the lifts and shelves in the current position and improve the current storage arrangement of the warehouse in order to design the existing places as optimal as possible after decreasing the area to find possibilities for adding extra shelves or lifts or even new storage facilities.
4.4. Problems and wastes

During doing the project, bunch of problems have been found out which can be categorized in two different fields; one is problems that identified during redesigning process, and the other one was those problems that were found out from the performance of the current design of the warehouse. Both types of problems had to solve in order to have a better redesigned warehouse and also better performance in the future.

4.4.1. Problems during redesign phase

During redesigning of the warehouse some problems were encountered. In below list of these problems are given:

1. The overall structure of the warehouse: problems occurred during this phase of design were in the field of type of using technologies and the way of assembling the orders. The main objective of redesign in this step was minimizing costs, both in investment and operation. Using new technologies such as using scanning system for pallets and components in order picking and storage activities, or Radio Frequency Identification (RFID) technology which plays an important role in material circulation and supply chain management, needed a huge investment and operation costs. So the chosen technology had to have the most benefit and lowest cost for the company.

2. Warehouse sizing and dimensioning: since in the new design the area of the warehouse will become limited more than 60% of the current area, sizing and dimensioning of each department in the warehouse became more important. This factor has direct effect on the overall costs. Since one of the storage facilities in the warehouse was paternoster lifts and they were fixed to the ground and moving them made costs for the company, changing the size and dimensioning of departments became more difficult. So in redesigning process this limitation object should be considered and there were not so much opportunities to change the size of departments in the warehouse. Again a trade-off point should be found out between cost, warehouse size, and the dimension of the warehouse departments.

3. Equipment selection problem: this problem was about level of automation in the warehouse and the type of storage and material handling systems. At least half of the existing equipment in the warehouse was old and they need to be replaced with new facilities. In addition, the warehouse needed new extra equipment such as more forklifts, paternoster lifts and regular shelves. One of the biggest problems of the warehouse was the long change over time in in the first station of the production line and it was because of the way of storing of materials in regular shelves or lifts. Hence one of the facilities that needed to buy by the
company was new storage facility for storing reels which called cylinder towers which was needed huge investment cost. In order to select the best equipment for the warehouse with reasonable investment cost, first the equipment alternatives based on storage/retrieval requirements should be identified and then the selection between these alternatives should be done.

4. Layout design problem: designing the layout of a warehouse is a complex task and almost all operations and physical factors after design phase is depended on the layout design. Various departments in the warehouse and their relationship together impact the layout design. In Enics warehouse, changing the layout design during redesigning process was one of the major problems that encountered and it was because of the storage facilities that the company was using (lifts) which were fixed to the ground and were costly to move. In addition, because of the limitation in warehouse area there was not so much opportunity to change the design of the layout in order to improve the warehouse performance. There were a few possibilities in the incoming goods and packing area but not at all in the storage and order picking departments. Number, length, and levels of regular shelves’ rows and aisles were determined where ever was possible in the redesigning process.

5. Storage assignment policy: there was no specified method for storing components in the storage department in Enics warehouse. The warehouse personnel tried to divide the storage area to the forward and reserve area. It seemed that at the primary design of the warehouse these two areas were defined and separated, but during the time, components were mixed up and at the moment there were no separated area for these two categories. Even though the purchasing department used ABC procedure for the components, but the sorting of them in the warehouse even wasn’t based on this method. Employees sorted new components in the first empty space only based on the size. As a result during measuring the empty spaces in the lifts and shelves so many empty pallets or boxes were found which were not registered in the computer system.

4.4.2. Identified problems in current warehouse performance

During doing the project, being in the company and evaluating the current performance of the warehouse, some kind of wastes and problems related to the current design of the warehouse were identified. First, the different problems that have identified will be discussed, and then the different types of wastes that are results of the problems will be given.

1. If one person from office part or outside of the company came to the warehouse, they were not recognizable for staffs that drove a forklift or other vehicles.

2. There was no specified path way for people who were passing the aisles between shelves, both forklifts and people were passing the same area.
3. For most of the pallets there was no label or were several labels on one pallet and most of them didn’t have any barcode. Staffs didn’t use scanner to identify article numbers and they only used visualization skills for reading article number and find the items, mostly trust on their experience.

4. When incoming goods came to the warehouse, staff put them on the ground until sort them on the shelves or in the lifts. Most of the times packages would be on the ground for several weeks, and even sometimes staffs took them directly from the ground for order picking. The first thing was that this amount of components took a huge space of the warehouse ground and might stock the people path way. In additional finding components in this situation was harder and more time consuming. It also should be mentioned that, after new design, all free spaces should be used for adding extra shelves, and there would be no empty space on the ground to put these components. Figure 4-10 illustrate the arrived incoming goods on the ground.

Figure 4-10: Incoming goods to the warehouse for sorting still on the ground

5. When a component came to warehouse at incoming department, staffs can only see the main and the last place of the material, so they put those locations on the label; the person who was sorting the material, if found that location full, he or she didn’t check the computer to see if there was another location for this component or not, only put it in the first empty pallet and registered the new location in the computer. It caused that there were several different locations for one item and none of them were full. Another problem that might happen in this
case, sometimes staffs forgot to register the new location in the computer, and finding it in the future would become difficult.

6. Some of paternoster lifts were too old, they didn’t work properly, sometimes they broke down and their speed was so low.

7. When company hired new people, there was no learning course to teach the job to them. Furthermore there were no updating courses for personnel in order to update them with new methods of work. For example there were some common human mistakes happen during work and the reason might was that people didn’t know how react against these problems.

8. Staffs didn’t force themselves to use the existing space in a more proper way. Sorting materials on the shelves and especially in the lifts was not on a good order, so much space was missing only because of this reason.

9. The current human resources who worked in the warehouse were not enough to cover all the jobs.

10. There was no specific rule for sorting materials and components inside the warehouse. People only sorted them based on size, and each type of material could be in any place inside the warehouse. In this case reaching to components became harder and caused different types of wastes.

11. Usually when something happened to a component like missing or was destroyed or became spoiled, no report signed up in the computer. So after a while the real number of that component on the shelf was less than the number that existed in the computer. Since the purchasing part, order components based on the numbers in the system, it caused shortage.

12. Another problem which was identified was saving materials or components that they were not used any more for production and only took space in the warehouse. Sometimes they were valuable, but some of them didn’t have much value. Company should decide to scrap or sell them out.

13. All shelves are more or less had the same height, and the same potential to put numbers of pallets, but the system was not used properly and there was so much waste of space in the shelves. As it is seeable in figure 4-11 shelves were not occupied with their full capacity, since size of each pallet was roughly 30cm, more than three pallets could be in each shelf, based on the height of the shelf. It was a common problem in the warehouse and most of the space was missed just because of this reason. In order to find the real empty space in the current warehouse, first this kind of problems should be solved and the current space should be organized in a better way, in order to find the real number of empty pallets in the current system. In figure 4-11 the arrangement of the pallets in the shelves and the amount of space waste is shown.
All problems mentioned above caused different types of waste, that with identifying and solving those, most of them can be reduced. The most types of wastes that problems mentioned above cause are:

- Waiting: which is any idle time created during waiting and time will be missing. Problems number 3, 4, 5, 6, 9, 10, and 11 make this waste.
- Transportation: it can be movement of material or people inside the warehouse which does not add value to the performance. Problems number 2, 4, 5, 7, and 10 make this waste.
- Non-value-added processing: there are always some activities in the warehouse that don’t add any value to the system, but because of problems exist or lack of knowledge, people force to do them. Problems number 3, 4, 6, 7, 10, and 11 cause this waste.
- Excess inventory: this waste happens when the company decide to have more inventories in the stock for reasons like no shortage or save money in order not to buy more expensive one of the same component in the future. However, excess inventory need more space and more space need more money, or even the space should be kept limited, excess inventory cause mess and inventory saving expenses. Problems number 5, 11, and 12 cause this waste.
- Under-utilizing people: if the company not uses well educated people or not use all potential of its human recourse, it will cause this waste. Problems number 7 causes this waste.
- Defects: defects are the most usual waste in any manufacturing system and especially in inventory and warehousing part. Always there are possibilities to miss a component or it becomes destroyed. Problems number 4, 5, 7, and 12 cause this waste.
- **Waste of space:** it is obvious from the name of the waste that it happens when the current space of the warehouse is not used properly and in an organized way. Problems number 4, 5, 8, 10, 12, and 13 cause this waste.

- **Accident and injury:** even though this one is not waste and it is about safety things, but it can be mentioned here because any accident apart from consequences that makes for the person who injured, it also cause waste of time and money for the company as well. Problems number 1 and 2 cause this type of waste.
5. ANALYSIS

Analysis of warehouse redesign process is done in this chapter in order to present the process of redesigning a warehouse and the problems encountered during redesign process and suitable metrics that should be used in performance evaluating based on theory part.

5.1. Redesigning process at Enics warehouse

According to Hassan (2002) during designing a warehouse there are several factors that should be considered which is started from type and purpose of the warehouse, location, demand forecasting and is continued with layout and different departments design and specification and will end up with zoning and determining of docks’ number and locations. However in redesigning a warehouse, some of these steps will be ignored, since most of these steps are already done like type of the warehouse and expected demand determination. Hence a designer should use the current facilities and opportunities in redesigning process and as a result has more limitations. In Enics warehouse redesigning process some steps were dismissed since the main purpose of redesigning was having the same warehouse with the current equipment more or less, but in a smaller area and at the same time improving the efficiency of the warehouse operation with consideration of minimizing the cost. Particular emphasizes has been placed on cost of warehouses in design phase from both investment and operating point of view which is in line to Rouwenhorst et al. (2000). So a unique procedure with seven steps was developed for redesigning process in order to improve the performance with minimum investment and operational cost with the main concentration on space utilization. It also can be say that, the redesign procedure was derived from five step designing process which is presented by Gu et al. (2010). The most important factors in redesigning a warehouse is space utilization to minimize the overall cost which also emphesized by Lihui and Tsai (2006). So the most consideration in redesigning process at Enics warehouse went to utilize the storage space. Enics warehouse is a production warehouse which is based on the production warehouse definition from Berg and Zijm (1999) is used for storage of raw material to feed the production line. Sometimes the company needs to store materials for a long time i.e. when batches of incoming goods are larger than the production batch or when the production batch exceeds the customer order quantity of finished products. In these cases storage of materials must be cost efficient, so they store them in large quantities in an inexpensive storage system like pallets on regular shelves. After the primary observations and measurements, different ideas were found in order to redesign the warehouse. The best proposal should be made in order to find a trade-off point between cost and space utilization and high performance.
5.1.1. Steps of redesigning process

Step 1- Data collection
In this step the current state of the warehouse was studied and all needed data were gathered in order to evaluate the current performance of the warehouse based on current design of it. Data such as current area of the warehouse, existing storage facilities, percentage of occupied space, different departments, and in summarize how the warehouse exists and performs today. This step was one of most time consuming steps and is needed careful attention to observe and gather all details that help the designer for redesigning process. At Enics warehouse this step is done through different activities including below:

- Identification of different departments and evaluation of each department’s performance
- Measuring all current area as well as remaining area after decreasing
- Finding and measuring the dimension of those areas that have the possibility to add extra storage facilities
- Identifying all existing storage facilities and their specifications
- Calculating all empty storage spaces in the lifts and on the shelves that can be improved
- Evaluating the performance of the storage facilities in order to improve them in the new design
- Studying the storage assignment policy of the warehouse and evaluating the overall performance of the warehouse operations

Detail of these activities and all quantitative and qualitative gathered data was presented in the result chapter.

Step 2- Generation of different proposals and their evaluations
Based on the data which gathered in previous step and evaluating the results of measurements some primary proposals were made. These primary proposals were discussed with the management and those ones were not good or impossible to implement were deleted. Since in redesign process there are some limitations in changing the current position of the layout based on structure and costs, the designer has to discuss all possible options with the management and all related divisions in the factory in order to find the best solution.

At Enics warehouse after evaluating gathered data four primary proposals were made and were discussed with the management and production division. Three of them were rejected based on some reasons which were explained at the end of chapter four.

Step 3- Establishing the best proposal
In this step the best proposal that fit the company’s goal was established. The final proposal was supposed to meet all the company’s expectations and was in a trade-off point of cost, space, and performance in order to give the best redesign of the
warehouse which was minimizing the space and cost and improving the overall performance of the warehouse.

This proposal at Enics was keeping all the existing lifts and shelves in the current position and improves the current storage arrangement of the warehouse in order to redesign the existing places as optimal as possible after decreasing the area to find possibilities for adding extra shelves or lifts or even new storage facilities, a good storage assignment policy for storing components and improve the overall performance. In addition in the final proposal it was decided to combine the small warehouse with the main warehouse by moving two paternoster lifts to the main warehouse and use new storage facility which is called cylinder tower for storing the reels.

The only thing that should be considered here is that, the production line should be redesigned at the same time with redesigning of the warehouse, and be in the U shape based on Lean principle and start right after the warehouse in order to reduce waste of time, space, transportation, and money. With elimination of the small warehouse the whole production line will be fed from one centralized warehouse.

**Step 4- Sizing and dimensioning of the warehouse layout and its departments**

This step is determining the space allocation among different departments within the layout of redesigned warehouse. Enics warehouse was a production warehouse and has four major departments: incoming goods, sorting department, order picking and accumulation, and shipment department. However since raw material for packing finished goods also were stored in this warehouse, so this department also consider as a part of the new warehouse design.

The main reduction of the area will be in the sorting, order picking, and shipment department in width from one side, hence the main objective was to design these departments in order to cover all missing storage areas and facilities and at the same time improve the efficiency of storing and order picking activities.

In the new reduced layout there were limitations for moving storage facilities (lifts) because of the reasons were mentioned before, all departments will be kept in their locations as today. Only in packing area there will be a reduction of 1.5m in width in order to add extra row of shelves.

**Step 5- Detailed layout determination within each department**

This step is about the design of the departments in order to add more shelves or lifts in the remaining space to cover all material storage with consideration of eliminating of waste, cost reduction, improve space utilization, and as a result improve performance efficiency.

With the reduction in the area of the warehouse layout, 374 storage pallets were missed. As mentioned in result chapter there were two possibilities to compensate this amount of storage space:

- Improve the way of using spaces in the existing storage facilities
- Add extra storage equipment
For the first option the possibilities from results chapter are as below:

- There will be three empty lifts (VF, W, H) and one half full lift (VO) after space optimizing inside the lifts
- 77 empty pallets from optimizing the empty spaces on the shelves
- 20 empty pallets from moving the LTB materials to the basement
- 21 empty pallets from accumulation of obsolete material on the shelves
- 10 empty pallets from changing three level column of shelves to the four level

So in total 128 empty pallets, as well as three and half empty lifts were found out after optimizing the spaces in existing storage facilities.

For second option, there was a possibility of adding 176 more pallets in areas number 1, 2, and 4, and two paternoster lifts in area number 3 in figure 4-9. In addition, for the reels from small warehouse there is need of 6 cylinder towers in order to cover the movement of all the reels in the small regular shelves to the main warehouse.

With all above calculation, number of total empty pallets after adding new shelves and optimizing the current space will be 304 empty pallets and three and half lifts which with six cylinder towers, in total will cover all 374 missing pallets from area reduction and reels from small warehouse from combining of two warehouses.

The overall structure in this step is redesigning the departments’ layout and storage capacity in order to cover the storage of all components in a limited area with minimizing the cost and maximizing the efficiency.

**Step 6- Storage assignment policy**

The sixth step is storage assignment policy and it is about determining the storage method within the warehouse that have to be considered in the design phase. After finding all needed storage space that can cover all the raw material in the new redesigned limited area, the next step would be the arrangement of material and components within the storage spaces.

There are five different methods for sorting materials in the storage area including: random storage, closest open location storage, dedicated storage, full turn over storage, and class based storage. No matter which one is chosen as a storage policy, one thing that should be considered in all type of storage is that, the storage area should be divided in to two separated parts, reserve and forward area, as presented by Koster et al. (2007). For example the lower level shelves could be devoted to forward area and higher ones to the reserve area and so on.

All types of storage policies can be used in a warehouse and it depends on the type of the warehouse, type of the components and selected storage facilities.

At Enics warehouse, based on class based storage policy, group of materials could be divided in to different classes. Since company used ABC category for the components, it can be a good classification for material storage as well. After that, each category could be separated in to two areas: reserve and forward areas and within the each group closest open storage policy could be the best option for sorting the materials in order to
access to the components be easier and faster. Figure 5-1 demonstrated the proposed storage assignment policy for production components in Enics warehouse.

Figure 5-1: proposed storage assignment policy for components in Enics warehouse

Based on definition of open closest location storage policy derived from Koster et al. (2007), personnel choose the closest suitable empty location for sorting an item based on two important characteristics: one is physical characteristics of the component like size, shape and volume, and the other one is frequency in usage. Huge items with less frequency or high demand quantities are better to be stored only in reserve area. In addition, regular components with normal size and shape that are used more often should be sorted in the easiest accessible locations.

The important thing in design phase is that each group should be centralized in specific area within the warehouse and both main storage and buffer storage of each category should be together.

**Step 7- Equipment selection**

The last step in redesigning a warehouse is warehouse equipment selection. This equipment could be in storage, order picking, transportation and other departments. In redesign process based on the functionality of the equipment, they can be kept, improved or be substituted with new equipment. Based on which way is selected there will be extra costs for the company. In the case of keeping existing equipment, the company will have operation and maintenance costs, while in the case of buying new
equipment or improving the existing one, the company is needed to spend more investment costs.

Buying new equipment and facilities could be a strategic long term decision for the company to replace the old equipment with new ones in order to improve performance of the warehouse.

At Enics, some existing equipment could be kept such as forklifts, most of the paternoster lifts, and all regular shelves. However, it also needed to add new shelves and pallets, computers inside the forklifts, scanners for scanning the barcodes both for pallets and materials in all departments, and safety facilities. In addition, the company has to have long term strategic decisions to buy new storage facilities like paternoster lifts and cylinder towers.

Based on different types of warehouses and current design of them, some more additional steps in redesigning process can be discussed as well. Steps like: number and design of aisles, number and location of input/output (I/O) points and docks, and zone formation. Hassan (2002) explained all 14 possible steps in designing warehouses.

5.2. Major problems during redesign a warehouse

During redesigning a warehouse five major problems would be encountered: overall structure, sizing and dimensioning, equipment selection, storage assignment method, and department layout which are in line to Rouwenhorst et al. (2000).

Selecting the proper using technology in order to maximize the benefit and reducing costs is one of the strategic decisions for solving the overall structure problem which should be taken in early stage of redesigning process.

Warehouse sizing and dimensioning is also an important problem which is directly related to the cost. The size and dimension of each department should be selected and measured carefully in order not to have waste or lack of space. After redesigning process, changing the size and design of departments not only is so hard and costly but also some times impossible.

The level of automation in warehouses and type of storage and material handling also are problems during redesign process under title of equipment selection. It is related to both investment and operational costs. Best equipment should be selected based on the functionality of the warehouse to be useful and improve the performance.

Storage assignment policy is also an important problem that should be solved in early stage of design phase which affects next steps.

Designing a warehouse layout is the most complex part of design and includes so many different design decisions and affects the overall structure of the warehouse department functions and all steps of designing. If this problem solve in early stage of design phase under strategic and tactical decision making level, it could improve the performance efficiency in large extent and prevent so many problems that may happen during operation phase and reduce investment and operational costs.
In addition, in section 4.4 some current problems and wastes were identified. They were related to the previous design of the warehouse. If these problems become identified, studied and solved, they won’t be repeated in the new redesign of the warehouse. The first two identified problems were related to safety issues and can be solved during redesigning process or in operation phase. In this section some solution will be suggested in order to solve the problems and decrease the wastes.

1- There should be two different kinds of vests that differ in color. One for people who work in the factory but in other department and the other one for people who come to visit factory’s warehouse from outside of the factory. These different colors of the vests give two different signals to the people who work with forklifts; the first one says that this person is from inside of the factory, so he or she is a little familiar with the environment and the second one says that the person is completely stranger with the environment. Based on these differences the person who drives the forklift take different approaches to be more aware and control the situation.

2- The aisle between two rows of shelves should be 3m in order to a forklift has enough space to move easily and safe. After new design this area should be determined with reflective tapes in order to separate the pathway of people and forklift route. It can be 50 cm for pedestrians and 2.5 m for fork lifts.

3- One of the problems that took so much time of the personnel and cause mistakes for order picking was identifying components; each shelf should have a label that demonstrate the shelf name and location and components inside it. For example imagine that there is four pallets on a shelf and each pallet consist of one type of component, so the label on the shelf should have four different parts; each part should give information about the name and location of the shelf, pallets number and the specific item number in the pallet, also should have a barcode in order to identify the component with scanner. In this case time will be saved and all mistakes that may happen by visualizing will decrease.

4- After new design there won’t be any empty space on the ground that employees can put the arrived components in order to sort them later. So all incoming goods to the warehouse should be sorted in the lifts or on the shelves immediately. One solution could be hire or devote one or two persons only for this job per shift, since company has arrivals every day. It is obvious that these persons can help other departments whenever they are free.

5- When a material come to the warehouse, the responsible person for sorting them, should check in the system the different locations of this component and see how many of them are full and take the one that is not full and put the component there in order not to have several different locations for one item which none of them is full. Two things that should be pointed here is that, always the status of a components should be updated in the system to be sure that what system shows
is match with the reality, and second for order picking, since each component has expire date, when a person check the system for finding the item’s location, he or she also should have the possibility to see the arrival date of the component in different locations in order to pick items with near expire dates.

6- One of the solutions that help too much for improving the efficiency is buying new paternoster lifts to speed up the work and taking less space. However, it should be considered that the cost of buying a new paternoster lift is around 600 000 sek which is a huge investment for the company and it can be a long term strategic decision.

7- When the company hires people, there should be a learning course at the start of the jobs at least for one week to teach them all activities that have to do in all departments of the warehouse. In this case, from early stage people learn to be flexible to work in all parts of the warehouse and have knowledge to do all warehouse activities. In addition to this, each six month the company can have one day courses in order to update personnel with new information and knowledge to prevent some common mistakes.

8- Paternoster lifts are important spaces to store materials, and it is more important to use all storing potential of the lifts. Personnel should force themselves to use spaces in the lifts in more ordered way. Put materials and boxes next to each other and try to use the whole space. For example when the materials inside a big box are few amounts, the box can become smaller in order to use another boxes for other materials. All mentioned, mean that personnel should use the spaces inside the lifts or even on the pallets in a better way in order to improve the efficiency and decrease waste.

9- Since the current personnel in the warehouse cannot cover all the jobs in the warehouse, incoming goods and packing, so it will be suggested to hire new young people, or have two fixed shifts with equal number of personnel per shift in order to improve the performance.

10- There should be a rule for sorting materials in order to access to them become easier and faster. Even though the variety of the raw material is huge, but there can be a rule for sorting them. (see sixth step of redesigning process)

11- Sometimes there are shortages of materials in the warehouse because personnel forget to update computer system manually when an item is missed or become destroyed. It is really important that the system become updated and it is the individual responsibility for each employee of the warehouse.

12- As mentioned before there are some obsolete material inside the warehouse that they are not used for a long time. Since most of them have high value, it should be a long term decision that they should be taken out of the warehouse during the time. They can be sold or scrapped based on their values.
13- The whole potential of each shelf should be used by storing proper number of pallets in order to save space. This needs a rearrangement of the warehouse based on height of the shelves, height of the pallets and material zone. All solutions suggested above are in the way to reduce wastes and increase the efficiency of the warehouse performance and as a result decrease the cost. Some of these actions can be taken immediately and some of them need more time, while the rest are long term decisions.

5.3. Evaluation metrics in a warehouse redesigning

For redesigning a warehouse, the current performance of the warehouse which is based on current design should be evaluated, in order to the performance of the new design become improved. There are several metrics that a warehouse performance evaluation can measured based on them. These metrics are divided in to quantitative and qualitative metrics, which is in line with Chan (2003). Quantitative metrics include cost and resource utilization and qualitative metrics include five factors: quality, flexibility, visibility, trust, and innovativeness.

Enics warehouse redesigning process and performance also evaluated based on these seven metrics. Below these seven metrics will be discussed.

Cost: all steps in redesigning process directly or indirectly related to the cost, which can be in different directions; space cost, inventory cost, warehouse cost, and equipment cost. In addition, identified problems during performance evaluation which cause waste, also will result in increasing the overall cost.

Resource utilization: resources are in four forms: labour, equipment, capacity, and energy. Equipment and capacity are directly related to the redesigning process, while labour and energy are indirectly related. During redesigning process of the warehouse, selecting the best and useful equipment for storage and material handling, and proper storage capacity are two important factors. Energy could be in type of human resource energy, which is labour selection and it is operational decision making and can be determined after design phase. Energy can be also considered as natural resource energy, and in redesigning process environmentally friend methods could be selected in order to save energy.

Quality: quality of a warehouse performance can be evaluated from different angles: customer satisfaction, customer response time, on time delivery, fill rate, stock out probability, and accuracy. In this kind of warehouse which is production warehouse, its customer is internal and is employees from production line. It can be said that the first factor, customer satisfaction, is based on good performance of the rest of the factors. In addition the percentage of orders delivered on time and orders that can be delivered immediately affect the customer satisfaction. Percentage of accurate items in correct amount also directly is related to the customer satisfaction. So from feedbacks and
comments that are received from employees in production line, the quality of the warehouse design and performance can be evaluated.

*Flexibility*: sub criteria of flexibility metric can be viewed from different points: labour, material handling, operation, and delivery. Human resource can be flexible with sharing responsibilities between different departments of the warehouse. If the storage area is divided into different zones, the flexibility of material handling can be evaluated between these different zones. Hence the number of existing path between different zones in the warehouse can be identified and be flexible. Operation of different departments should be also flexible in order to reduce cost and improve the performance outcome. Flexibility in order delivery also can be evaluated from feedbacks of the customer.

*Visibility*: visibility can be viewed from time perspective and it is the time which is needed that a designer changes his idea. In redesigning phase, it is important that steps be done one by one even though they are interrelated. Decisions should be taken carefully and redesigning process should be done step by step, because when a decision is made and a step of designing is passed, changing is hard, and time and money consuming.

*Trust*: the metric trust in warehouse design and performance is evaluating by consistency and it is the percentage of late or wrong delivery.

*Innovativeness*: it is the use of new technology and it will reduce waste of time and cost, and improve the performance. Some of these technologies that could be used in redesign process of the warehouse are using scanners to scan bar codes of items and pallets, using of new facilities for storage and material handling, and using new developed methods for storage and order picking operations.

As a summary in order to increase the performance efficiency and as a result control and reduce the cost, the only way is to find the best solution for redesigning the warehouse and finding the best trade-off point between time, cost and performance.
6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

Design and control of a warehouse system is a complex task, and different level of decision making play an important role in order to solve this complexity. Majority of academic papers are primarily analysis oriented and does not give a systematic method and techniques as a basis for warehouse redesign.

The aims of this project were to develop steps of redesigning process of a production warehouse, discussing major problems during redesign process, and identifying evaluation metrics which should be used during warehouse redesigning process.

Since this thesis project was a case study, the best method which fit with the characteristics of this specific production warehouse was chosen, in order to redesign the warehouse system after reduction of space for more than 60 percent with the consideration of existing facilities and reducing the cost in all departments of the warehouse. Furthermore, the performance of the current warehouse system was evaluated based on seven metrics and some suggestions were made in order to improve the warehouse performance after new design.

A redesign process with seven steps was suggested. These seven steps are: data collection, generation of different proposals and their evaluations, establishing the best proposal, sizing and dimensioning of the warehouse layout and its departments, detailed layout determination within each department, storage assignment policy, and equipment selection.

Storage assignment policy as one of the steps during a warehouse redesign phase was discussed in detail, since the major problem of the current design was in this field. Between different methods of sorting materials those that most fit to the system needs were found and a procedure for storage system of the components were suggested. 13 different problems regard to design and performance with different type of waste that they cause, were identified and solution were suggested in order to be more cost efficient and improve the performance of the warehouse.

Evaluation metrics in redesigning process were discussed which were seven metrics in two types of quantitative and qualitative form. However in this study because of time limitations evaluation metrics haven’t measured precisely and only they were introduced. In order to improve the redesigning procedure they should be measured more carefully.

6.2. Recommendation and further research

Since this study was done on a single case study, for validating the developed process of a production warehouse redesign results should be repeated in different cases in order to reach to the same results.
Since the study did not go through details in cost evaluation, and it was just discussed about the cost of buying new facilities or substituting old machines with new ones, further research is needed in order to find out the exact reduction percentage of the overall cost. However it is obvious that the investment cost will increase since the operational cost will be reduce with buying new facilities, which is an important strategic decision for management.

Since there is a lack of defined method for redesigning of the warehouses, further research is suggested with focusing on developing of a complete reference model in order to establish a systematic design approach for warehousing redesign process. In particular finding a trade-off point between cost, space and operational performance of redesigning of any production warehouse, should be the subject of future studies.
7. REFERENCES


Riege, Andreas M. "Validity and reliability tests in case study research: a literature review with "hands-on" applications for each research phase." Qualitative Market Research: An International Journal (Emerald) 6, no. 2 (2003): 75-86.


8. APPENDICES

Appendix 1:

Time plan

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Appendix 2:
Questions of focused interview

1- How often the incoming goods arrive?
2- How the staffs sort them? Based on any special procedures?
3- Are there any zones or areas based on difference of material?
4- How they identify them?
5- Who and when should decide to order new components if the warehouse become run out of materials?
6- Is there any kind of inventory on the shelves that is used very seldom?
7- How much different kind of components exists in the warehouse?
8- How often warehouse receive orders from production line?
9- How long it takes to deliver the order?
10- Is it easy to find components?
11- In the warehouse do they use single order picking or batch picking? Which method they use?
    Sort while pick or pick and sort? Are they satisfied with the method? How long it takes? Any problem?
12- How often happen that they make a mistake while picking orders? With a wrong amount or wrong component?
13- How long it takes an order come to the warehouse from production line until that station be fed?
14- Are staffs satisfied with this time? If not what kind of problems they have?
15- If they have any problem that they suffer?
16- What kinds of wastes do you think that currently exist in the warehouse?
Appendix 3:

Current area of Enics warehouse
Appendix 4:

Remaining area of the warehouse after elimination