Improving facility layout & logistics to increase the material flow efficiency

Förbättring av interna flöden & anläggningsplanering för att uppnå en effektiv materialhantering

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Preface & Acknowledgement

This thesis was conducted at Scapa Bedding AB in Rydaholm, Sweden, from March to June, 2013. The thesis completes the Bachelor program in Human Resources & Industrial Management at Linnaeus University in Växjö.

I would like to start with thanking everybody that contributed to this thesis, in one way or another for their support, answers and guiding.

I would like to give a special thanks to my tutors, Anders Ingwald, Martin Jacobsson and Ia Williamsson for their help and time throughout the entire thesis period. The discussions and feedback that I have received from both tutors have been of great importance for me and this thesis.

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Växjö, June 2013

Dino Besic
Summary in English
When the internal logistics of a company is in a well working condition, the manufacturing process is more efficient and a more efficient material handling process can be developed. A company with the interest of decreasing internal material handling is Scapa Bedding AB, a middle size bed manufacturer situated in Rydaholm, Sweden. Today, Scapa Bedding AB is facing a problem since there is no documentation regarding the material handling, no maps have been developed that displays the internal transports. This thesis attends the question of how to decrease the material handling within the production areas. To construct a solution for the material handling problem tools such as PDCA and DMAIC were used as a foundation in the development of a model that would be applicable on a company of this size. The purpose of the work is to locate and identify the wasteful activities regarding the material handling, and to streamline the activities to reach a minimum of material handling. By extracting data from observations, discussions and interviews the thesis will provide the reader with a problem background and a constructed model the tackle the problem. The model will provide support to locate inefficiencies within the company and in a later stage to develop improvement alternatives relevant to the case. The chosen improvement alternative will in a cost effective way be a solution to the problem.

Keywords: Logistics, internal logistics, transportation, material handling, model development

Summary in Swedish

Nyckelord: Logistik, intern logistik, transporter, materialhantering, modellutveckling
List of definitions & abbreviations

**MCDM**: Multi Criteria Decision Making

**DMAIC**: Define, Measure, Analyze, Improve, Control

**PDCA**: Plan, Do, Check, Act

**SQM**: Square meter

**Lead time**: The total time between the order placement and its receipt (Vitasek 2005).

**Cost-effectiveness**: Indication of how much invested capital can be economically beneficial in the long term (Al-Najjar & Kans 2006).


**Defect**: The non-fulfillment of an intended requirement or an expectation for an entity, including one concerned with safety. BS 3811:1993.

**Test**: Technical operation that consists of the determination of one or more characteristics of a given product, process or service according to a specified procedure. BS 3811:1993.

**Ergonomics**: The study of the relationship between workers and their occupation, equipment and environment and particularly the application of anatomical, physiological and psychological knowledge to the problem arising therefrom. BS 3811:1993.

**Down time**: The time interval during which an item is in a down state. BS 3811:1993.

**Operation**: The combination of all technical and administrative actions intended to enable an item to perform a required function, recognizing necessary adaptation to changes in external conditions. BS 3811:1993.

**Step**: A single identifiable action carried out as one element in a procedure or series of actions. BS 3811:1993.

**Waiting time**: The part of attendance time other than unoccupied time during which a worker is available but is prevented from working. BS 3811:1993.

**Availability**: The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. BS 3811:1993.

**Capability**: The ability of an item to meet a service demand of given quantitative characteristics under given conditions. BS 3811:1993.

**Efficiency**: The ratio of useful work performed to the total energy expended. BS 3811:1993.

**Maintenance**: The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function. BS 3811:1993.
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1. Introduction

The introduction will provide a description of the problem in hand, as well a background to the problem. Furthermore the presentation and discussion of the existing problem in this thesis will be introduced. The purpose, delimitations and a time frame are as well included in this chapter.

1.1 Background

Logistics is often a misunderstood concept, and is often associated with transportation. In reality logistics cover a lot more and affects all producing companies, both within the company walls and externally. From the point that raw material is ordered to the point that it is sent to the customer it is constantly affected by different forms of logistics, internal and external (Segerstedt 2009).

Council of Supply Chain Management Professionals (2004) definition of logistics management is the following:

“Logistics Management is that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.”

Logistics is now an essential part of most businesses and most of them have dedicated departments that only monitor and work with product- and material flows. This enables a company to continuously improve the handling of products, material, information and leads to a greater market position. The focus is mostly on the internal logistics within producing companies since there is much to gain in the area, by improving flows a company can develop a better production which will eventually result in faster deliveries and higher customer satisfaction (Jonsson 2011). A company can, as a result of the facilities planning- and material handling improvements become more productive and flexible. By mapping the material flows through a facility a company can discover areas that require improvement work to eliminate unnecessary costs and use of resources. Removing these unnecessary activities that are not adding any value to the company will result in reduced costs all over (Tomkins et. al. 2010). To increase a company’s competitiveness problems like these need to be addressed, in the industries of today it is very unlikely for a company to produce a unique product and expect to have that advantage on the market, instead the importance of increasing the efficiency of a company is a high priority (Jonsson 2011).
1.2 Problem Discussion

Logistics is an important part of the business world, to define flows of material and information, and to affect these flows is a large part of what logistics is all about. By reducing the amount of flows, or the distance that the material/information travels a company can also reduce costs. According to Tomkins et al. (2003) Material handling costs can reach 15-70% of the total cost of a finished product and could be significantly reduced if companies moved more attention to improving material and information flows. Still not enough time and resources are invested towards improving and optimizing internal logistics.

A company usually starts in a smaller scale and evolves into something bigger that requires more space and another facility layout. It is not enough by only adding area to the facility, but to adapt it to fit the material handling is crucial (Kerns 1999). Having an efficient facility layout is not always enough, it is also necessary to have a structured way of working, to have certain routines that are followed. Without these routines unnecessary activities will occur on a daily basis and it is hard to develop it further (Tompson et. al. 2010). By working without structure and routines a company loses the ability to visualize the possibilities. When e.g. transportation routes are unorganized and unstructured it is hard to find areas for improvements. Problems like these are not highlighted enough in today’s industries and cause companies to have unnecessary expenses (Lumsden 1989). At the moment non-value adding activities are occurring within companies, since material handling is considered a non-value adding activity, it is important to eliminate as much of the handling as possible. By eliminating the unnecessary activities and organizing the remaining activities to be as efficient as possible, the company can reduce costs significantly (Jonsson 2011).

To have a systematical approach to solving issues, Lean and Six Sigma approaches such as the PDCA or DMAIC can be used. By using these kinds of methods, a structured way of dealing with issues is provided. This allows the user to see the issues from a systematical point of view and handle the issues in the right order.

1.3 Problem Presentation

The problem that requires a solution regards the facility layout and the material logistics. Time and effort that is used for the material handling because of the quantity of movements, the length of movements and the faulty facilities layout is very high. To reach efficient flows and to reduce the costs for logistical activities these times and efforts have to be minimized. Already existing models with the purpose of improving material flow efficiency can be combined and used as inspiration when developing a model for improving material handling inefficiencies.

1.4 Problem Formulation

How can the material flow efficiency within the production be increased cost-effectively through improving the facility layout and the internal logistics?

1.5 Purpose

The purpose of this work is to develop a model that operates as a base for material handling process improvement. The aim of the model is to aid users in the work of eliminating unnecessary non-value adding activities to reach an efficient flow and reduce costs within a facility. This is made possible by making the internal logistics and facilities planning more efficient.
1.6 Relevance

Material handling and facilities planning is an acknowledged area of great importance (Grant et al. 2006). Tompkins et al. (2003) suggests that a big part of the total expenses for a company are related to the logistical activities, more precisely the material handling. Because of this it is important to focus resources on this area to minimize the costs and increase the efficiency (Tompkins et al. 2003). Still, many companies have not optimized these areas. According to Grant et al. (2006) cost savings within the logistics area influences the profits for companies’ more than increased sales do. This thesis will cover a subject that combines the material handling with facilities planning, through the use of recognized theories and models to develop a unique model that is simple to understand and effective in most producing industries.

1.6.1 Literature Search

In order to validate the study, a literature search was done. By using different search terms concerning the area of interest in a chosen database various results were received. In this case, the database used was Emerald which is a large database containing great amounts of scientific articles. The articles have mainly been used as inspiration while some have been used for support. The articles recovered from the searches are listed below:

List of relevant articles:

- Facility layout overview: towards competitive advantage (Canen & Williamson, 1998)
- A framework for selection of material handling equipment in manufacturing and logistics facilities (Hassan, 2010)
- Material flow improvement in a lean assembly line: a case study (Domingo, Alvarez, Pena & Calvo, 2007)
- Determining the most important criteria in maintenance decision making (Triantaphyllou et. al 1997)
- Facilities design design incorporating just-in-time principles for ramp-up light factories in Singapore (Low & Show, 2008)
- Effective logistics management (Gattoma, Day & Hargreaves, 1991)

There exists a large amount of information about logistics and material handling in general and it is fairly easy to find connections and useful data. Every search that was made offered a large amount of articles; a few fairly relevant, although not a single article highlighted the exact same problem that this work is covering. A large amount of articles focused on the material handling and how it is possible to decrease the material handling activities through the improvement of facility layouts. The factor that most articles had in common was how to decrease movements within a company since this is according to most investigated articles not a value adding activity. The way that the material handling was decreased was through rearranging the facility layout to streamline the material handling which leads to a reduction of material handling costs.
1.7 Delimitations

The thesis will not include the company’s external transports and will mainly focus on the production area, not the warehouse area because it lacks connection to the production. No economical figures will be analyzed because of the lack of information.

1.8 Time Frame

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*Table 1, thesis time frame.*
2. Method
This chapter displays which methods that have been used and how information has been gathered. Also this chapter contains the explanation of data gathering methods and research methods that have been used in the thesis.

2.1 Qualitative & Quantitative Research
A qualitative analysis means that an understanding is developed for the chosen subject through different forms of data collection methods. Instead of using the quantitative method that contains numbers and measurable data, the data that is used in qualitative research is gathered through observations, discussions, interviews etc. By using above mentioned methods one receives an opportunity for follow-up questions and feedback that offers more in-depth data. An example of a qualitative work is often the case study since it brings an understanding and in a certain way involves the researcher. Unlike qualitative research, the quantitative research method is based on statistical analysis - and processing methods. Quantifiable information is gathered, analyzed and summed. The quantitative methods are in particular used on measurable data, e.g. data from a survey that has been answered by a number of people (Wallén 1996).

2.2 Primary- and Secondary data
Gathering of data can be done in different ways, whatever the chosen way is; it requires that the data and the sources are reviewed thoroughly. Gathering of primary data can occur in numerous kind of ways, e.g. through interviews, surveys and observations. These types of data are considered primary data because it has not existed before the gathering. Secondary data is pre-existing data and also an important source of information that can save time for the author. It is important to take into consideration that the initial information and its author are not always objective and may very well have affected the reliability of the information (Wallén 1996).

2.3 Data Collection Methods
Observation
According to Patel and Davidsson (2003) the observation method can be both positive and negative. The positive aspects include the depth of information that the researches receives when studying peoples behaviors and different processes in their natural environment. The unique nature of the information gathered through observations can often be combined with other information gathered with the use of other research methods to achieve data of high quality. The obvious disadvantages with this research method is according to Patel and Davidsson (2003) the cost and time consumption that follow, also it becomes difficult to stay objective when entering other individuals natural environment and developing relationships with the studied objects.

Discussion/Brainstorming
Brainstorming is a widely used tool and is highly popular because of its simplicity. There are several different methods available when brainstorming, such methods are; individual, group and electronic brainstorming. The most popular brainstorming method remains the group method, which contains three or more participants. During the brainstorming sessions it is usually allowed to bring any kind of ideas and thoughts to the table, also the participants are given individual time to consider the mentioned ideas and thoughts. Later, the ideas and
thoughts are gathered and openly discussed within the group where the participants can aid one and other to further develop ideas (Buggie 2003).

**Interviews**
When conducting an interview it is crucial to ask the correct questions and to be a good listener. Yin (2008) discusses that not only the answers are of importance but also the ability to gather data properly, deciding what information to use and elaborating it further through the interview to achieve more “rich” information. Preparations are important before conducting an interview, making sure that the questions are well defined and understandable, this to receive well formulated answers. The interviewer should not block out contradictory information and only focus on his preconceived opinions and thoughts since this often has the ability to affect the final outcome of the interview (Yin 2008).

**Literature Studies**
When searching for appropriate literature it is important being able to formulate the search terms well to achieve a giving search. It is important to be aware of the existing literature within the studied area and to investigate former strategies and research to ensure that the planned work will not simply be a replication of already existing research. By having all this in mind, the researcher is able to locate relevant theoretical backgrounds for the area of interest (Bryman 2002).

### 2.4 Reliability
The main purpose with reliability is to ensure that errors and imbalances are eliminated, or at least minimized as much as possible within the work. In order to achieve a reliable research the author must minimize any randomness and be confident that the reached results would be the same if it was a different study with the same methods and goal. It is of great importance to document all the steps and procedures consistently to ensure the reliability of a research when it is reviewed by an outsider (Yin 2008).

### 2.5 Validity
Validity is a display of how reasonable a result that is drawn from the collected data is (Bryman 2002). It ensures that the appropriate research is performed in order to reach the objectives of the work. To achieve reasonable results it is necessary that the operational measures chosen have the purpose to reach the planned objectives. Validity is simply explained the “how” and “what” to study, “how” as in how to perform the study and “what” as in to research the right area. Reaching validity in a qualitative research is dependable on the understanding and interpreting abilities of the researchers and in a quantitative research the validity is achieved by comparing sources (Holme & Solvang 1997). When developing the model in this thesis it will be validated through the use of theories.
2.6 Work method

The thesis will be written as a qualitative case study. After the purpose is discussed at a case company, the work will begin with a simple data gathering process. By simply receiving a tour of the property, the researcher can achieve a wider perspective. The staff responsible for the facility contributes with information in form of layout drawings and discussions. By using the layouts and discussions, the researcher can combine that information with the data gathered from literature to map out ideal routes. Literature in form of books, articles is relevant to this case, but also a review of previous work done in this area could provide some help. After the data gathering, when the situation is thoroughly understood and described, a model is developed to fit the situation and line of business. The model is intended to be used to develop solutions to the discovered issues.

1. Presentation
2. Facility tour
3. Discussions & Interviews
4. Literature studies
5. Development of model
6. Develop solutions
3. Theory

This chapter presents the different theories used in the work. The theories are explained so that an independent reader can gain the necessary understanding.

3.1 Lean Production

The purpose with Lean Production is that a company shall produce greater volumes by using fewer resources in less time. This concept was founded in Japan, more specifically at Toyota which is one of the bigger car producers in Japan. This concept was meant to save money for the company while increasing the customer satisfaction and was going to be the key solution for Toyota to be able to compete on the market with the large American car manufacturers (Dennis 2002).

3.1.1 Lean – Value Stream Mapping

A value stream is an essential part of Lean Production, the purpose of this method is to offer an overview of all the flows within the production. Since this method displays all the flows from the raw material procurement to the final product it is considered an important part of Lean Production. Value Streams can be conducted on entire companies but also be adapted to certain departments within the companies (Womack & Jones 2002).

Value Stream Mapping in steps:
1. Decide what to analyze
2. Map, overview current condition
3. Analyze current condition
4. Identify wastes
5. Offer solutions

3.1.2 Lean – Kaizen

Kaizen is a Japanese expression for continuous improvements and is one of the more important parts of Lean Production. Continuous improvements mean that there is a constantly ongoing work to develop processes and make them more efficient, this is done with the support and commitment from all affected parties e.g. employees and management. Continuous improvements can be everything from great radical improvements to smaller improvements that evolve processes step-by-step. The main goal with Kaizen is to prevent and eliminate waste that result in unnecessary costs (Dennis 2002).

3.1.3 Lean – The Eight Wastes

By making use of value streams an opportunity to separate value adding and non-value adding activities is created. Since non-value adding activities exclusively result in a cost in the form of time and resources, these activities ought to be reduced as much as possible (Dennis 2002).

Overproduction

Overproduction is one of the greatest forms of waste since it affects further steps in the process and contributes to even more wastes. Overproduction means that a company produces too much and/or too early, this affects the storage costs and lead times in a negative way.
**Wait**
When time is not optimally organized waiting time occurs, this can be the result of numerous reasons e.g. the waiting for material, stoppages in the production or insufficient maintenance. Since time can be directly translated into money it is important to put focus on this area to avoid inefficient time.

**Storage**
It is a waste to be in the possession of a big storage since storing products or material is not a value adding process. Having a large storage means that there is a large capital employed that does not contribute the company at all. Only the simple fact that storage is taking up space that could be potentially used for something more important results in a pure waste. By having a big storage containing products and raw material a company’s flexibility on the market is affected and the company gets a hard time matching its flows to the market.

**Unnecessary movements**
Unnecessary movements by employees that affect health, safety and is time consuming shall be eliminated as much as possible. These movements can be anything from heavy lifts to long walking distances which can potentially affect the employer negatively and not only the employee. By handling the material manually there can also be a potential risk for damaged goods.

**Re-work & defects**
Producing failed products cost both time and money, this is something that needs to be overviewed early in the process and avoided at any cost. If the defect products get delivered to the customer it can also damage the company reputation.

**Overwork**
Today, unnecessary processes are conducted everyday within companies, often the same work can be done using more simple and less complicated tools. This is something that costs money and in some cases time. Planning these processes will ensure a company to avoid overwork when more simple work could perform the task.

**Long transports**
Long and unnecessary transports should be avoided to most possible extent because transportation is not value adding and can also affect the condition of the goods. Long distance transports can be avoided by placing processes closer to each other.

**Unutilized creativity**
In every company with employees there also are skills to be found, a company needs to take advantage of these skills and the creativity of its employees to make sure that they are not missing out on ideas and knowledge.
3.2 Facilities Planning

Facilities' planning is and should be an important part of every company, most often it is the facility that is of most value for a company, and is one of the biggest expenses for a majority of companies. It is important to organize a facility layout properly at an early stage to avoid future logistical problems and difficulties. The most important aspect that a company needs to have in consideration when planning and designing a layout is the material handling, and how costs can be lowered for the material handling by having a well planned facility. Sims (1990) discusses that faulty material handling leads to problems for companies, both economical and logistical problems.

“The best material handling is no handling” (Sims 1990).

Solving a layout problem can be a complicated process, mathematical figures are often used to display how important it is with closeness of departments and material. If only the quantitative method is used and not other qualitative aspects such as safety and aesthetics there is a possibility that the layout fails. To achieve the ultimate layout several factors need to be taken into consideration and not just the most “logical solution” (Kerns 1999). Lumsden (1989) lists three major facility layout methodologies:

- **Functional oriented layout** – Machine and equipment of the same type are grouped and placed near each other. A functional oriented layout can offer a company high flexibility since operations can be moved from one machine to another and still achieve the same results. A layout of this type makes it hard to use any transportation device other than wagons and forklifts; a handling like this contributes to the flexibility but also makes it hard to receive an overview of the material flow.

- **Flow oriented layout** – Machines and operations are gathered in groups to achieve a simple and fast flow of products. The operations are arranged for a specific product which enables a company to easier follow the material flow. This type of layout offers a higher output in the production but also requires more fixed material handling equipment.

- **Product oriented layout** – Contains different combinations of the two layout types mentioned above, and keeps the product in the centre. The operations for a product or a group of products are all carried out in the same area and the purpose is to be able to overview the entire processes.

3.3 Physical work environment

The most common causes for having employees absent from work is due to muscle and joint injuries. This is one of the main issues concerning the work environment and studies show that injuries are caused by monotonous loads to the body. Employees that are absent due to sick-leave result in high costs for companies, not only because the employee receives pay but also because of the disturbance in the production process. “Load” is a word frequently used when describing how hard, heavy and how often a employee has worked. It is necessary for the human body to perform certain movements in order to maintain the body functions, but to
perform a heavy, repetitive movement causes wear on the human body. When the body is exposed to identical movements over a longer period of time the body is a victim of “monotonous repeated load” which can cause pain, temporary injuries or even long term injuries. Heavy temporary lifts or “occasional heavy load” can cause wear or even worse, failure of muscles and joints which would result in a work injury. The best way to maintain muscles and joints vary between individuals, but generally it is preferable to have variety in the work and to have a balance between work and rest. It is important to adjust the work to certain individuals to make sure that they are comfortable with the work tasks and that they can withstand the workload without becoming a victim of an injury (AFS 1998:1).

3.4 Activity Relationship Chart

Activity relationship charts are used frequently in the work of designing layouts. The tool displays how high the importance of closeness is between departments and activities. First, the departments/activities are designated and secondly they are graded in a figure. By using the information received from an activity relationship chart the risk of future logistical difficulties is lowered (Kerns 1999). Figure 1 displays an example of a standard Activity Relationship chart.

The closeness is rated by using letters with different meanings:

- A: Absolutely necessary
- E: Especially important
- I: Important
- O: Ordinary
- U: Unimportant
- X: Undesirable

![Figure 1. Activity Relationship Chart.](image-url)
3.5 Physical Process Map (Spaghetti Map)
A physical process map shows movements of these entities through a process in a simple manner which helps the user to easily visualize, streamline and optimize a process (Wedgwood 2006).

A Physical Process Map is a widely used Lean Sigma tool; it displays physical flows of entities such as products, raw material and information. The tool displays travel distances and patterns. Developing a Physical Process Map is very simple when done right; the procedure begins with deciding what to analyze, which entity to use and to define the start- and end point. After the decisions a drawing of a process or a facility is obtained. Then the different process locations/steps are marked and the steps are connected with lines. The lines should not be straight because it is unreal that physical flows take the “flying path”. When the lines are drawn, calculate the distances with a measuring tool of own choice. When this step is completed, look for non-value adding activities and unnecessary paths and gather data to construct a new layout/map.

3.6 Material Handling
Material handling has for a long time been an underestimated part of the production in a company since it is not a value-adding activity. This is not reason enough to disregard it, material handling is too expensive to ignore. In a normal industrial facility the material handling is accountable for one fourth of the employees, it takes up 55% of the total space in the factory which is more than half of the facility and 87% of all production time. The material handling, when calculated on finished products is estimated to be between 15% and 70% of the total cost for producing it. The goal is to reduce the amount of material handling, to reduce all non value adding movements internally and externally. Reducing the material handling can make the process more efficient but is not a clear solution in the long run, it is necessary for a company to establish a well working material handling system since it can often be the factor that differentiates the company from its competition (Tompkins et al. 2003).

3.6.1 Importance of well designed factory layout
A well designed facility layout with modern handling can generate good results. A layout that is not well thought through can cause congestions, delays and obstruct the production planning. A facility layout with straight simple flows and more free surfaces can offer better flow orientation, increase the capacity and floor surfaces for production, simplify the planning and decrease the handling costs (Lumsden 1989).

3.6.2 Transportation Systems
When concerning transportation systems, most companies will argue that they are using forklifts, pallets and racks because it offers the company flexibility. Solid conveying devices are expensive and not movable which can cause difficulties when re-planning the facility and changing the production greatly. It is hard to argue against the flexible solutions that can adapt to almost anything but the definition of flexibility is hard to explain. Even though it is important to achieve flexibility in companies, Lumsden (1989) argues that it also is necessary to combine the flexible equipment with solid conveying devices.
3.6.3 Transportation Choice

According to Lumsden (1989) the factors that generally affect the choice of transportation are;

**The material-flow direction**
The material flow can vary between different procedures in the production, theoretically there are four defined flows available; the straight-line flow which is characterized by three circumstances; a start and end point, the material transportation is only in occurring in one direction and that the material flow remains consistent using only one route. The divergent/convergent flow which contains group work and thus requires more space. The return flow which allows faulty products to go back into the production process without affecting the actual production and passing opportunity flow which is a straight-line flow with the possibility of skipping production stations for a product that does not require the treatment given on that station.

**The product**
The way that the transportation system ought to be shaped depends on the character of the product, the solution is usually characterized by the main attribute of the product. If there is only one product that needs to be considered when choosing transportation system the process can be simple, if there are several products involved the choice can be harder to make.

**The transport frequency**
Transportation frequency is more about the amount or volume of the transportation system since it is directly connected to those factors. When making analysis on the transport frequency it is important to investigate if the frequency is even, if it varies and if it is a one-time job. If the flow is even and controlled it should not be a problem adapting the transportation system to the flow, if it on the other hand is irregular it can cause difficulties when choosing transportation system. If a company chooses to cover all required transportation when it is on a maximum point, resources will go to waste when the production decreases, if the transportation system is adapted to the company average needs it will not be enough during peak production.

**The mechanization possibilities**
The mechanization used to be directed towards the production, now it is more necessary for companies to mechanize warehouses and transportation devices as well. This is founded in the philosophy that the employed capital should be minimized. Also the on- and offloading process within companies ought to be mechanized to achieve efficiency.

**Technical demands on the transportation device/system**
Some conditions and desires put technical demands on the transportation device/system, these conditions and desires are; reliability, the environmental aspects, maintainability and the resistance to environment (cold, heat, wet etc.). Although, some studies determine that the most important factor to keep in consideration when choosing from transportation devices/systems is the product. This is because the product is the ultimate “customer” of the transportation device and the product factors that affect the choice is the size, weight and shape of it and also how sensitive it is and the condition of it. Other factors that can also affect the transportation choice is the products texture and aggressiveness (Lumsden 1989).
**3.7 Define, Measure, Analyze, Improve, Control (DMAIC)**

DMAIC is a method for improvement used mainly within Six Sigma and can be compared to other approach methods such as Plan, Do, Check, Act (PDCA). The differences are quite big since the PDCA is a method used mostly on less extensive improvement work while DMAIC can be used on a larger scale (George et al 2004). The DMAIC improvement process follows the structure displayed in *Figure 3, DMAIC model and its phases*. To achieve a systematical approach using DMAIC there are certain check points to follow. The check points operate as a support for the user, but it is not always necessary to make use of each point (Magnusson, Kroslid & Bergman, 2003). See *figure 2* that displays the 5 head steps of the DMAIC and explains the DMAIC more closely.

![DMAIC model and its phases](image)

To make the best use of this Six Sigma approach it is necessary and required that the DMAIC contains all previously mentioned steps, in the order that they are mentioned (George et al 2004). The steps are defined below:

<table>
<thead>
<tr>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop prob. Statement</td>
<td>Brainstorm KPIV’s</td>
<td>Micro level process map</td>
<td>Diagnose KPIV performance</td>
<td>Apply mistake proofing principles (if applicable)</td>
</tr>
<tr>
<td>Identify project scope</td>
<td>Develop data collection plan</td>
<td>Benchmark</td>
<td>Establish KPIV performance objectives</td>
<td>Develop control</td>
</tr>
<tr>
<td>Identify customers</td>
<td>Analyze and validate measurement system</td>
<td>Quantify KPIV’s and improvement opportunities</td>
<td>Identify alternative solutions</td>
<td>Metrics (SPC) on KPIV’s</td>
</tr>
<tr>
<td>Develop high level process map</td>
<td>Perform or review FMEA</td>
<td>Root cause analysis</td>
<td>Determine optimal solution</td>
<td>Develop long term MSA plan</td>
</tr>
<tr>
<td>Estimate customer satisfaction</td>
<td>Collect data</td>
<td>Define performance objectives</td>
<td>Update FMEA</td>
<td>Establish or update SOPs</td>
</tr>
<tr>
<td>Identify KPOV Metrics</td>
<td>Establish baseline DPMO/Sigma level</td>
<td>Update project management system</td>
<td>Cost/benefit analysis</td>
<td>Establish or update training plan</td>
</tr>
<tr>
<td>Create project timeline</td>
<td>Identify project objectives</td>
<td>Project champion review</td>
<td>Develop and implement pilot plan</td>
<td>Validate control plan by process owner</td>
</tr>
<tr>
<td>Update project management system</td>
<td>Update project management system</td>
<td>Validate improvements</td>
<td>Establish BB audit plan with timeline</td>
<td></td>
</tr>
<tr>
<td>Project champion review</td>
<td>Project champion review</td>
<td>Update project management system</td>
<td>Update project management system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Figure 2, DMAIC (own figure).*
Define
Define the process and the project objective and calculate the profitability of it. To make the decision to start the project it is necessary that calculations display that it will bring profits. In this step it is important to have gathered knowledge about the process being improved and to have an overview of the actual situation.

Measure
Gather measurable data to establish a baseline and data for further analysis. It is important to establish a baseline to be able to see how the situation looked before the improvements. To be able to gather proper data it is necessary to have knowledge about the factors that affect the project outcome in advance.

Analyze
Perform analysis on data to detect connections between different factors. The goal being aimed for in this step is to investigate which factors affect each other and what the root cause for this impact is. When the factors that affect the result have been identified, and the way that they affect the result is established it becomes simpler to lead the process in the right direction.

Improve
Improve the process in hand, make follow-ups on the changes and verify.

Control
Through follow-ups and control ensure that the changes and improvements are sustained.

3.8 Plan, Do, Check, Act (PDCA)

PDCA is a management method in four steps used in different kind of businesses to improve processes, products and to sustain the improvement continually. PDCA is short for Plan, Do, Check and Act; these abbreviations are defined below and displayed in figure 3 (Bose 2010).

PDCA Steps
Before launching a project it is necessary to establish a plan, identify goals, set up tasks and milestones for it to be successful. When developing the plan it is important to document the process because the data from the plans can be helpful later in the process when the effectiveness of the project is measured. When the plan is established it is time to carry out the planned project. In the “do” phase it is crucial to document any unexpected observations and problems to compare with the initial plan. After the “do” step is completed and all the data is gathered it is time to analyze the data in the “check” step which works as an inspection. It is important to understand the analyzed data and convert it into real usable information. This step is reoccurring in chosen periods, for example annually or quarterly. The last step of the PDCA is the “act” step, in this step the differences between the planned results and the actual situation are discovered and corrective or preventive actions are requested. Further analysis is made on the differences to find the root cause that differentiates the planned outcome from the actual outcome. What kind of changes and where to make them to reach an improvement of the process/product is determined. Implementation and standardization of the solution on the area is conducted. After the “act” step the PDCA then continues back to the “plan” step where the procedure is repeated again to continue the cycle (Bose 2010).
3.9 Cause and Effect Diagram (Fishbone Diagram)

Cause and effect diagrams is a tool used to narrow down a problem into different causes and is commonly known as a Fishbone diagram because of the way it looks. The tool provides a structure containing different categories such as people, equipment, process, material, technology and environment, although the diagram can be altered to fit the problem in need of a solution. Under these categories the user narrows down the problems to different factors causing them, the causes can be several and the amount is optional. To construct a diagram of this sort it is important to have knowledge of the area that is highlighted and to conduct a type of brainstorming to discover as many causes as possible (Goldsby & Martichenko, 2005). See figure 4 for an example of a standard Cause and effect diagram.
3.10 Maintenance

Maintenance is one of the most important factors when discussing life length of equipment and safety of staff. Maintenance work contains a set of tasks that are different depending on the maintenance type. When conducting maintenance it is important to have a set of goals to strive for, such as to increase availability, safety and quality. Whichever maintenance strategy that is used (see below) it is important that it is documented so that the procedures can be improved in a later stage (Johansson 1997).

Maintenance work contains a set of tasks that are different depending on the maintenance type

Corrective Maintenance
Corrective Maintenance is a method which excludes any kind of maintenance before the equipment suffers a failure and can be compared to the “run to failure” concept. By only performing corrective maintenance a company can, under certain circumstances, reduce costs for staff since there is no need for inspections or any technical work whatsoever during the time that the equipment is functioning. To maintain a corrective maintenance strategy within a company or on a certain piece of equipment it is important that the “usual occurring errors” are understood by the staff performing it and also, it is important to have the necessary spare parts in stock. This strategy can pay off if it is handled correctly but may cost a company much time if the necessary spare part is not in stock (Sullivan et al. 2002).

Preventive Maintenance
Preventive maintenance is a method which works with the objective to avoid machine and equipment breakdowns by performing maintenance on a scheduled basis. This scheduled maintenance can prevent failures from occurring and because of this it often increases the availability of the equipment. This type of maintenance can reduce costs for companies since it extends the life of the equipment and prevents unplanned downtime (Sullivan et al. 2002).

Predictive Maintenance
Predictive Maintenance is similar to Preventive Maintenance in a way, the maintenance tasks are performed before equipment fails. When conducting Predictive Maintenance a company performs several scheduled measurings which can include oil inspections or bearing vibration measurements. The information retrieved from the measurements is used as decision support for maintenance scheduling. For example; instead of changing a bearing in a machine on a certain time basis, the bearing condition is analyzed to see if it is degrading or if it is functioning properly and it is only changed if necessary (Sullivan et al. 2002).

3.11 Multi Criteria Decision Making (MCDM)

Multi Criteria Decision Making or MCDM short is a method or an approach that functions as decision support. The MCDM requires several types of data from the researcher and is often used to choose among alternatives. The researcher must provide criterions and values to the MCDM, depending on the case the criterions can vary. For example, when purchasing a house the important criterions could be size, layout, appearance, location and price. These criterions are then given a value in form of a quantitative number which are eventually used to find the best alternative (Triantaphyllou et al. 1997).
3.12 Cost Benefit Analysis (CBA) & Cost Effectiveness Analysis (CEA)

Cost Benefit Analysis
CBA is an approach used to weigh and compare benefits of a project or a decision with the costs for it. CBA is often used to make a decision of whether the project is a good investment or not, the analysis can also be used further like a basis when planning new projects. The data that is used in a CBA is expressed in monetary figures which are appropriate for producing companies but can be ineffective if the results of a project are not only calculated in money (Boardman et al. 2006).

Cost Effectiveness Analysis
CEA is similar to CBA but different in the matter that not only monetary values are necessary, the outcomes or effects from a CEA can be expressed in various ways for example working environment or different improvements that do not necessarily affect the economics. When performing a CEA the human factor is involved more than when performing a CBA since the results are not in monetary values on both sides of the chart, The CEA user in this case needs to evaluate the value of certain effects to make a decision (Wolfe 1973).
4. Model

This chapter will provide the reader with an explanation of the various steps in the model and the model displayed as a figure.

4.1 Model development – Fundamental idea

The purpose of the developed model is to offer a simple way to review the efficiency of a company and to develop alternatives for improvements for the same company. It will be designed in a way that it fits a wide area of companies and it includes the possibility for great improvements but can also be limited to minor improvements for companies with restrictions such as fixed layouts. The steps that are included in the model are inspired by the existing PDCA and DMAIC models, but modified to fit companies in this size range. It will be generalized so that it can be adapted to various kinds of companies. The model will also be designed with the purpose of being simple to understand and each step is illustrated in a way that brings understanding to future potential users. It will contain different approaches such as the Activity Relationship Chart that is designed to highlight the importance of closeness of objects which is well applicable on an industrial company. The Activity Relationship Chart will show what objects need to be close to each other and what objects are not necessary to be located closely; this information is helpful in the planning process before constructing a facility layout. The Cause and Effect Diagram is also a part of the model and it is helpful when identifying inefficiencies and the root causes for why they are occurring. The model is inspired by the PDCA and the DMAIC and just as those it is also an ongoing process, this due to the fact that perfection is considered impossible to reach and therefore improvements can be made continuously.

4.1.1 Detailed model development

Step 1. Purpose

In the first step of the model it is important to establish the main purposes of the facility and the material handling process. This is done to ensure that the correct objectives are set, these objectives may vary between companies, but standard objectives that could be used as templates are important to start from. Such could be to simplify the material handling process, shorten the material handling distances through a more efficient facility, eliminate or minimize unnecessary movements and create more space where it is necessary.

When the purpose is defined and established, a plan is developed to provide assistance in the following steps, the plan in this stage presents the wanted goals for the process, it contains information about what data is necessary to gather, where and how to find it and what it will be used for in a later stage. The plan is thoroughly documented to be as simple as possible to understand since it will be re-used through all steps and is necessary for comparison when a result is reached. In order to continue to the next step it is necessary to gather information concerning the current situation. By having a well thought out plan the procedures in the next step become simpler, it becomes easier to gather the relevant data when following a plan and knowing which questions to ask and what to observe. *See step 1 in figure 5*

Step 2. Data gathering

In step 2 data that concerns the facility and the material handling is important to gather, preferably over a decided period of time. By making observations and conducting interviews, qualitative information concerning the material handling can be received; this will also provide the researcher with an understanding of the situation. It is important to investigate the current situation to receive an understanding of why it looks the way it looks and to see what restrictions exist within the company. It is important that the subjects interviewed are not only
management staff but also the employees in the production since they might have very useful information and proposals for improvement. Depending on the case company, it can also be important to gather quantitative information that can be compared to the final result. When the observations, interviews and calculations are done it is necessary to document the results in detail to have something to compare with the final result. The information gathered in this step will provide data for the analysis in step 3 and allow the using of certain tools. See step 2 in figure 5

**Step 3. Analyze**

Step 3 will contain the previously gathered information, and the information will be used to describe the existing situation. In this step improvement tools such as the Activity Relationship Charts are used to get a view of the importance of closeness within a company’s walls. The analysis will show connections between different factors and can show how these factors affect one and other. By having an understanding of how factors affect each other and the results negatively, simplifies the pursuit for the root cause. By analyzing the observations and other information gathered, the causes for errors can be found. A supporting tool in this phase is the Cause and Effect Diagram (Fishbone diagram) that highlights the errors and the causes of them. By highlighting the errors and the causes of them it is easy to rewind the error back to its root cause, by having the root cause visible a company can in an easier way focus resources towards creating solutions for specific problems. A list of existing problems found by using the Cause and Effect Diagram and the Activity Relationship Chart is created in this step, this list is constructed to provide an overview of the errors. By creating a problem-list, the development of alternatives to solve the problems in step 4 is made possible. See step 3 in figure 5

**Step 4. Develop**

In step 4 alternatives will be presented for the improvement of the current situation. When considering alternatives it is important to have the difficulties of the actions that are included in the alternatives in mind, such as:

- Can the budget support this change?
- Will the change be profitable within a wanted period of time?
- Will the current transportation devices be applicable after the change?
- Is it possible to change the facility this much?
- Is there enough space in the facility to support the changes?

The improvement alternatives that are developed ought to be constructed with the respect of the information gathered in the previous steps. A factor that is necessary to consider when developing improvements is the maintenance, since maintenance can affect the outcome of the improvements. While developing it is also important to document the ideas and alternatives to have the ability to improve the suggestions in a later stage through brainstorming sessions. By following this template the best possible improvement alternatives can be produced. When the improvement alternatives have been developed and documented the procedure continues to the implementation in step 5. See step 4 in figure 5
**Step 5. Implement**

In step 5 it is important to gather the responsible and managing staff to make a decision. When making the decision it is important to make a detailed list of pros and cons of each alternative that contains information such as the cost for specific alternative, the improvement range and the time consumption. To achieve a numerical value of the improvements a MCDM can be used, by using the score from the MCDM and conducting a Cost Effectiveness Analysis a decision can be made. The improvements that the chosen alternatives will provide are important to compare to the existing conditions and the quantitative information gathered. When this is completed an estimation of the benefits is calculated and the best alternative/alternatives are implemented. Step 5 is the last step in the model, but it is important to make follow-ups and repeat the steps again in pursuit of more inefficiency causes. Since conditions are changing within companies daily, it is important to stay in front. See step 5 in figure 5.

![Figure 5, the developed model.](image)
5. Empirical Findings

In this portion of the project you can find the information about a case company. Data concerning the facility and the material handling of the case company will be presented. The data that is presented in this chapter is gathered through observations, interviews and discussions.

5.1 Company Description & Production

Hilding Anders is one of the leading actors on the bed and mattress market, since the company was founded in 1939 in Bjärnum, Skåne it has grown to become one of the world’s leading bed manufacturers. At this moment the Hilding Anders group contains more than 30 producing companies spread out on more than 20 countries and two continents. The group is owned by the british venture capital firms Arle Capital Partners and MezzVest, it is also partially owned by Hilding Anders management. In total, the group produces approximately 8 million beds and mattresses per year and the demand is increasing. The group has grown rapidly last 10 years; this is mostly because a large number of companies have been recruited. Only in the last ten years the Hilding Anders group has doubled their turnover. In total Hilding Anders has 6300 employees spread out over Europe and Asia. The case company for this paper is Scapa Bedding AB which is a part of Hilding Anders group and located in Rydaholm, Sweden. Scapa Bedding AB have just below 100 employees and their turnover is around 250 million SEK. At this factory Hilding Anders produce approximately 250 000 beds per year to customers such as IKEA and JYSK.

Within the Scapa Bedding facility there are several production stations, the largest one is located in the C-hall and it produces regular beds and mattresses. Within the C-hall there is also a production line that manufactures larger beds; this line is connected to the regular bed production lines since it uses the same conveyor belt to move the finished products to the plastic wrapping machine. In the B-hall the company produces the luxury bed models within the “VIP-department”. The manufacturing method is very similar within all production stations; the only differentiator is size and the material quality. The manufacturing of a bed starts in the sewing department where bed covers are sewn using wadding and different materials. The next step of the bed manufacturing process within Scapa Bedding is the assembly where the sewn bed covers, cores, frames and latex are put together. After the assembly the finished bed is wrapped in plastic and packaged together with the appropriate legs.

5.2 Facility Layout

Scapa Bedding has a 24 000 m² facility located in the small town of Rydaholm, near the 27 highway. The facility is divided into five different halls, three which contain production, production storage and WIP(work in progress), the remaining two operate like warehouses. The three halls chosen for this work are the A, B and C-hall which are all used for production. For size and usability information see table 2.
<table>
<thead>
<tr>
<th>Hall</th>
<th>Used for</th>
<th>Size (Approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Storage of wadding, and sewing area</td>
<td>80x50m</td>
</tr>
<tr>
<td>B</td>
<td>Storage of polyether, latex, VIP details, and VIP bed production</td>
<td>65x40m + 45x25m</td>
</tr>
<tr>
<td>C</td>
<td>Storage of various bed products and bed production of different sizes and models.</td>
<td>100x55m</td>
</tr>
</tbody>
</table>

*Table 2, hall size table.*

The halls concerning this thesis are 13 000 m² large in total and contain three different production areas; regular bed production/assembly, VIP bed production where the specially ordered beds are manufactured and a sewing area. Each of the halls has separate receiving dispatch areas where material is received. There are several small offices spread out in the facility, but the main production office is located in a corner of the C-hall. The storage areas within the A, B and C hall have the purpose to contain material for the production lines and are located around the production areas. The facility consists of two types of production layouts. Within the facility one can find both the functional oriented layout and the flow oriented layout. The way that the bed production lines are placed can be described as a functional oriented layout, because they perform the same and are placed next to each other. The facility is in a way also a product oriented layout since it contains a complete manufacturing system.

The plant has a space problem and lack of forklift passages. The staff moves material over a long distance frequently. The space problem can also be seen at the dispatches that are not large enough to be able to receive all the incoming material. Instead two other dispatches receive the material which is driven across the facility to where it is stored. The production stations are also lacking space in the surroundings and cannot be in the possession of a buffer stock. The surrounding shelves store much of the material that is used in the production, but as much is stored in other areas of the company. The production stations have to stop operating at times when the staff is unable to retrieve the material from the other areas in time. Due to the lack of space the forklifts cannot pass the production area, which prevents the material retrieving being done by forklift. See figure 6 and appendix A for the current layout.
Scapa Bedding AB has a facility layout situation that is the side effect of expanding for several years. Over the years new machines were bought, new products were developed, new production stations opened and the company had to sacrifice space to be able to satisfy the customer needs in the market. In other words, the company grew but the facility layout remained the same.

5.3 Transportation & material handling within the facility

Within Scapa Beddings 24 000 m² facility most material and products are transported by forklift since the layout is adapted with planned forklift transportation routes. These forklifts run on electricity which is of high importance since they are only used inside the facility where combustion engines would not please the work environment. The lighter material, such as the polyether, is transported by trolley, which are manually pushed by so called service personnel. The main purpose with these is to deliver frequently used material in a fast manner to the producing stations that lack surrounding space.

Material handling is a wide area with many involved actors and a big variety of activities. Within Scapa Bedding material handling is of great importance since it is an activity that costs both time and money. Within the plant there are several employees which are assigned only to transport material through the facility. When goods arrive to the plant it is temporarily stored on the material square next to the arriving dispatch to be able to off load the trucks faster. When all goods are off loaded it is transported to either the warehouse or a storage shelf within some of the production halls, depending on the goods. There is no path for the forklift drivers through the main production hall (hall-C), instead they pass through the surrounding halls and production areas to get to the other side of the facility.
5.4 Material handling equipment

The equipment that is currently used offers the company flexibility in a wide range of areas. Most of the material handling is carried out by using electric reach forklifts which fits the company well and has the capability to transport material back and forward in a fast manner. When maintaining the forklifts the company uses the corrective maintenance strategy, which means that they run the forklifts until the battery is incapable of working for eight hours straight. In that case the company has spare batteries which are easily changed. A company that uses forklifts as the main transport system can also be very flexible since the forklifts can be used however the production develops, unlike a conveyor system that is not movable and cannot adapt to changes in the same way. Since the plant has a functional oriented layout, with production lines placed next to each other, Scapa Bedding have a roller conveyor system in front of these lines, which moves the material through a plastic wrapping machine. The conveyor solution works in this situation because it can combine several lines and using forklifts for these operations would just be an increase of work. However the conveyor belt is not easy to move and could become an issue when the production develops and changes. Big amounts of light material, mostly polyether is transported throughout the plant and delivered to the production lines, this transportation is performed with trolleys that are also equally flexible as the forklifts but lack the speed and simplicty of the electric driven forklifts. The trolleys are poorly maintained which causes the wheels to lock and the steering and pushing of the trolley becomes difficult, however the trolleys have the possibility to be lifted by forklifts which are used at the dispatch to offload polyether from trucks when they are available. For data concerning the transportation devices see table 3.

<table>
<thead>
<tr>
<th>Transportation Device</th>
<th>Capacity</th>
<th>Propellant</th>
<th>Products moved</th>
<th>Area of usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forklift</td>
<td>1.1 tons</td>
<td>Electricity</td>
<td>All</td>
<td>Entire facility</td>
</tr>
<tr>
<td>Roller conveyor</td>
<td>Unknown</td>
<td>Electricity</td>
<td>Finished beds</td>
<td>C-Hall</td>
</tr>
<tr>
<td>Transportation trolley</td>
<td>Lighter material</td>
<td>Manual</td>
<td>Polyether, wadding</td>
<td>B- &amp; C-hall</td>
</tr>
</tbody>
</table>

Table 3, transportation device table.

5.5 Transportation routines

The routines occur in a high frequency and are quite inefficient. Because of the layout problems and the lack of set routines the material handling staff passes big distances on a daily bases. Since the routines are not standardized and there is a big variety of movements occurring within the facility it is hard to track who does what and when it is done which makes it hard for the company to track and improve the movements. Some of the routines that were tracked were long and several forklifts went in the same direction or the opposite and returned empty. Some routines were tracked, the distances and purposes can be seen in appendix G.
6. Analysis – Model application

This chapter will present the analysis of the gathered data. The developed model will be trialed and evaluated.

6.1 Step 1- Purpose

The purpose is to achieve a higher efficiency regarding the material handling process through removing non-value adding activities. Since material handling in itself is considered a non-value adding activity, the purpose is to decrease the amount of material handling and simplify the actual handling of the material. To achieve this it is important to locate the most serious issues affecting the material handling together with the smaller issues that prevent the efficiency from increasing. This is done by measuring the travel distances within the facility and observing the driving patterns. To optimize the situation an overview of the occurring non-value adding activities and their effect on the production is created. When the present situation is described a plan can be developed to simplify the further in the process. The plan contains information about what data that is necessary and where and how to gather it (see table 4). The plan is thoroughly documented to be as simple as possible to understand since it will be re-used through all steps and is necessary for comparison when a result is reached.

<table>
<thead>
<tr>
<th>Data gathering plan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What</strong></td>
</tr>
<tr>
<td>Material Handling(forklifts)</td>
</tr>
<tr>
<td>Material Handling(forklifts)</td>
</tr>
<tr>
<td>Production</td>
</tr>
<tr>
<td>Material Handling/manual</td>
</tr>
<tr>
<td>Material Handling(all)</td>
</tr>
<tr>
<td>Equipment</td>
</tr>
<tr>
<td>Distances</td>
</tr>
<tr>
<td>Inefficiencies in total</td>
</tr>
</tbody>
</table>

*Table 4, data gathering plan.*

6.2 Step 2- Data gathering

In this step the developed plan from step one is studied and the plan is set in motion. The data collecting procedure is performed through various measurements, interviews and other types of observations. By gathering data that has the ability to be measured a type of “baseline” can be established and used for further analysis, this baseline can be used to display the situation before any changes were done to it. It is important to understand what factors that affect the project outcome in advance to be able to retrieve usable data. By gathering the relevant data an understanding is developed and the information can be used in the following steps. All of the gathered data, the expected information and the deviations are documented thoroughly so that it can be used properly further in the process.

By searching for the non-value adding activities highlighted in the Lean theory regarding the eight wasteful areas, data concerning the inefficiencies could be gathered. The inefficiencies concerning the case company can be seen below;
**Long transports**

The waste concerning the off-loading of material is associated with the interim storage of goods. Because there is not enough off-loading space at one of the sites, the goods get offloaded at the opposite side of the building. This results in long, unnecessary transportation on a daily bases and could be avoided by rearranging the off-loading sites to allow more space for interim storage. Drawing of the facility and the off-loading sites marked can be seen in Appendix A. The placement of shelves and the way they are adapted to material sizes also contribute to waste. Material is often stored in shelves far away from their area of usage and requires the forklift drivers and the service personnel to frequently pass long distances in order to fetch material (see appendix B for example). In the example below (see figure 7) the shelf has the capacity to take twice as much material than it is at the moment because of the poor adaptability.

![Figure 7. example of the current use of shelves.](image)

**Overwork**

Because a very wide range of material sizes and weights are used at Scapa Bedding it is important to consider what type of transportation equipment to use for each material type. It is necessary to avoid using equipment that is more complicated, heavier and takes more time to use. For example it is unnecessary to use a forklift to deliver bedcovers to the production stations because they are of low weight and are located roughly 20 meters away.

**Unnecessary movements**

Heavy and uncomfortable procedures such as the ones performed by the service staff when fetching material will eventually affect the productivity and the quality. By offering the service staff forklift possibilities the unnecessary body movements can be avoided, which in the long run will increase the efficiency of the service staff and lower the risks for body injuries.

**Wait**

The waste concerning waiting is associated with the time that is gone to waste while waiting for the service personnel to resupply the production stations. The requirement for material is extensive, but because of the lack of space in the area around the production stations not much material can be stationed there. The service personnel move all material manually or with the help of a wagon on wheels, this forces them to wait for available forklift drivers when material from shelves needs to be extracted. Trucks with polyether arrive at different times every day which force the service personnel to leave the “feeding” work and aid with the off loading; this affects the production stations which have to be stopped when the material runs out.
**Unutilized creativity**

Within Scapa Bedding this can be directed to the service personnel that are willing to take a forklift license to be able to work faster and easier. Scapa Bedding could achieve a higher productivity and eliminate a lot of the waiting time by doing so. Also there is unknown creativity within the forklift team, personnel within this team sit on information and ideas that could be used to the benefit of the company.

### 6.3 Step 3 – Analyze

Using the knowledge perceived in the previous step it enables the creation of a Relationship Diagram that provides the necessary data concerning the location of the materials and areas. This method displays and highlights what areas and materials have the necessity to be metrically near each other. For this trial there will be two Relationship diagrams constructed, one that displays the importance of the closeness between production areas and material, a second diagram that displays the importance of closeness between loading bays and material. These two were chosen to be constructed because of the obvious non-value adding activities concerning these areas which were discovered through the observations. These two display the optimal facility situation and how the company would prefer the distances to be between departments/material. The performed analysis will be of help when producing improvement alternatives in the next step of the model.

The Relationship Diagram constructed for the closeness of production areas and material clearly showed that the polyether, bed covers, bed frames and bed cores were especially important to be located near the regular bed production stations (see figure 8). Also the wadding was absolutely necessary to have close to the sewing department since it is a frequently used material.

![Figure 8, Activity Relationship Chart (departments).](image-url)
The Relationship Diagram for closeness between loading bays and material highlighted the importance of having the bed cores close to both the offloading bays at the B-hall and the C-hall and that it was absolutely necessary to have the wadding located closely to the offloading bay at the A-hall (See figure 9).

Figure 9, Activity Relationship Chart (loading bays).

Since the model not only concerns the facility layout and the issues concerning the facilities planning it will also include a Cause and Effect Diagram (see figure 10) which will display the inefficiency issues that have been observed in the previous step. This diagram will show the areas of inefficiency and a breakdown that displays the causes for the inefficiency.

Figure 10, Cause and Effect Diagram (inefficiencies).
The categories that are used in this Cause and effect diagram are:

**Facility**
One of the categories in the diagram was named “facility” and is concerning the excessive material handling that is occurring because of the long and unnecessary transportation routes and unorganized loading bays. This is an issue because there is a lack of space surrounding the loading bays, and there is also a lack of space in the production area which prevents the forklift drivers to pass through it. Instead the drivers have to make detours around the entire production hall to get access to the rest of the facility. Material locations are as well not planned to fit the material handling in an optimum way which causes longer distance tours than necessary and only contributes with wasteful activities.

**Equipment & Stoppages**
The equipment used for transporting material within the facility is often outdated and is not as efficient as it could be. The forklifts are mainly well working except for a couple of forklifts that might need replacement because of their age and condition. The main concern regarding this area is the equipment that is used by the service staff that provides the production stations with materials. At the moment the material is transported using a trolley (in this case a wooden core with wheels), the providing of material takes more time and causes wear on the staff conducting the work. Because the material arrives on such trolleys, the service staff often off-loads the trucks manually by pushing the material filled trolleys even though there is a possibility for a forklift to lift the entire trolley. Because all of these procedures are time consuming and inefficient they can be the cause of a stoppage in a production line because they lack the material to continue producing. The material (polyether) is stacked on the trolleys and the stacks can vary in height, the stacks height often exceeds the height of the responsible staff. In cases where the stacks are too high, a wooden stick is used to extract a polyether sheet from the top of the stack, even though polyether is a light material this can be a challenge for the staff and can in the long run result in work injuries. Since some of the trolleys are in a poor condition, with wheels locking due to insufficient maintenance, it also becomes a challenge to push the light material across the facility. Because the service staff have no forklift licenses and no forklifts available they have to call for help from the forklift operators which have their own work and are busy at moments, even if they are able to aid the service staff, resources are removed from the forklift crew. This is often something that causes waiting time when the service staff is unable to extract a certain material from high shelves and is obligated to wait for a forklift driver. The core problem concerning this area is the lack of space, especially surrounding the production lines which causes stress to the service staff and often causes stoppages when they are not able to deliver material in time.

**Routines**
At the moment there are no set routines to follow, instead the drivers are divided in zones and have responsibility for several activities each. By over viewing these activities, several routes could be combined to save time and avoid twice as many trips back and forth. The off-loading procedure at the B-hall loading bay is confusing and often the responsible staff is not present when the truck arrives, this tears other forklift operators from their actual work and forces them to attend the off-loading. There is no obvious leader within the forklift staff and the contact between the operators is in need of improvement. The fact that the service staff lack forklift drivers permits is also a negative aspect since they have to do the off-loading manually and they also deliver material to the production lines manually, since they are not
able to extract all material from all shelves without a forklift they often have to wait for the forklift drivers.

**Discovered inefficiencies**

The table of discovered inefficiencies will provide assistance when developing improvement alternatives in the next step. One of the main objectives of the improvement alternatives must be to provide solutions for the inefficiencies stated in the table below (see table 5).

**Table 5, discovered inefficiencies.**

<table>
<thead>
<tr>
<th>Discovered inefficiencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long transportation distances – from loading bays to material locations</td>
</tr>
<tr>
<td>Material locations and shelves are not well organized</td>
</tr>
<tr>
<td>Unsynchronized routines</td>
</tr>
<tr>
<td>Lack of education/permits – material handling staff</td>
</tr>
<tr>
<td>Lack of appropriate equipment – material handling staff</td>
</tr>
<tr>
<td>Lack of forklift passages</td>
</tr>
<tr>
<td>Lack of space surrounding production stations</td>
</tr>
<tr>
<td>Lack of space at loading bays</td>
</tr>
<tr>
<td>Lack of management - material handling staff</td>
</tr>
<tr>
<td>Lack of communication devices – material handling staff</td>
</tr>
<tr>
<td>Lack of capacity due to facility layout</td>
</tr>
<tr>
<td>Lack of space – production stations</td>
</tr>
<tr>
<td>Lack of space to expand business</td>
</tr>
</tbody>
</table>

**6.4 Step 4 – Develop**

The alternatives have been developed to offer the company several options and have been divided in a list from low cost to high cost for implementation. These alternatives were chosen since they were the most logical ones after the use of Relationship diagrams and Fishbone diagrams. By making sure that the alternatives cover all the discovered issues it will simplify the choosing process for the company and enables a cost-effectiveness analysis to be conducted. The analysis will in this case not include monetary values; instead the costs will be assessed in three steps which are high, medium and low.

The Activity Relationship diagrams clearly showed that different types of material needed to be located close to production stations and off-loading bays, this information and the data extracted from the Cause and effect diagram concerning the facility was a good foundation for the construction of a new facility layout. By having the knowledge of what objects and areas have the need of closeness the risk factor when producing a new, improved layout is decreased. When producing a new facility layout various inefficiency causes from the Cause and Effect Diagram will be considered to achieve a layout that could simplify several of the procedures mentioned.

With the information gathered in previous steps, improvement alternatives have been created. They are placed separately in a list below (see “list of alternatives”) but can be combined if necessary.
List of alternatives:

*Alternative 0*
Alternative 0 is to not make any changes to the work habits or any changes to the facility layout. This is the simplest alternative and has no direct cost, though it might be expensive over time. By not making changes there is a risk that the same bad working habits will continue and the company will not have an efficient production and material handling in the future.

*Alternative 1*
Alternative 1 is to overlook the routines and highlight the minor inefficiency causes that occur at the moment. By studying the routines and the inefficiency patterns the company can focus on synchronizing the routines so that no unnecessary material handling is occurring. By highlighting the minor inefficiency causes and making slight modifications the company can save time and resources that could be used for other purposes.

Examples of possible routine changes and modifications:

- Synchronizing the travel patterns by studying the distances traveled, constructing a Physical Process Map the unnecessary and colliding patterns can be dealt with. This will prevent forklift operators to travel long distances when it is not needed, instead they can be divided in zones and have the responsibility for their area. Establish a leader within the forklift team that will overview the activities, distribute work and continuously strive for improving the routines.

- Changing the transportation device for the service staff and provide them with a reach-forklift (see appendix F) will increase their capacity and also allow the higher shelves that stand empty at the moment (due to their height) to be used and increase the storage of material in the production hall. The forklifts would also be helpful when offloading polyether trucks in the D-hall so that the forklift drivers do not have to leave their actual work to attend the polyether offloading. The forklift provided to the staff is similar to the existing forklifts and uses the same type of battery to simplify the maintenance tasks. By enabling this equipment to the service staff they save time, avoid waiting time when in need of help and of equal importance they save their health since the manual work is a big strain on them.

- Improve the communication between the forklift drivers themselves and between the forklift drivers and the service staff. By providing sufficient communications equipment, for example some intercom system in the shape of a headset so that it can work in loud environments and doesn’t require the use of hands to operate.

- Modification of shelves within the facility. By setting a routine to adapt the shelves to the necessary height for the purpose in question the shelves capacity can be increased which will result in less traveled distances for retrieving material.
Alternative 2
Alternative 2 is to modify the entire facility layout and focusing mostly on the C-hall where the modifications would offer the most. By moving most of the production units to the C-hall and rearranging the current production lines the company can create space around the production lines and the shelves in the same area. This will enable the forklifts to get access to the production lines and speed up the material delivery from the stock to the production lines and remove the need of manual trolley transportation that is necessary at the moment because of the lack of space. This solution will also enable every production line easier access to the plastic wrapping machine and simplify the packaging process. The change will also provide more space in the B-hall which is important and necessary for the off-loading since much of the goods that belong in the B-hall today is delivered through the C-hall loading bay. The corresponding changes made in alternative one are applied in this alternative as well (see appendix C for the new facility layout).

Alternative 3
Alternative 3 is considered a high cost alternative because it requires that changes are made to the facility structure, this alternative will provide the company with more space in the B-hall which would simplify the off-loading process greatly and save time and strength for both the forklift drivers and the service staff. The change would add approximately 250 SQM inside the B-hall (see appendix E) which will be used as an interim storage for the arriving goods, and the 250 SQM change will be sufficient for the purpose.
Changes in detail:

- More space in the B-hall loading bay.
- More space for shelves in the B-hall – less travels
- Space added in the production area of the B-hall
- High frequency material moved closer to production lines.

6.5 Step 5 – Implement
By reviewing the improvement alternatives and comparing them with the cost/effort of implementation the best alternatives can be chosen (see figure 11). Important factors to consider in this step are the time and resource savings, and the time and resources that are necessary to implement these changes. When the necessary information is gathered a group brainstorming is used to discuss the alternatives further and to come to a decision of which or what alternatives are to be implemented.

Figure 11, decision support figure.
When evaluating improvement alternatives it is important to consider what the changes will affect. The present inefficiencies are presented in a MCDM-list, which can be compared to the alternatives (See table 6). The weight data in the MCDM-list was retrieved through discussions and brainstorming within the company. The value of each alternative and how much it offers were estimated by the author.

<table>
<thead>
<tr>
<th>weight</th>
<th>Criteria</th>
<th>Alt.0</th>
<th>Alt.1</th>
<th>Alt.2</th>
<th>Alt.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Shorten transportation routes – load. bay/material locations</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Material locations &amp; shelves – improvement of capacity</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Synchronize routes/routes –</td>
<td>7</td>
<td>10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Education/permits – material handling staff</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Appropriate equipment – material handling staff</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Forklift passages</td>
<td>0</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Space surrounding production stations</td>
<td>0</td>
<td>10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Space - loading bays</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Management for the forklift drivers</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Communication device- material handling staff</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Facility layout – capacity</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>buffer stock – avoiding stoppages</td>
<td>0</td>
<td>10</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Possibility of expanding business, expand facility.</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Total score</td>
<td>0</td>
<td>199</td>
<td>459</td>
<td>339</td>
<td></td>
</tr>
</tbody>
</table>

Table 6, list of improvements in form of a MCDM.

When choosing an appropriate alternative for improvement, different factors have to be reviewed. In this case the relevant factors are the time savings, distance savings, area released, work environment and the cost. The implementation possibility and the cost information were retrieved from discussions with staff within the case company, to make a decision the estimated costs for the implementation are compared to the score obtained in the MCDM. See table 7, which displays a list of estimated costs for implementation tasks.

### Significant cost factors for alternatives

<table>
<thead>
<tr>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human resources</td>
<td>Human resources</td>
<td>Human resources</td>
</tr>
<tr>
<td>Forklift &amp; battery (maintenance) purchase</td>
<td>Moving equipment</td>
<td>Material</td>
</tr>
<tr>
<td>Communication device</td>
<td>Remodeling electricity</td>
<td>Straighten the ground</td>
</tr>
<tr>
<td>Forklift &amp; battery (maintenance) purchase</td>
<td>Build foundation</td>
<td></td>
</tr>
<tr>
<td>Communication device</td>
<td>Roof and walls</td>
<td></td>
</tr>
<tr>
<td>1 week estimated production stop</td>
<td>Remodeling electricity</td>
<td></td>
</tr>
<tr>
<td>4 week estimated production stop</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion:** low cost

**Conclusion:** medium cost

**Conclusion:** high cost

Table 7, Significant cost factors.
Alternative 0 is the current situation and must be considered as an alternative. Alternative one is a low cost alternative and is rather simple to implement but does not offer large distance- and time savings. Alternative two offers high distance- and time savings and also releases area and improves the work environment. Alternative three has several advantages, mostly regarding the space, but has a high cost and a low implementation possibility since the company is trying to avoid changes to the facility structure. Due to this, it is excluded as a candidate. The alternative that offers most is alternative two because it improves the situation the most and is a realistic suggestion.

When the appropriate alternative is chosen the implementation tasks are defined to offer more clarity in the matter. The tasks are divided and handed to the responsible staff so that the work for improving the efficiency can begin. When the implementation tasks are completed and the changes have been done the situation is observed over time to be able to retrieve data. The retrieved information is compared to the initial goal of the project to verify if it is reached or if there is something missing. The follow ups are done continuously to make sure that the new processes are being conducted properly so that new inefficiencies cannot thrive.
7. Results

This chapter will show the results of the developed model.

7.1 Model Evaluation

The model was trailed with data gathered in the case company and performed well in the testing. The data was analyzed and it offered guidance to develop three relevant improvement suggestions, all based on the information gathered in earlier steps of it. The main purpose of the model was to develop it in a way so that it would be easy to understand, adaptable and function in several scenarios. The model was only tested on one case company but the author is certain that the model has a high adaptability and that it could function in different environments. The model differentiates itself from existing models such as DMAIC with its simplicity. Even though it is similar to the DMAIC when regarding the steps and the ongoing cycle philosophy, it doesn’t include as many steps and is adaptable to fit several users. The model makes use of tools like Activity Relationship Chart, Cause and Effect Diagram to retrieve necessary data and MCDM in a later stage to simplify the choice of improvement for the decision maker, these tools are as well easy to understand and repeat for future users. Depending on the situation, the tools can be exchanged for more appropriate ones to achieve more from the model. Since the model is generalized this will not change or affect any further steps in the process.

7.2 Findings from the case company

The Purpose to decrease the material handling was defined in the first step of the model. The result of step one was the developed plan which enabled the data gathering in the next step. In step two the plan was set in motion and the data gathered. This data provided the user with insight and developed a table of routine distances (see Appendix G).

In step three where the data was analyzed and two Activity Relationship Diagrams were developed. The diagrams showed for example that the wadding was absolutely necessary to be located close to the sewing department and to be received at the offloading in hall A, also it was especially important for the polyether to be located near the production stations (see figure 8 & 9).

The Cause and Effect Diagram discovered inefficiencies connected to the facility, equipment, work routines and material handling routines (see figure 10).

In step four, 4 improvement alternatives were developed which included alternative 0 which was not to make any changes. The three remaining alternatives offered improvements in three economical steps that ranged from minor cost to extensive cost. Alternative one focused on the routines, while alternative two and three focused on changing the facility layout to increase the space.

In the final step of the model, step five, alternative two was chosen. It was chosen through a high score in the MCDM (see table 6) chart compared with the costs for the implementation (see table 7). This information was used to choose the most cost effective solution.
Alternative two features:

**Synchronized and shorten material handling**
By addressing the procedures that occur within the material handling staff and by focusing resources to optimize the material locations, alternative two offers a faster and less wasteful material handling.

**Equipment improvement**
By supplying the staff with relevant education and matching equipment alternative two can speed up the delivery of material to the production lines.

**Layout improvement**
Alternative two offers a new layout without the need of expansion for the company. This results in more space for the material handling staff and production staff. Routes are shortened and buffer stocks can be implemented to avoid the stoppages in the production. The details of the facility layout changes can be seen below and displayed in Appendix C.

Machines moved to C-hall:
- Enables more space in the B-hall production area and offloading zone
- Enables the total use of the B-hall loading bay
- Enables more machines the use of the plastic wrapping machine
- Enables more space for storage shelves in the B-hall

Area released in the C-hall.
- Space for buffer stocks
- Space which enables the material handling staff to approach the production using forklifts
- More storage shelves in the C-hall
- A passage for the forklifts through C-hall
- A production flow which goes in one direction
- Decreases the need of frequent material handling
- Decreases the congestion of forklifts in the A-hall
8. Conclusions & Recommendations

This chapter will present my thesis conclusions and recommendations for the case company.

Answer to the problem formulation
For this study the problem formulation was:

*How can the material flow efficiency within the production be increased cost-effectively through improving the facility layout and the internal logistics?*

The developed model in this thesis provides a company with a base for improvement. The model enables the responsible staff to discover the issues concerning the material flow efficiency, to analyze them and in a later stage a development and implementation of an improvement can be conducted. The decision maker can make a cost-effective decision by using the model properly to enhance the company performance.

Areas of importance
In this certain case it was discovered that a problem area was the lack of space in different areas of the company (see table 5). The improvement alternatives that was developed and chosen through using the model provided a new facility layout that partially focused on providing more space in required areas. The area released offered more space for buffer stocks, loading bays and forklift passages. The extra space will noticeably speed up the material handling to the production and enable the company to reduce the amount of travels back and forth.

Recommendations
I would recommend the case company to make use of this model, with the proper information that is necessary to come to a decision. By using time, distance and area as factors they can use the model to detect inefficiencies and develop solutions. Because the layout drawings used in this paper are not completely up to date I would recommend the case company to produce new layout drawings covering the entire facility. I would also recommend the company to implement the layout and improvement suggestion that is included in this paper or to construct a new layout to create more space and that fits the transportation devices better. Since the model is standardized it can also be modified to fit several tasks, by including other tools/methods or replacing the existing with others it can be used with several different scenarios.
References


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Appendix

Appendix A, current layout

Current Layout
Appendix C, layout improvement
Appendix D, current routes

Appendix E, expanding B-hall
Appendix F, reacher forklift
### Appendix G, distance table

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Purpose</th>
<th>Tool</th>
<th>Length (one dir.)</th>
<th>Length (both dir.)</th>
<th>Frequency</th>
<th>Length /week (one dir.)</th>
<th>Total length /week</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-hall dispatch</td>
<td>B-hall storage</td>
<td>Deliver the offloaded products</td>
<td>Forklift</td>
<td>150m</td>
<td>300m</td>
<td>30 times/week</td>
<td>4500m</td>
<td>9000m</td>
</tr>
<tr>
<td>C-hall</td>
<td>B-hall</td>
<td>Service staff resupplying production lines</td>
<td>Trolley</td>
<td>80m (depending on material)</td>
<td>160m</td>
<td>Aprox. 75 times/week</td>
<td>6000m</td>
<td>12000m</td>
</tr>
<tr>
<td>A-hall</td>
<td>B-hall</td>
<td>Transport wadding</td>
<td>Forklift</td>
<td>175m</td>
<td>350m</td>
<td>20 times/week</td>
<td>1500m</td>
<td>3000m</td>
</tr>
<tr>
<td>A-hall</td>
<td>B-hall</td>
<td>Scrap material to compactor</td>
<td>Forklift</td>
<td>150m</td>
<td>300m</td>
<td>50 times/week</td>
<td>7500m</td>
<td>15000m</td>
</tr>
<tr>
<td>C-hall</td>
<td>F-hall</td>
<td>Fetch latex</td>
<td>Forklift</td>
<td>200m</td>
<td>400m</td>
<td>Unknown, high dependability</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>B-hall</td>
<td>B-hall</td>
<td>Off loading polyether</td>
<td>Trolley</td>
<td>50m</td>
<td>100m</td>
<td>Many tours/day</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total length (one direction)</th>
<th>Total length (both directions)</th>
<th>Total length/week (one direction)</th>
<th>Total length/week (both directions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>805m</td>
<td>1610m</td>
<td>18 000m+unknown</td>
<td>36 000m+unknown</td>
</tr>
</tbody>
</table>