Where to Stack the Chocolate?

Mapping and Optimisation of the Storage Locations with Associated Transportation Cost at Marabou

Saga Almqvist & Lana Nore

Acknowledgements

This report contains our master thesis, the final work for our Master in Industrial Engineering and Management at Umeå University. The master thesis describes the result from our research on optimisation and logistics, which was carried out at Marabou a subsidiary of Mondelēz International. These 20 weeks have been challenging, both on personal level and in terms of planning and logistics. The greatest task was to integrate our knowledge from our theoretical studies to a real practical problem. We learned a lot working on this report, and will surely benefit from the experience in our future careers and studies.

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Sammanfattning

Idag är lagerhanteringen i Marabou fabriken ordnat på sådant sätt att artiklarna är lagrade utifrån vilken linje den tillhör och därmed står i ett lager nära den specifika linjen. Dock finns det lagerplatser idag som inte är optimerade, i den mån att det endast är lagrade från vana och vad som anses enklast. Därmed är lagerplatserna inte ordnade utifrån någon standard.

I detta examensarbete föreslår vi därför de mest optimala lagerplatserna med hänsyn till totala transportkostnaderna. Det här problemet kan modelleras som ett matchningsproblem som kan lösas av en så kallad Ungersk algoritm. Denna ska resultera i den optimala matchningen mellan produktionslinjens behov mot lagerplatserna i fabriken med tillhörande kostnad. För att använda Ungerska algoritmen samlade vi in data av den totala mängd artiklar som fanns i fabriken för 2016, vilket togs fram genom datasystemet SAP som Marabou använder sig av. Därefter justerade vi datat genom att dela upp alla artiklarna i antalet pallar samt vilken linje den tillhör. Denna information kompletterades med empiriska undersökningar genom egna observationer samt kvalitativa intervjuer med de anställda i fabriken. I metoden använder vi tre olika implementeringar av den Ungerska algoritmen. I resultatet presenteras resultaten från de olika tillvägagångsätten tillsammans med flera palloptimeringsförslag. I slutet sammanställs flera förbättringsförslag och idéer om vidareutveckling i rapporten.

Nyckelord*: Ungersk algoritm; Lagerplatser; Transportkostnader.*

Abstract

Today, inventory management at Marabou is organised in such way that articles are stored based on which production line they belong to and are sent to storage locations close to their production line. However, some storage locations are not optimised, insofar articles are stored out of pure habit and follow what is considered most convenient. This means that the storage locations are not based on any fixed instructions or standard. In this report, we propose optimal storage locations with respect to transportation cost by modelling the problem mathematically as a minimal cost matching problem, which we solve using the so-called Hungarian algorithm. To be able to implement the Hungarian algorithm, we collected data regarding the stock levels of articles in the factory throughout 2016. We adjusted the collected data by turning the articles into units of pallets. We considered three different implementations of the Hungarian algorithm. The results from the different approaches are presented together with several suggestions regarding pallet optimisation. In addition to the theoretical background, our work is based on an empirical study through participant observations as well as qualitative interviews with factory employees. In addition to our modelling work, we thus offer several further suggestions for efficiency savings or improvements at the factory, as well as for further work building on this report.

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1 Introduction

In this section we will present the purpose and background of our project, and give a glossary of important terms.

1.1 Background

Marabou is one of the most famous and well-loved chocolate brands in Sweden. It was founded in 1916 and its factory is currently located in Upplands Väsby. Marabou is a part of one of the world's biggest confectionary companies, Mondelēz International (Marabou, 2017).

Marabou has a number of articles, consisting of raw materials, semi-finished materials and packaging materials. The factory consists of the production lines *Jensen 1*, *Jensen 6*, *O'boy*, *Noblesse*, *Twist* and *Frostbite*. Each production line has two sides, called *warm-side* and *cold-side* respectively. The lines are producing the actual product on the warm-side and the cold-side packs the finished products. The needs of the materials for each production line vary in time. The production lines run according to a schedule. Currently, there is a desire from the company to establish a holistic mapping of the internal logistics at the factory to optimise the flow of materials. This is necessary to provide all the production lines with the required materials according to the production plan. Previously, some students have made studies of the factory from Royal Institute of Technology (KTH). These students made a holistic mapping over the material flow of the factory and some suggestions of improvements, which were based on their own observations. Unfortunately, their study was not completed with any data provided by Marabou and mathematical theories. Therefore, our task is to continue further on this path.

1.2 Purpose

The purpose of this project is (i) to construct a holistic view of current internal logistics of raw material, packaging material and finished products at Marabou factory and (ii) to develop a mathematical model to optimise the storage locations with respect to transportation costs and achieve a more efficient flow of materials.

1.3 Report Overview

Firstly, an overview of the project is established with a project plan with milestones and project timeline. We evaluate with regards to its internal logistics and storage locations, to identify potential areas for improvement. The current state analysis is based on observations of the factory, interviews with employees at Marabou and through a previous report by other student interns, mentioned in section 1.1. However, in their project the improvement suggestions are based on qualitative data from interviews and visual studies. For this project, a deeper understanding of the internal flows will be complemented by the analysis of quantitative data provided by Marabou and supplemented with qualitative interviews and mappings from own observations.

Secondly, when the current state is mapped, we conduct a theoretical study with regards to logistical and inventory management and different mathematical theories, which are relevant to the project. Other improvement methods based on practical implementation will also be presented, such as lean management.

Thirdly, in the methodological section, Section 4.1 and 4.2, we present a description of the mathematical model we developed from the problem and associated data collection. Then, we discuss how we collected data from the internal data system (SAP) at Marabou. We conduct a data analysis to understand the material flow of in and out of the factory. Later, we use a mathematical model associated with a computer program for determine the best location with respect to out modelling assumptions.

Lastly, we present our result followed by a discussion where we critically evaluate and comment the result with respect to its validity and reliability. In conclusion, we give a brief presentation of future work in the report.

1.4   Glossary

Table 1 shows frequently used technical terms throughout this master thesis.

TABLE 1: GLOSSARY USED IN THE REPORT.

The Factory	Factory A, part of the Marabou factory complex (not including the Daim factory).
Jensen 1(J1)	The production line where chocolate bars weighing 180-250 grams are manufactured. This is the production line, which stands for ⅓ of the total production at Marabou.
Jensen 6 (J6)	The production line where chocolate bars weighing size 25 - 150 grams are manufactured.
Frostbite (Fb)	The production line where chocolate pralines are made, for example Aladdin and Paradis.
O'boy (Ob)	The production line where the powder chocolate beverage are manufactured.
Noblesse (No)	The production line where thin chocolates flakes are manufactured.
Twist (Tw)	The production line where bags with different varieties of chocolate pralines.

Cold-side (K)	The side of the production line where the packaging of the finished chocolate product is handled.
Warm-side (V)	The side of the production line where the chocolate praline is manufactured, from liquid chocolate to the finished praline.
SAP	*Systems, Application, Products* (SAP) is a software which allow companies to track their interaction with their customers. The system is popular for its Enterprise Resource Planning (ERP) and data management programs (Business Dictionary b, 2017).
Dock	The dock receives most of the materials that comes to the factory, except for the chocolate mass which unloads automatically at a different location in the factory.

2 Current State

In the following section we will present facts about the current state set by qualitative interviews and participant observations. In addition, a deep explanation of transportation cost regarding the forklift drivers' workload and the placement of the storage locations.

2.1 Interviews

To gain an overview of the production, information was collected from qualitative interviews with employees and team leaders for each specific production line, and planners and other employees working in the factory. Each interview, including a tour and an introduction to each production line, took approximately one hour. The main goal for all the team leaders is to make sure that the line is operated according to plan. This plan is provided by the planners but is changed several times before a final plan is determined. The final plan is specified on the first day of the production week or at latest the day before the new calendar week. Forklift drivers at the dock unload materials from trucks as they arrive into the factory. The forklifts are also responsible for delivering the materials to the production lines. On some days, the incoming material from the dock is needed at the production line on the same day whereas several other materials are not needed on the same day but stored close to their production line. Since all the production lines are on the second floor, most packaging materials are placed in storage locations on the second floor whilst raw materials are stored on the first floor where the cold/hot-storage locations are located. The only production lines that have their packaging materials stored on the first floor are Noblesse and Twist. The truck drivers believe there is enough space to store the pallets by the production line but employees at the production line say the opposite.

2.1.1 Flow of Materials

The dock is responsible for receiving all materials in the factory. Forklift drivers unload all deliveries to the factory here. Through interviews it surfaced that most deliveries are made in the morning, at the end of each week, or on the first day of the calendar week. Firstly, the materials are unloaded by the forklift drivers and placed in storage locations near the dock. Then, the amount of material is checked manually and delivered to respective production lines' storage location on the second or first floor. Lastly, a forklift driver working at the line or at the dock either delivers the finished materials to the pallet square automatically with rolling or with a forklift. For the finished materials, it is only Jensen 6 and Noblesse that need assistance from a forklift driver to transport the finished products to the pallet square where they are wrapped in packaging and loaded into the warehouse. Figure 1 below, shows the flow of materials within the factory. The data was collected from SAP. More information on data collection can be found in Section 4.2.
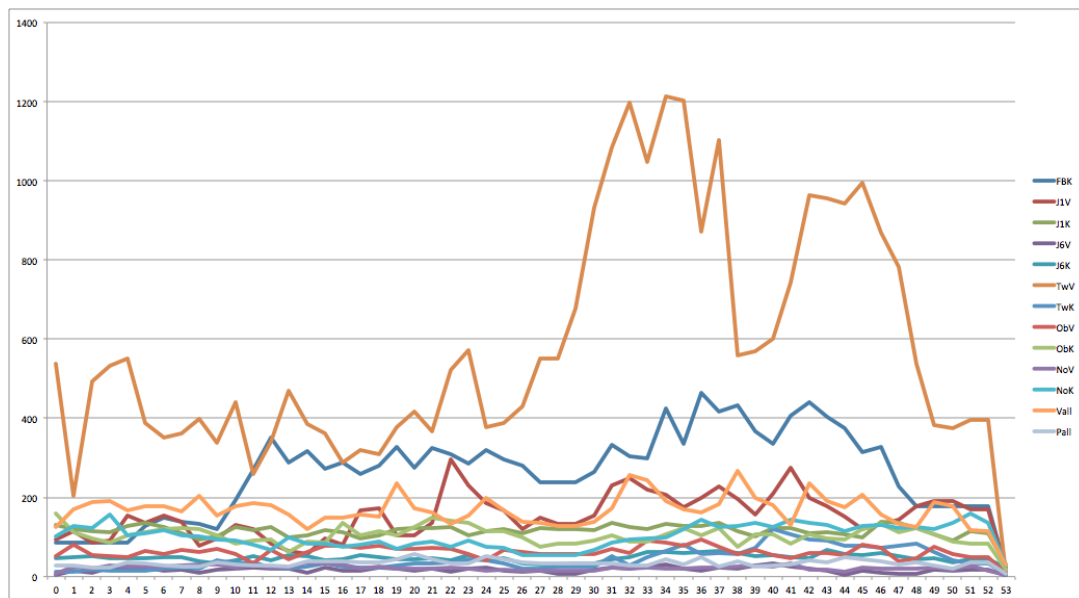
FIGURE 1. THE FIGURE REPRESENTS THE PALLET FLOW FOR EACH ONE OF THE PRODUCTION LINES IN THE FACTORY. X-AXIS REPRESENTS THE NUMBER OF WEEKS AND Y-AXIS REPRESENTS THE NUMBER OF PALLETS. THE DIFFERENT COLOURS REPRESENT EACH PRODUCTION LINE.

2.1.2 Bottlenecks

There are a couple of bottlenecks that affect the material flow for each production line. One of the problems is that the received materials are checked manually, which is a time-consuming process. In the warehouse an automatic system for checking the finished products is being implemented, which the employees at the dock also wish for. Unloading one truck, with several forklifts is another time-consuming exercise, and a waste of manpower. Moreover, there are several communication problems between the production lines and the forklift drivers from the dock. In addition, the forklift path in the central part and the one in the south part are used more often, and some paths are considered as dangerous by employees working at the dock. For instance the road to the first floor in the northern part of the factory has an increased risk of collision (see figure 1).

The forklift drivers follow a learning-by-doing principle with no working standardised/formalised operating procedures. Therefore, each forklift driver makes his/her own prioritisation according to what he/she feel is most urgent or have learned from a colleague. Furthermore, the storage is not optimised and is sometimes placed far away from the production line, which means that there are a lot of empty spaces in the racking which affect every production line in the factory.

All production lines run during one to five shifts on weekdays. Noblesse is the only production line that runs on the weekend. Noblesse usually receives help from Jensen 1's forklift driver but during the weekend there is no forklift driver available. This in turn means that transportation is not supported fully, which in turn affects the capacity and productivity for Noblesse.

2.2 Mapping current state

Observations in the factory have been made to create a holistic view and to identify the storage locations that are currently in use. In this subsection we describe our own observations, which are later supplemented by interviews.

By looking at different sections of the production lines together with a map from the company, a forklift path was established in figure 3 (storage locations on the first floor) and figure 2 (storage locations on the second floor). The pink spots are the official pallet racks and the green spots are the less official pallet storage areas on the floor. The letters represent storage locations and the grey circles indicate the location of the production lines, see figure 2 and 3. Throughout this report, every cold side of a production line is shortened to K. The same structure is used for naming the warm side of every production line but with the letter V. For example Frostbite Cold is called FbK and Jensen 6 Warm is called J6V from now on. More about these abbreviations are available in the glossary in section 1.5.
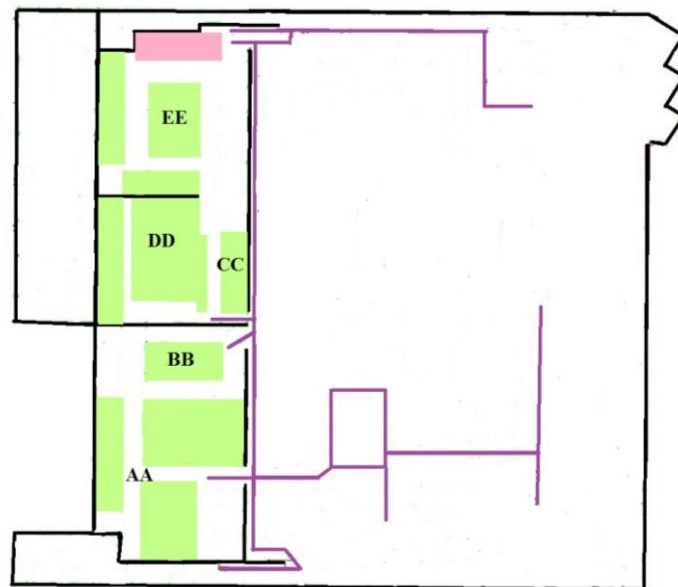

FIGURE 2. MAP OF THE FIRST FLOOR IN THE FACTORY. THE LETTERS REPRESENT THE STORAGE LOCATION. THE PINK AREA ARE RACKS WHILE GREEN ARE FLOOR STORAGE LOCATIONS. THE PURPLE LINES ARE THE FORKLIFT PATHWAYS.
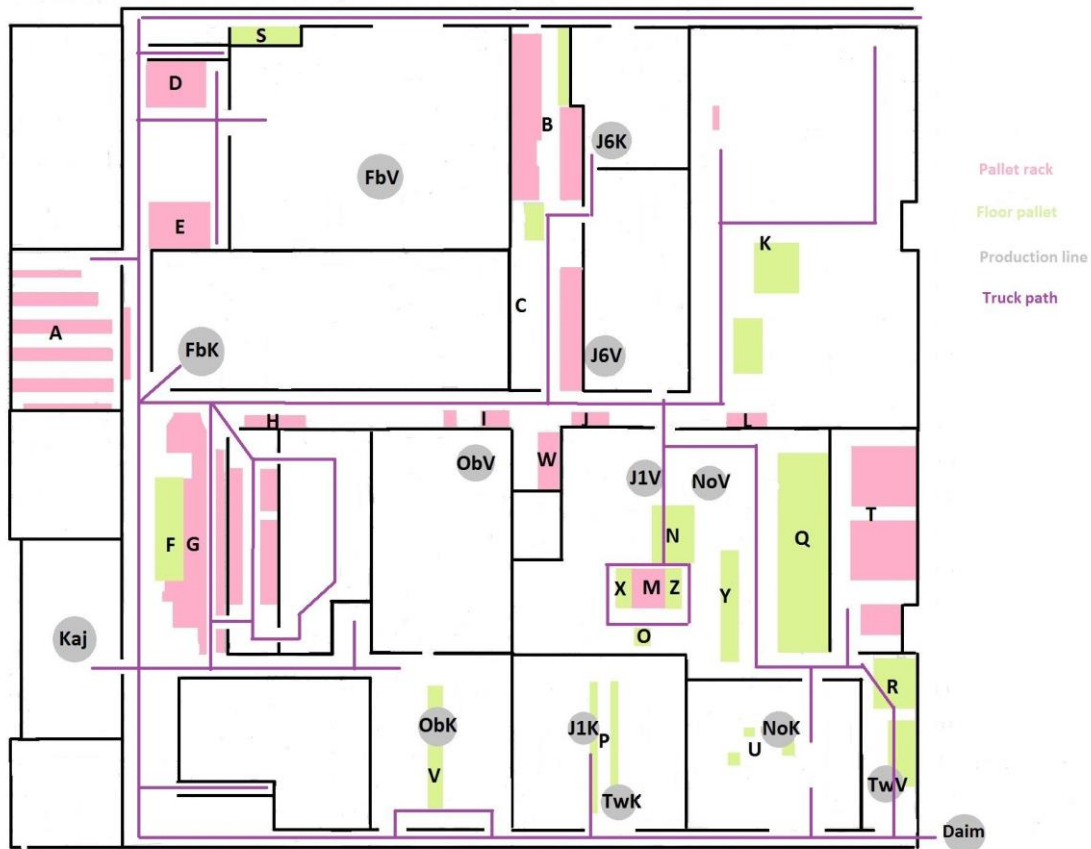
FIGURE 3. MAP OF THE SECOND FLOOR IN THE FACTORY. THE LETTERS REPRESENT THE STORAGE LOCATIONS AND THE SHORT-NAMES, WRITTEN IN A GREY CIRCLE, REPRESENT EITHER THE WARM-SIDE OR THE COLD-SIDE OF A PRODUCTION LINE. THE PURPLE LINES ARE FORKLIFT PATHWAYS. THE SOUTH SIDE OF THE FACTORY IS IN THE LOWER PART OF THIS FIGURE AND THE NORTH SIDE IS IN THE UPPER PART OF THIS FIGURE.

2.2.1   Forklift Drivers

In total, there are four forklift drivers working at the dock, two of them working the morning shift and the other two working the night shift. A forklift can transport at most 1000 kg, so that some pallets can be transported two by two while others cannot. Except from the four forklift drivers working at the dock there is one full-time forklift driver at Jensen 1 and Frostbite respectively. Other production lines have a forklift ready at any time but not a driver; hence they usually acquire help from the forklift drivers from the dock.

The forklift drivers prioritise transporting the finished products over unloading the trucks at the dock. The transportation pathways that are often used are the one in the middle/centre and the south in the factory, the pathway that connects the dock with Daim, see figure 3. It is not specified which employee completes which task, rather the first person available or called on is assigned the job. The forklift drivers aim not to drive an unloaded forklift but this is not yet achieved. The information flow between the forklift drivers and the employees at the production lines is unclear in the sense that there is no clear standardisation on how to communicate. When help is needed, an employee at the production line calls a forklift driver by mobile phone or gets help directly from a nearby forklift driver. Communication problems regarding what has and has not been delivered often arise in this system where no one is in charge and the division of

duties is unclear. In order to make it easier for new employees to learn and quickly find mistakes, a standardised work specification, which allows employees to follow a clear guideline, would be desirable.

2.2.2 Forklift Drivers Worklod

There are two loading locations in the factory, one at the dock and one on the first floor. The forklift drivers that work at the dock are in charge of unloading at both locations. The forklift drivers' workload is different depending on the day. Mondays, Thursdays and Fridays are days with most deliveries to the dock, which increases the workload. On Tuesdays and Wednesdays, the workload is lower. When the workload is low, the forklift drivers usually collect trash, collect finished pallets or search for other things to do. This uneven flow of material is due to the planning system, SAP, which makes ordering only possible on Sundays, Mondays and Tuesdays.

2.2.3 Storage Locations

The current understanding of the factory's inventory planning varies from employee to employee. The forklift drivers say that there is a floating inventory management. By floating inventory management, the forklift driver simply finds the most convenient space for placing the pallet which means that no other employee than the specific employee can track the placement of the pallet. Other employees say that they work with a fixed inventory management, which means that every material has its own fixed location in the factory. However, there is no way of tracking the materials in the factory. It is conceivable that some of the employees we questioned on this matter did not understand the precise meaning of the expression "floating inventory management" and gave misleading answers as a result.

Moreover, the material with the latest date marked is supposed to be used first. To do so, one has to remember what material is available and where it is located. Because one employee at the plant often knows this information, the production may suffer if this employee is absent. In the long run this can have a negative impact for the production and the company. There are 31 storage locations on both floors with a total of 5989 pallet storage places, shown in figure 6, and some of these storage locations are used for a specific cause, such as cooling down or heating up. The distribution of the storage locations on each floor is shown in figure 4 and 5. However, storage location F is not regarded further in the calculations since it is only used for empty pallet storage. The number of pallets differs from week to week, as shown in figure 1. Marabou wants to investigate where it would be possible to store all materials on the second floor, thereby avoiding transport to the first floor (which is a cause of accidents and is time-consuming). An overall plan of the storages locations for each production line is found in appendix a.

FIGURE 4.VOLUME OF STORAGE CURRENTLY AVAILABLE AT EACH OF THE STORAGE LOCATIONS ON THE SECOND FLOOR. X-AXIS REPRESENTS THE STORAGE LOCATION ON THE SECOND FLOOR AND Y-AXIS REPRESENTS THE NUMBER OF PALLETS PLACES.
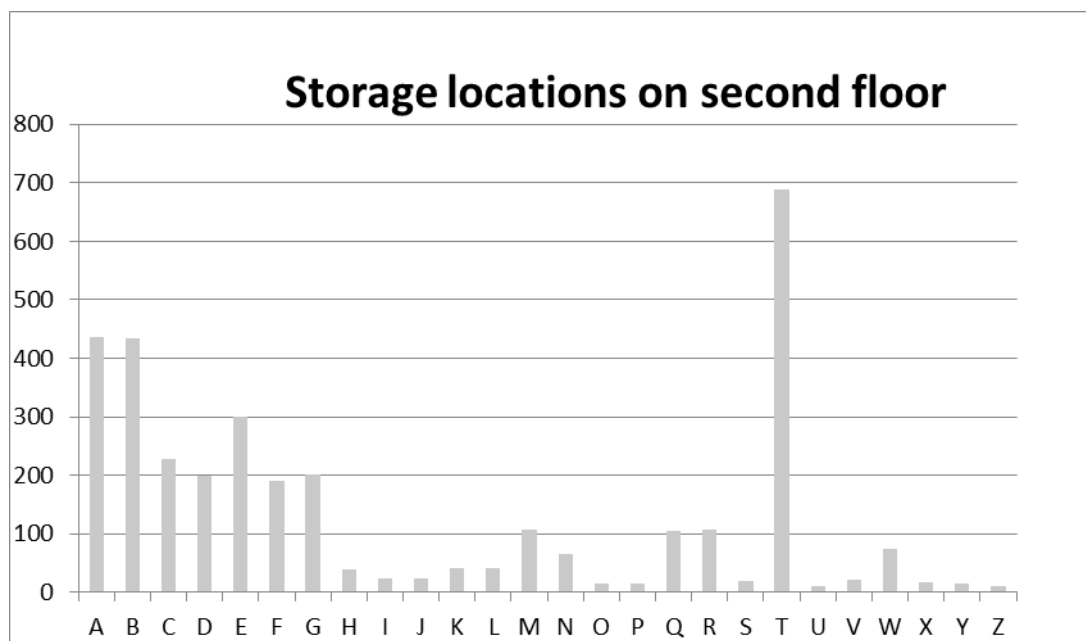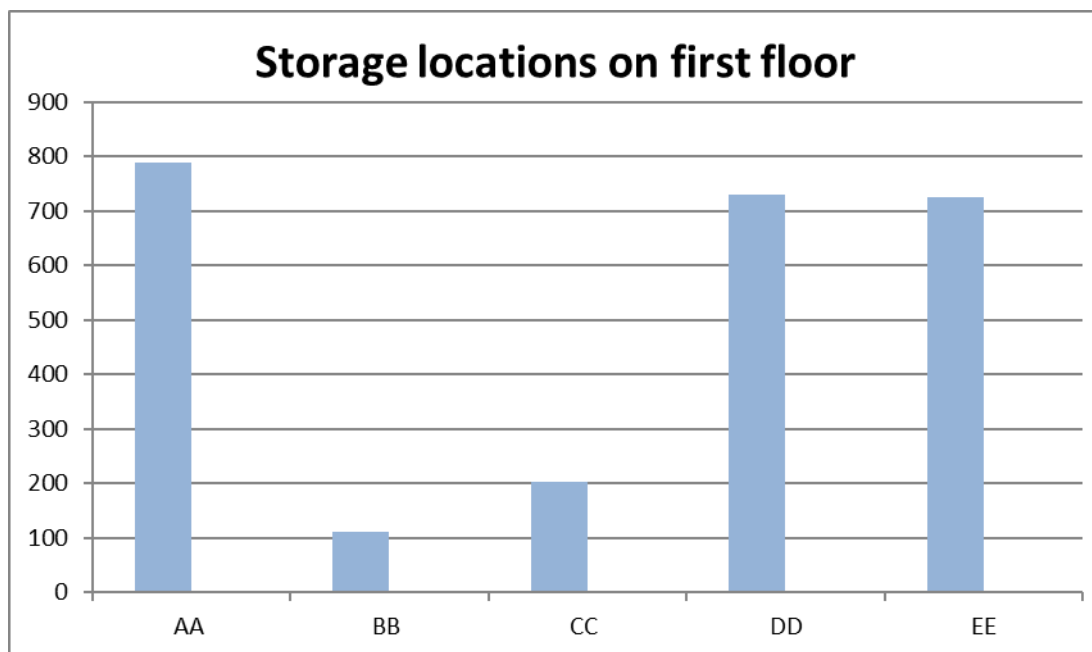

FIGURE 5. VOLUME OF STORAGE CURRENTLY AVAILABLE AT EACH OF THE STORAGE LOCATIONS ON THE FIRST FLOOR. X-AXIS REPRESENTS THE STORAGE LOCATION ON THE FIRST FLOOR AND Y-AXIS REPRESENTS THE NUMBER OF PALLETS PLACES.
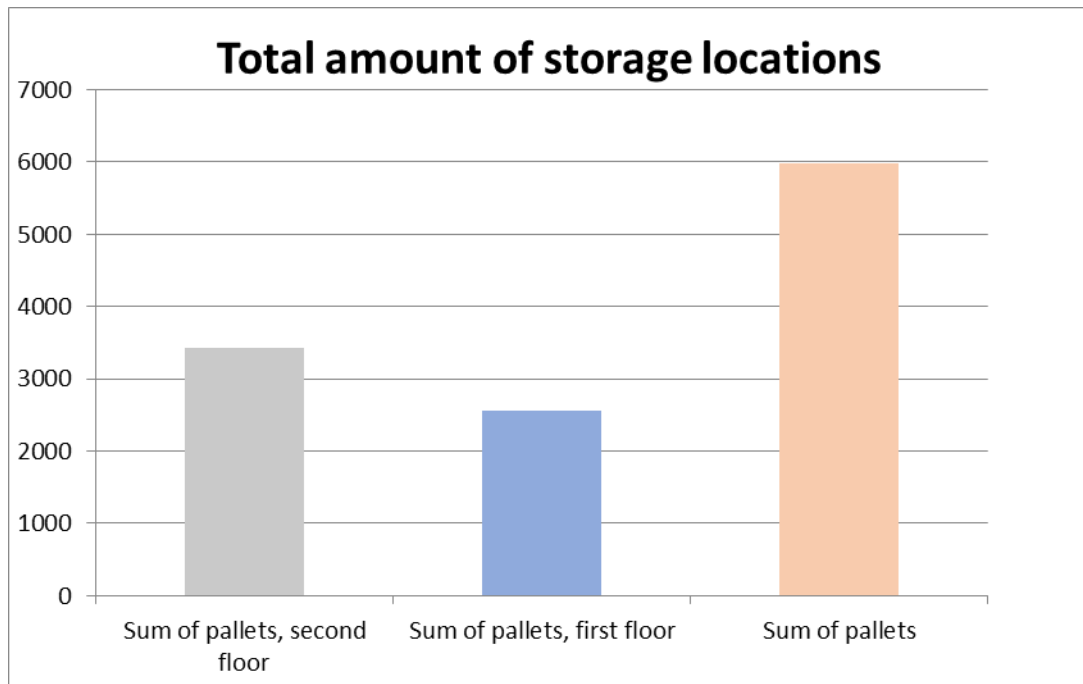
FIGURE 6. SUM OF THE TOTAL AMOUNT OF STORAGE LOCATIONS ON THE SECOND FLOOR, FIRST FLOOR AND IN TOTAL IN THE FACTORY

3 Theoretical Framework

In this section, we outline the theoretical background for our work using important theories regarding internal logistics, supply chain management, material and information flow together with enhancement tools such as lean management and change management. Furthermore, we present mathematical optimisation theories such as matching problems and the Hungarian algorithm.

3.1 Flow Theory

According to Brunner and Rechberger (2005), material flow analysis is a methodical assessment of the flow of materials and materials within an organisation's time and space. Information flow refers to the ideas, data and opinions running throughout the organisation. Information gives value in terms of an increased level of understanding and decreased uncertainty (Business Dictionary b, 2017). Theory regarding material and information flow is relevant for understanding the flow of materials and for gaining an overview of the factory.

3.1.1 Total Cost

Total cost is a crucial notion in logistics, which includes all the costs involved in the production: stock, inventory, warehousing, transportation, administration and other expenses. Total cost is an important measure since a reduction of costs in one production line may affect the costs in other production lines (Oskarsson, 2014; 38-39). Warehousing is the cost for keeping the products in a warehouse. Transport costs refer to both the external and internal transport costs. Administrative costs include the costs for planning and ordering. Lastly, other expenses include information, packaging and material (Oskarsson, 2014, 40-41). In this project, all of these factors are regarded as important for a holistic understanding of the factory thus all the aspects would be considered when calculating the total cost.

3.2 Improvement Theory

In this section, we describe improvements methods that could be used in practice. The difficulties with implementing these improvement methods will be explained later on in this section. When optimising it is also important to look at the human behaviours of the employees since it play a significant role for the efficiency in the factory.

3.2.1 Lean Management

Lean management aims to maximise customer value by reducing waste and minimising the total costs (Business dictionary a, 2017). Lean management is about continually finding improvements at every level in the whole organisation (Business dictionary a, 2017). To constantly work with continuous improvement by reducing non-value creating activities is called *Kaizen*. This is regarded as one of the most important tools for lean management. The practices can be seen as small changes within the business that will give great results, regarding

business performance and profit. To make such a change, everybody involved in the organisation have to be willing to make a change. The difficulties that arise when making organisational changes are explained in Section 3.2.2 (Kaizen, 2017).

3.2.2 Change Management

Change management is about making it easier to adapt and implement a desired change in a company (Management meditations, 2017). There are two different forces within an organisational management (i) driving forces that encourage changes and (ii) restraining forces that want to preserve the status quo and prevent changes (Mind Tools Ltd, 1996-2016). For an improvement or change to be possible, the driving forces need to be greater than the preserving forces (Mind Tools Ltd, 2016). The biggest challenge that change management presents is gaining a positive response from workers and employees. Usually some resistance will occur and it is very important to handle this in a good way so the workers do not feel left behind or overruled (Kritsonis, 2005).

3.3 Mathematical Theory

In the following section, we discuss various mathematical models relevant to the problem of finding the optimal storage locations with respect to transport costs. Towards the end of this section, we present the Hungarian algorithm for solving the minimum-cost matching problem relevant to this project.

3.3.1 Matching Algorithm

We often want to find the best way of pairing objects together. This has led to the mathematical study of many different kinds of *matching problems*. Before we continue we need some definitions. A *graph G =(V, E)* consist of vertices, V, that are connected to each other with *edges E*. If *V,* is discomposed into two disjoint sets V_1 and V_2 where each edge connects a vertex in V_1 with a vertex in V_2, this is called a *bipartite graph*, seen in figure 7 (Ahuja & Magnanti; 1993; 461-463). A *weighted graph*, on the other hand, has a cost associated to each edge (Mathworld b, 2017). A *weighted balanced bipartite graph* is a graph where both the sets V_1 and V_2 have the same number of elements (Cour, 2005;1). One such problem, which is relevant to this project, is the *assignment problem*. In an assignment problem, one seeks to find a minimum weight perfect matching in a weighted bipartite graph (Harvard, 2005). A perfect matching is a matching where each vertex is incident to at most one edge of the matching. Therefore, this matching consists of n/2 edges (where n is the number of vertices); this is only possible on graphs with even number of vertices (MathWorld a, 2017).
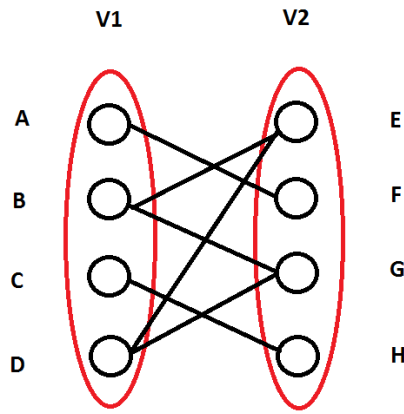
FIGURE 7. VISUALISATION OF A BIPARTITE GRAPH $G = (V_1, V_2, E)$ WHERE $V_1 = \{A,B,C,D\}$ AND $V_2 = \{E,F,G,H\}$ AND E ARE THE EDGES CONNECTING THE VERTICES.

3.3.2   The Hungarian Algorithm

The Hungarian algorithm is a combinatorial optimisation algorithm for implementing and solving a matching problem. The input to the algorithm is a matrix, which is built on a weighted bipartite graph with nonnegative weights. The output is a sum of weights of all pairs in a perfect matching.

First of all, the Hungarian algorithm is defined by the graph $G = (A, B, E)$. A matrix $D = NxM$ where N is the number of vertices in set $A = \{a_1, \dots , a_N\}$ and M is the number of vertices in set $B = \{b_1, \dots , b_M\}$. Each vertex i in set A must find a match with a vertex j in set B and vice versa until all vertices in the set which has the smallest number of vertices is a match. For each matched pair $E = (a_i, b_j)$, where E represents the edge, there exist a nonnegative associated cost c_{ij}. This can be illustrated with a weighted bipartite graph (mentioned earlier in Section 3.3.2) where our aim is to find a perfect matching of A to B which minimises the total cost by summing all pairs $E = (a_i, b_j)$ which are in the matching. The goal for the algorithm is to find a perfect matching of E with the lowest cost possible. A solution may be viewed as a binary matrix D^*, where $x_{\{i,j\}} = 1$ if vertex i is matched with vertex j, and 0 otherwise. This becomes a binary integer program mentioned in Section 3.3.1.

If the problem is not a weighted balanced bipartite graph we have to add so called *dummy vertices* to the set with least amount of vertices. For simplicity, $N<M$, which means that A has fewer vertices than B and therefore has to be added with new vertices so that $N=M$. These dummy vertices in N are now to be connected to the vertices in M, which yet not have been connected with an edge E. The new added edges will receive the maximum weighted cost found in the matrix. The complexity of the Hungarian algorithm is polynomial in the size of the weight

The steps in the Hungarian algorithm are presented below. Assume we have a matrix $K = NxN$.

1. *Row reduction*. For each row r_i, find the entry c_{ij} with the smallest value, and reduce r_i by subtracting c_{ij} from every element in the row.

2. *Column reduction*. For each column s_j, find the entry c_{ij} with the smallest value, and reduce c_{ij} by subtracting c_{ij} from every element in the column.

3. *Test for an optimal matching.* To find the optimal solution, we cover all zeros in the matrix with least number of lines L as possible. These lines could either be drawn horisontally or vertically. If $L = N$, an optimal solution is found and we can continue directly to step five.

4. *Shift zeros.* If the covered lines $L < N$ we have to go through step four. Reduce every uncovered element with the smallest value $c_{i,j}$ in the matrix and add every element, $c_{i,j}$ that is covered by an intersection of two lines in the matrix with the same value $c_{i,j}$. The lines are then removed and we continue to step three.

5. *Final matching.* We now want to find N zeros where one zero is found for each r_i and c_j in the matrix. The optimal solution is calculated by summarising each pair of c_{ij} in a perfect matching, P. These costs are found in the zero-elements in the original matrix.

(Munkres, 1957)

4   Methodology

In this section a description of the mathematical model of the minimum cost matching problem is given. Firstly, we model the problem as a minimum cost matching problem, and then solve it using the Hungarian algorithm. Lastly, limitations, delimitations, approximations, assumptions, validity and reliability of the project are discussed.

4.1   Description of the Model

This section presents the mathematical model to solve the matching problem. A description of the mathematical model's features is presented with objective function, constraints, parameters and variables. The model is developed step by step and the final model is presented at the end.

The mathematical model is used to find the best storage locations for all articles in the factory with respect to transportation costs. The model will also calculate the transportation cost of the optimised matching. In total there are 31 storage locations, 5989 pallet locations and 12 production lines. The mathematical problem is a modified version of the Hungarian algorithm. For this problem, all the storage locations are assumed to be empty. By this it means that any line could place their pallets in any storage locations that are available. These empty storage locations are "filled" according to the Hungarian algorithm.

By referring to figure 7, a bipartite graph, there is one vertex, b_i, to each storage location i in set B to be the collection of all b_i. There is one vertex, a_j, for all pallets belonging to each production line in set A to be the collection of all a_i. An edge $E = (a_j, b_i)$, a_j in A and b_i in B we have an associated transportation cost c_{ij}. To sum up, all pallets belonging to one production line, a_j, are matched with one storage location, b_i.

However, what is desirable is to match one and only one pallet that belongs to a production line to one storage location. To do this, three different modification to the Hungarian algorithm are made which are described later Sections 4.3.1 - 4.3.3.

4.1.1   Mathematical Model

The mathematical model is based on parameters, variables and objective function with associated constraints. The goal is to minimise the total transportation cost over all pallets belonging to production line j, stored at storage location i in week k.

Input: Matrix where each element represents the transportation cost from each pair of vertices.

Output: A matching where $x_{ijk} = 1$ if storage location I is matched with production line and 0 otherwise. Also the total transportation cost, c_{ijk} for the pairs in the perfect matching.

Parameters - Here are the different parameters that are used

>   *A – a set of production lines in the factory*
>
>   *B – a set of storage locations in the factory*
>
>   *j – pallets belonging to each production line*
>
>   *i – storage location*
>
>   *k- number of week for year 2016*

Variables – Here are the different variables that are used

> a_j *–all the pallets belonging to one production line j in the factory*
>
> b_i *– storage location in the factory*
>
> c_{ij} *– transportation costs from storage i to production line j*
>
> x_{ijk} *– amount of pallets belonging to production line j, stored in storage location i in week k.*

Objective function: Minimise the transportation cost over all x_{ijk} in the factory which is a perfect matching.

$$Min \sum_{j=1}^{N}\sum_{i=1}^{N}\sum_{k=1}^{N} x_{ijk}c_{ij}$$

Constraint 1: Each pallet is assigned exactly one storage location

$$\sum_{i=1}^{N} x_{ijk} = 1, \qquad \forall j, k = 1 \dots N$$

Constraint 2: Each storage location is assigned at most its storage capacity's worth of pallets

$$\sum_{j=1}^{N} x_{ijk} \le d_i, \qquad \forall i = 1 \dots N$$

4.2 Data Collection

In this section, the data collection is presented. The data required for the model used in this project is information regarding the inventory levels of all the articles in the factory. This information is not explicitly provided in SAP. As the information was not accessible immediately, three data collections were done.

Firstly, the articles are collected on a weekly basis for year 2016. The inflow is the materials delivered to the dock and the outflow will be the usage of material by a specific production line. Those in-and out flows of materials are later added to the current inventory level.

Secondly, the production line to which the articles belong to is collected. In SAP, all the materials are collected in different unit sizes, thus in kilograms, grams or pieces. Afterwards, each article is divided into three different product types; semi-finished material, packaging material or raw material.

Lastly, the number of pallets that belongs to each production line is obtained by dividing the amount of material with the weight of a pallet (kg, gram or pieces). Depending on the product type, each product is then sent to either the warm-production line or cold-production line. We chose to work with the unit *pallets*, since most of the materials are received and sent on pallets by a forklift.

4.3 Hungarian Algorithm Program

A short description of the programming application is presented in this section. We chose to work with the programming tool, Matlab. In this section we will also describe the input and output in detail.

The Hungarian Algorithm is written in Matlab-code since Matlab is a powerful tool for solving complex mathematical problems and mathematical libraries. However, Matlab is not quite as good when it comes to computational power. As matrices are the basic data element for Matlab, the programming tool works fine for our problem. Hungarian algorithm involves a lot of operations and matrices, Matlab works well for this problem. The input file is an N by N matrix which is sent into the program. The entries of the matrix that are used in the program are based on the distances from a storage location to a production line and the associated transportation cost.

All were determined by first measuring the distance from the dock to the production lines. The distances between each storage location and each production line are then estimated. All these distances are measured by hand from the map provided by Marabou (see figure 2 and 3). The number of pallets that belongs to a specific production line is multiplied with respective distance connected to it. The distances are represented in a matrix. There are 12 production lines and 31 storage locations there are in total of 372 elements representing the distances in the matrix. This transport cost matrix can be found in appendix b. The Matlab program analyses this matrix and

finds the best match.

We chose to use the Hungarian algorithm since the algorithm gives us exactly what we want, namely a minimum cost matching. The required input is the total number of pallets for one week, thus each element in the matrix represents one pallet multiplied by the transportation cost. As mentioned before, the pallet flow varies in time, so that an optimal storage assignment will potentially change in time too. Finally, the Hungarian algorithm has a complexity of $O(n^4)$ and can be modified to $O(n^3)$ and therefore efficient to run in theory and practice.

4.3.1   Hungarian Algorithm – With Different Scenarios

The program prioritises so that each production line gets the best storage location depending on other lines and storage locations, thus for this case six different scenarios are outlined. The reason for these six is because we want to know the "Max", "Min", "Mean", "Median", "Max week" and "Packaging materials" since these scenarios are considered to be covering a wide range of change in the flow of materials, table 2 describes these divisions of the pallets in more detail. The result will be pallets belonging to one production line matched to one storage location. No other line can have the same storage location as another since the iteration is only done once for each scenario. The result from this scenarios are henceforward be called A1 for "Max", A2 for "Min", A3 for "Mean", A4 for "Median", A5 for "Max week" and A6 for "Packaging materials".

TABLE 2. THE DIFFERENT SCENARIOS ARE DESCRIBED.

Pallet scenario	Description
"Max"	Every production line's maximum amount of pallets during the year is summed up.
"Min"	Every production line's minimum amount of pallets during the year is summed up.
"Mean"	Every production line's mean amount of pallets during the year is summed up.
"Median"	Every production line's median amount of pallets during the year is summed up.
"Max week"	The week where the maximum amount of pallets are stored in the factory
"Packaging material"	Every production line's maximum amount of pallets during the year is summed up when only the packaging material is considered. Only the storage locations on the first floor are allowed

.

4.3.2 Hungarian Algorithm – With Three Iterations

The program prioritises the best storage location depending on other lines and storage locations. In other words, a specific production line cannot have the same storage location as another production line. The program thus gives a suggestion for a matching depending on how many pallets that are being submitted into the program.

In the first iteration, the result shows the best matching of the system so that one storage location is paired with one production line. However, there are some pallets which cannot be stored since the storage location cannot take any more pallets, thus it is already filled up to maximum amount.

For the second iteration, the remaining storage locations, which are not yet filled, are now matched against production lines with pallets left to be stored. One difference is that the storage locations on the first floor are not considered for this second iteration because we want to see if the maximum number of pallets can be distributed on the second floor. This is done again and after three iterations all pallets have a place in the storage.

Nonetheless, the result is only fairly accurate because the prioritisation is not completely reliable. For example, if one production line is prioritised higher than another production line, the remaining pallets (if there are any left) for the higher prioritised production line does not get the correct storage location in the second iteration because some other line with less prioritisation has already taken it. This is due to the one-to-one matching, thus one production line is only matched to one storage location in each round, even though not all pallets are eventually fitted. The result from these three iterations is henceforward called B1 for the first iteration, b2 for the second iteration and B3 for third iteration.

4.3.3 Priority Method – Independent Matching

Apart from the matching computed by the Hungarian algorithm in the previous sections 4.3.1-4.3.2, the following, and last, method is henceforward called Priority method. Each production line is considered independent with no regards to the other production line when making the prioritisation. With this said, the hope is to see which storage locations that are most popular in the factory. Each pallet that belongs to a specific production line selects the best storage location and fills all the storage spaces. Thereafter, proceed to the next in the prioritisation scheme, and so on. This process is repeated until all the pallets belonging to a production line are matched against storage. With this said, Marabou can make their own decision on which production line that should be prioritised to one specific storage location. For this priority method, the maximum number of pallets for all the articles during year 2016 is used. The reason for choosing maximum weight is to ensure that every pallet obtains a pallet place; this would be the "worst-case-scenario" and the result for this independent matching will henceforward be called C.

4.4 Delimitations, Limitations, Approximations & Assumptions

In the following section, delimitations, limitations, approximations and assumptions are thoroughly described to understand how the methodology of the project has been working out as well as the creation of the model.

4.4.1 Delimitations

The project is done during a limited time, from 23.01.2017 until end of May 2017. The project will only regard the internal material flows within the factory, which refers to all material coming into the factory, until it is transported as a finished product to the warehouse. The Daim-line is not included since the pallets for the Daim-line are stored in another part of the factory, as mentioned earlier in this report. It is only material that is transported on forklifts that is considered, thus not chocolate mass transported in tubes or material that is so small one can manage it by lifting. The data for this project are from 31.12.2015 to 31.12.2016. Moreover, it is only the pallets that are transported manually that are being optimised. This is mentioned since some pallets are collected automatically. Another limitation is the fact that we have only considered the transport costs, thus omitting other costs such as product costs and inventory costs.

4.4.2 Limitations

One limitation is that the measures of the internal distances in the factory are estimated values, as there was no accurate method in place for measuring this. The measurements are made by hand as no materials for making this process more accurate were available. The data from SAP does not have any easily accessible information about the inventory-levels, therefore it took some time to gather all the information needed for the project. Some adjustments were also made since there was information missing for some articles in SAP.

4.4.3 Approximations

Some necessary data such as the weight for each pallet with a specific product was missing in SAP, which meant this information was collected from employees, either based on their own knowledge through experience or approximations. This presents some issues of reliability, since the information provided by employees are mere approximations and were not independently verified.

Currently, there exists no information regarding where the materials are stored in the factory. The mapping in this report is done by us and is based on real observations involving manually counting every pallet existing at the pallet storage at that time. As the racks have an outlined maximum capacity of pallets the number of pallets that fit the racks is accurate. However, the pallet storages on the floor are not as accurate because the number of pallets there can differ from one day to another. Therefore an approximation of pallets capacity is made for each storage location.

4.4.4 Assumptions

When creating the data document all articles are sorted into the different lines. To do so some assumptions were made regarding where the material belonged. This assumption is based on the type of article. All of the packaging material is assumed to belong to the cold side of the production line and the semi-finished products together with the raw material were assumed to go to the warm-side of the production line.

4.5 Validity and Reliability

There exist two types of information gathered for this project. Firstly, some of the data are collected from first-hand observations. Secondly, other parts of the data are collected from the internal data system SAP. Both these sources have a high degree of reliability and validity. The data from SAP is registered and updated regularly since 1996 when it was implemented, which makes the data valid and reliable. In addition, the production volumes do not change very much from year to year, and therefore can be seen as valid for 2017. The data collected through participant observations are also highly valid as they were collected during the time period in which the project was carried out. The degree of validity is high as well since the observation is made this year (2017). The only limitation to collecting data through observation is that there may be some human-errors. Additionally, as transportation is complex which makes it difficult and may cause some error measurement or some paths might be overlooked. The busiest time period is during the fall and winter, which makes the production volume higher. The production volume on the other hand is less during spring. For this project, observations are made during spring, which makes the reliability not so optimal since it is not compared to the autumn's production volume. However the validity still remains credible for the spring production volume. The mapping of the factory is compared with previous work done by other students, some parts for the current state is changed for this project and some other information is confirmed through interviews. Therefore is the overall mapping of the factory both fairly reliable and valid.

5 Result

In the following section the results from all the different computations of the Hungarian algorithm are listed below. First, the results from the first method are represented as A1… A6. Second the results from the three- iteration method are presented as B1, B2, B3. Lastly, the result from the priority method is presented as C.

5.1 Result – Hungarian Algorithm – With Different Scenarios

TABLE 3. SHOWS THE RESULT FROM THE HUNGARIAN ALGORITHM WHERE SIX DIFFERENT SCENARIOS ARE PRESENTED. THE NUMBER OF PALLETS BEING STORED IS MAXIMUM, MINIMUM, MEDIAN, AVERAGE, THE WEEK WITH MOST MATERIAL FLOWS AND LASTLY ONLY WHEN PACKAGING MATERIAL IS CONSIDERED. THE LETTERS IN THE TABLE CORRESPONDS TO THE OPTIMAL STORAGE ASSIGNMENT FOR EACH LINE UNDER SCENARIO A1…A6, AND REFER TO THE MAP OF STORAGE LOCATIONS, SEE FIGURE 2 AND 3. MORE EXPLICIT EXPLANATION ABOUT THE DIFFERENT SCENARIOS IS PRESENTED IN TABLE 2.

Scenario / Lines	Max	Min	Median	Mean	Max week 34	Pack material max
FBV	E	E	E	E	E	E
FBK	A	A	A	A	A	A
J1V	E	J	H	H	H	H
J1K	P	P	G	P	P	G
J6V	J	I	J	J	J	J
J6K	C	C	C	C	C	C
TwV	V	R	V	V	V	R
TwK	AA	V	P	AA	AA	P
ObV	I	H	I	I	I	B
ObK	G	G	AA	G	G	V
NoV	N	N	N	N	N	I
NoK	U	U	U	U	U	U

The result in table 3 does not consider the number of pallet places for each storage location. Thus, it only regards the most suited storage location. The production lines FbV, FbK and NoK are the only production lines that are given the same storage location for all the A1 – A6. The other production lines changes for A1 and A2 since these are "extreme" or "worst case scenarios" and for the A6 it only considers the storage on the first floor.

5.2   Result – Hungarian Algorithm – With Three Iterations

TABLE 4: RESULT FROM THE HUNGARIAN ALGORITHM WITH THREE ITERATIONS IS SHOWN HERE. THE NUMBER IN BRACKETS CORRESPONDS TO THE STORAGE CAPACITY.

Production line	Hungarian 1	Hungarian 2	Hungarian 3
FbV	E(300)	D(66)	-
FbK	A(436)	W(75)	-
J1V	H(40)	N(30)	W(47)
J1K	P(14)	G(42)	R(82)
J6V	J(24)	C(10)	-
J6K	C(68)	-	-
TwV	V(21)	T (because of cooling)	-
TwK	AA(120)	-	-
ObV	I(24)	Stored close to production line	-
ObK	G(160)	-	-
NoV	N(36)	-	-
NoK	U(11)	V(21)	Q(104)

The result from B3, (shown in Table 4 in column "Hungarian 3") it is only the production line J1V with 179 pallets and NoK with 23 pallets that have pallets left to be stored. The storage locations on the first floor are not considered for B2 and B3, as mentioned in Section 4.3.2 (shown in Table 4 in Hungarian 2 and Hungarian 3.). For instance, the material for ObV is a special case and not considered since its material is already stored close to the production line. This is also the case for TwV, because the pralines need a cooling storage, storage location T is preselected.

There are plenty of storage locations to be filled, which can be seen in appendix a. This iteration is done when the amount of articles existing in the storage is maximum. What can be interpreted here is that the storage locations are not used completely at any time of the year.

5.3   Result – Priority Method – Independent Matching

Many production lines prioritise the same storage locations; which can be seen in appendix c. What is common with these storage locations is that they are located in the centre or in the south of the factory when looking at the map in figure 3 in section 2.2.
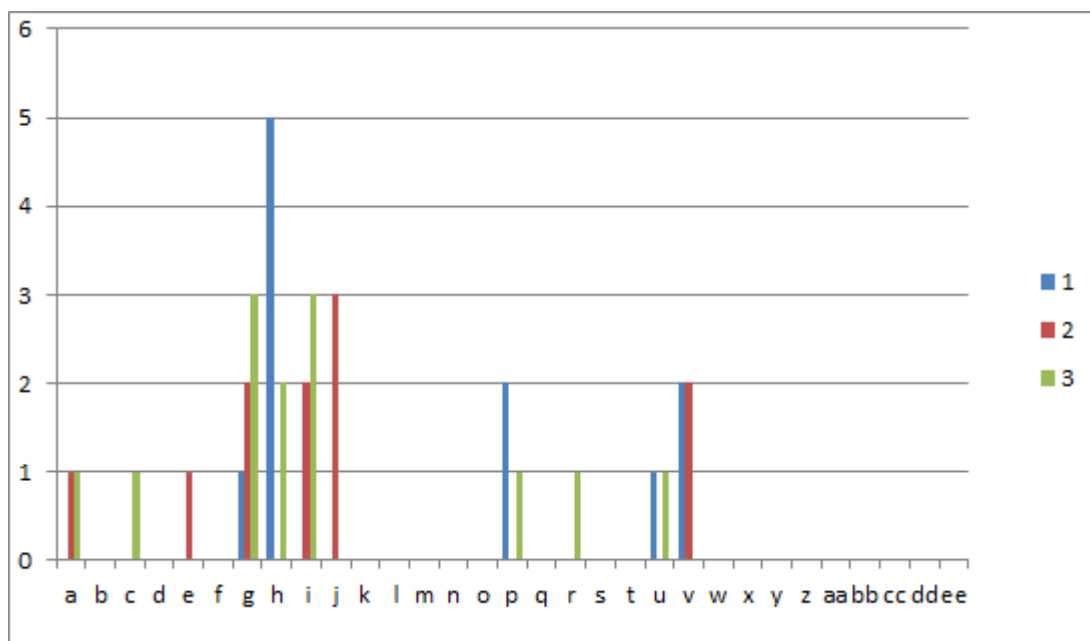
As the result in figure 8 shows, the most popular storage locations are G, I, K, P and Q for all the production lines in the factory.
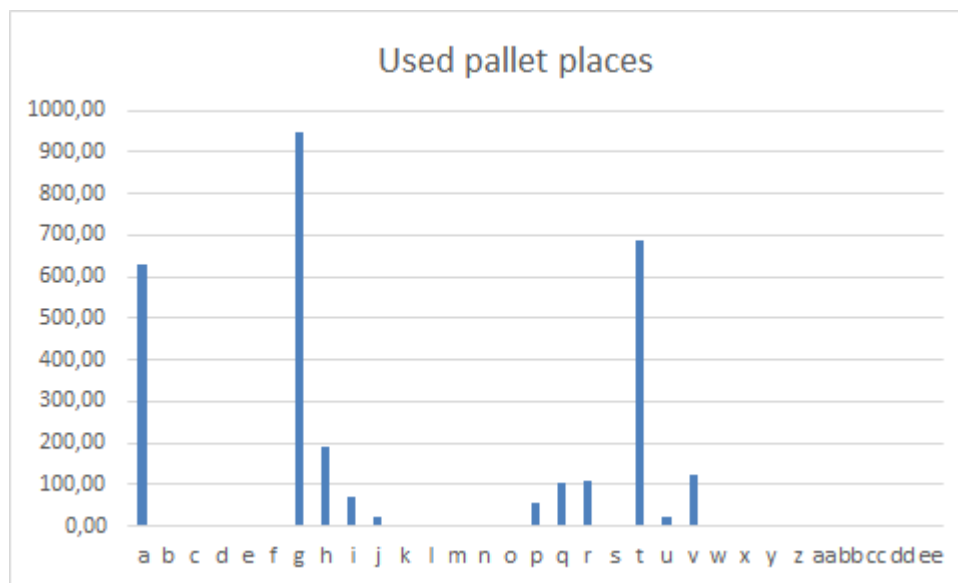
FIGURE 9. SHOWS HOW THE PALLETS SHOULD BE PLACED IN THE FACTORY IF ALL LINES ARE INDEPENDENT AND THEY COULD STORE THEIR PALLETS ACCORDING TO THEIR PRIORITISATION. HOWEVER, THIS IS NOT A REALISTIC VIEW OF THE FACTORY. THE X-AXIS REPRESENTS THE STORAGE LOCATION AND Y-AXIS THE NUMBER OF USED PALLET STORAGE LOCATIONS.

As figure 9 shows the storage location that is used the most it G. Other popular storage locations are A and T.

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5.4   Result for Each Production Line

> *In this section a map for every production line is presented, with a red star for every storage location the priority method suggests, a blue star for the three-iteration method, a green star for the six-scenario method and a purple star for the current state. If a star is in more than one colour this means that more methods have that storage location as a result. Every warm-side production line, except for TwV and ObV, has their storage locations on the first floor as well but this is not shown in any map.*

Frostbite Warm

FbV should choose storage location A for the result C. From results B1-B3, storage location E and D are chosen and the same according to the results A1-A6, which in this case is different from what the current state suggest, which is storage location H. Today some articles for FbV must be stored on the first floor, which makes the result inaccurate in a sense because the program only suggests storages in the second floor. For visualisation of the different results, look at figure 10.

FIGURE 10: MAP OF THE STORAGES FOR PRODUCTION LINE FROSTBITE WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Frostbite Cold

FbK should choose storage location A and G according to the result C. Based on the results B1-B3 FbK should choose storage location A and same for the results A1-A6. In this case is different from what the current state suggest, which are the storage locations A, D, E and S. However, since this is one of the lines with most pallets, which also means most transportation, this line should be prioritised in all cases. For visualisation of the different results, look at figure 11.

FIGURE 11: MAP OF THE STORAGES FOR PRODUCTION LINE FROSTBITE COLD. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Jensen 1 Warm

J1V should choose storage location G, H, I, J and V from result C. Based on results B1-B3, J1V should choose storage location H, N and W. Results A1-A6 chooses storage location H. Currently, storage location W, J, B and Y are used. However, it is not possible for J1V to only use storage location H because the number of pallets exceeds the allowed amount in the storage. Result C prefers storage location J after that, because it is close to the production line. Jensen 1 is the production line that stands for ⅓ of the production in the factory, therefore should be prioritised when it comes to storage locations and transportation costs. For visualisation of the different results, look at figure 12.

FIGURE 12: MAP OF THE STORAGES FOR PRODUCTION LINE JENSEN 1 WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Jensen 1 Cold

Based on result C J1K should choose storage location G, H, I, J, V, H and N. According to results B1-B3 J1K should choose storage location W. For results A1-A6 storage location P should be chosen. Today storage locations X, M, N and O are in use for J1K and if the passage between J1K and J1V became available these storage locations would probably be preferable. One interesting observation is that the suggested storage location of J1K is far away from where the storage location is located today. This was also one of the observations that were done in the beginning of the project when the forklift driver drove around the whole factory when supplying J1K with packaging material. In the past, forklifts could drive through the door that separates J1K and J1V but after an accident occurred this was prohibited. The storages however did not move which makes the transportation of it much longer today. For visualisation of the different results, look at figure 13.

FIGURE 13: MAP OF THE STORAGES FOR PRODUCTION LINE JENSEN 1 COLD. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Jensen 6 Warm

According to result C, H is the storage location J6V prefers. Results A1-A6 chooses storage location J and results B chooses storage location J and C. All of these suggested storage locations are different from the current state, which is storage location B. All of these storage locations are located close to each other and it is not so many pallets that need to be transported so it does not matter which storage location that is chosen. For visualisation of the different results, look at figure 14.

FIGURE 14: MAP OF THE STORAGES FOR PRODUCTION LINE JENSEN 6 WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Jensen 6 Cold

According to result C, J6K chooses storage location C, H, and I. From results B1-B3 J6K should choose storage location C. For the results A1-A6 it suggests storage location C. The current state storage location B is used. For visualisation of the different results, look at figure 15.
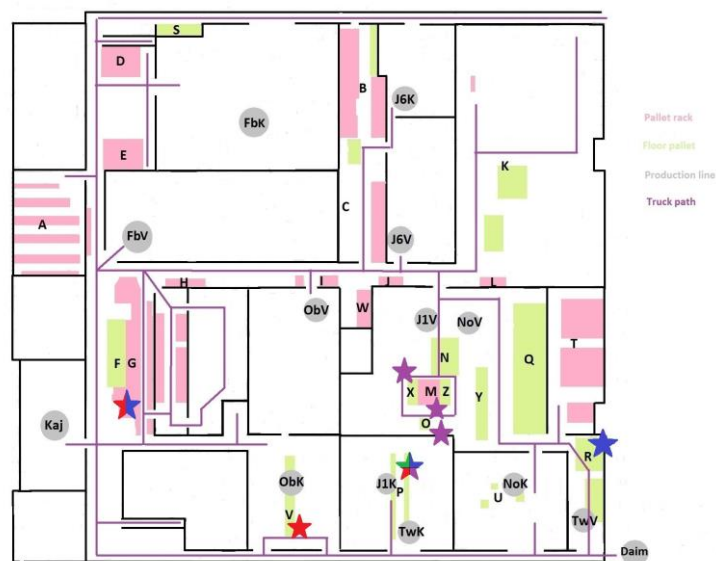

FIGURE 15: MAP OF THE STORAGES FOR PRODUCTION LINE JENSEN 6 COLD. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Twist Warm

According to result C, TwV prefers storage location G, P, Q, R, T, U and V. The results B1 – B3, TwV chooses storage location V and T. According to results A1-A6 TwV should choose storage location V. The current state suggests storage location T, Q and R. This is the production line with most pallets, as shown in figure 1. The pallets are also in need of a cold storage location, for

example storage location T as is used today. For visualisation of the different results, look at figure 16.

FIGURE 16: MAP OF THE STORAGES FOR PRODUCTION LINE TWIST WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Twist Cold

According to result C, the storage locations G, P and V are preferred. Result B1-B3 and A1-A6 chooses storage location AA. The current state is storage location AA and P. No change should therefore be done. For visualisation of the different results, look at figure 17 and 18.

FIGURE 17: MAP OF THE STORAGES FOR PRODUCTION LINE TWIST COLD, LEVEL 2. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

FIGURE 18: MAP OF THE STORAGES FOR PRODUCTION LINE TWIST COLD, LEVEL 1. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

O'boy Warm

ObV should prioritise storage location G, H and I according to result C. ObK should choose storage location I, which resulted both in B1-B3 and A1-A6. Therefore, this line does not have to change from what it is currently in use since this is the optimal place for storage. Also some pallets need to be stored in the ObV section, which is not shown in the map since these storage locations only were meant for some specific articles. For visualisation of the different results, look at figure 19.

FIGURE 19: MAP OF THE STORAGES FOR PRODUCTION LINE O'BOY WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

O'boy Cold

ObK should prioritise storage location G and V according to result C and storage location G according to results A1-A6 and B1-B3. These are also the storages that are currently in use, meaning no changes are necessary regarding this production line. For visualisation of the different results, look at figure 20.

FIGURE 20: MAP OF THE STORAGES FOR PRODUCTION LINE O'BOY COLD. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Noblesse Warm

NoV should prioritise storage location H according to result C and storage location N according to results A1-A6 and B1-B3. Today storage location N and Z are in use which means the storages do not have to be moved. These storages are also closer the production line and therefore should be preferable. For visualisation of the different results, look at figure 21.

FIGURE 21: MAP OF THE STORAGES FOR PRODUCTION LINE NOBLESSE WARM. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

Noblesse Cold

NoK should prioritise storage location P, Q, R, U and V according to result C. From the results B1-B3 storage locations U, V and Q should be chosen. From result A1-A6 storage location U should be chosen. Currently the storage locations are U and AA. Therefore NoK should not use storage location AA because all methods suggest that. For visualisation of the different results, look at figure 22 and 23.

FIGURE 22: MAP OF THE STORAGES FOR PRODUCTION LINE NOBLESSE COLD, LEVEL 2. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.
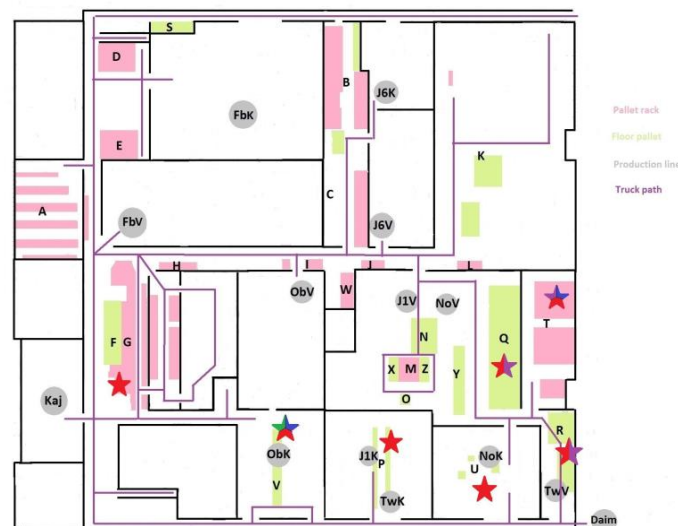

FIGURE 23: MAP OF THE STORAGES FOR PRODUCTION LINE NOBLESSE COLD, LEVEL 1. GREEN = A1-A6, BLUE = B1-B3, RED = C, PURPLE = CURRENT STATE.

5.5   Summary of the Results

In conclusion, the storage locations that should be chosen for the most important production line, based on the result C this storage location is H (five production lines prioritised this storage location the highest and two production lines prioritised this the second highest), G (one production line prioritised this storage location the highest, two production lines prioritised this the second highest and three production lines prioritised this the third highest), V (two production lines prioritised this storage location the highest and two production lines prioritised this the second highest), I (two production lines prioritised this storage location the second highest and three production lines prioritised this the third highest) and P (two production lines prioritised this storage location the highest and one storage location prioritised this the third highest). The rest of the storage locations are prioritised between the highest and the lowest of two or less production lines. Because many production lines want the same storage locations these should be divided based Marabou's priorities. What is significant for these popular storage locations are that they lie in the central part of the factory with good transportation possibilities to and from the dock and most of the production, as shown in figure in section 5.4.

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6   Discussion

In this part, we discuss the mathematical model as well as the result with regard to theoretical and practical issues. Secondly, we suggest different improvements and how they could be implemented in practice.

What could be concluded based on the results A1 – A6?

From table 3 one can see great similarities between the results from the different scenarios. This means that it doesn't really matter how much material that is in the storage, the placement of the material will more or less be the same over time. Our work tells us which storage that should be used, which does not always match up with the current storage. Marabou should have some efficiency savings already by interpreting this result. In reality more storage locations need to be used for each production line than shown in table 3.   However, the prioritisation does not consider the number of pallets that are being transported.

What could be concluded based on the results B1 – B3?

Based on the result from the Hungarian algorithm with three iterations a complete plan for the storage management of the factory can be implemented. The result is not completely accurate due to the fact that we match all the pallets to one storage location. This result however is better to use in reality because the materials that belongs to one production line will be collected in a few storage locations instead of spread out in the factory, which is also desired for by Marabou. Although, it can be good to make further investigations by sending each pallet to one storage location and compare this with the result when all pallets are sent to one storage location. The Hungarian algorithm exactly solves our problem because it makes a clear prioritisation based on the transportations cost and the pallet flow. This result also shows that all material can fit in the storages on the second floor, which was a result that was requested by Marabou. As the result states, there are many storage locations that still has empty spaces after the three iterations method. To sum up, this is also the method we suggest should be used for prioritising because it is the most accurate and it is dependent on every line and gives a complete storage plan for the whole factory.

What could be concluded based on result C?

The result shows the most popular storage locations in the factory. The interesting fact is, as mentioned before, that most of the storage locations either lie in the central or close to the production lines. More detailed description and visualisation is shown in figure 3. The transportation costs from the storage locations in the south are less than the transportation costs from the storage locations in the north, which is why these are chosen.

Firstly, An advantage of this result is that one can interpret that the most popular paths are the middle-path or south-path. Because of the high usage of the paths they probably require higher maintenance.

Secondly, numbers of pallets are taken into consideration. By looking at the map for this prioritisation method some storage locations are popular for many production lines. For

example storage location G is seen as important for most of the lines, however to place all the pallets there is not possible. Another disadvantage is that the pallets are distributed and spread across the factory, which is not preferable for Marabou. Marabou desire to store most of the pallets in the same storage location or, failing that, in several nearby located storage locations.

What could be concluded based on the pallet flow method?

Figure 1 in section 2.1 shows the inventory level, thus the total number of pallets for each production line for every week during 2016. The interesting fact about this pallet flow is that TwV is the production line with most pallets every week. Therefore, TwV should be prioritised. Also FbK, J1V and Vall should be prioritised since these production lines require a more frequent storage management. The remaining production lines do not have high frequency but rather more constant flows, which suggests that these pallets should be prioritised after TwV, fbK and J1V.

What could be interpreted by comparing all results and the current state?

By comparing the results from all different methods used in this report the most accurate of them all is the three-iteration method since the result is dependent on all the production lines. However, if Marabou wants to make their own prioritisation they should consider the most vital production line according to the priority method. One suggestion is also to not reserve the storage locations to a specific production line. Instead one should see them as ordinary storage locations that any production line's pallets could use. For example, today storage location V belongs to ObK because it is the one closest to the production line. Instead J1K could use parts of the storage location to save time and transportation cost, instead of using storage M. The six-scenarios method suggests storage AA for TwK and ObK that is on the first floor.

In the end, all methods are used to iterate an optimal storage location for all the pallets with regards to the transportations cost. There are different parameters that should be evaluated when making the prioritisation such as supply and demand, volatility of the inventory level and the relative importance of the production line to the central factory. Also, some production lines such as TwV and ObV needs special storage locations due to cooling or special packaging. What could be interpreted from the result above is that most of the storage locations should be more centralised than decentralised thus the storage locations used should be located in the centre of the factory, closer to the production lines and the dock.

Storage management

To make the storage management more efficient, an implementation of a system should be done so all of employees can search and find materials in the database. The materials and articles in the factory are similar all year round. Therefore they could use a permanent inventory management. Instead, of driving around with a forklift to search for the article time can be saved by tracking a product. As mentioned in the section 3.2.2 about change management, the resistance that might occur needs to be considered when implementing the new system. It is very important to try hard when these conflicts arise and not to give in. In the end it is the forklift drivers that will gain on this change because their workload will be less. Also, making sure that every employee working with storage management has the same information about locations of material, so that the information does not lie with one or a few employees. This information could be a gathered as a working manual. Worth considering is the change

management theory mentioned in section 3.2.5, to make the implementation of the system easier.

Signal system

Today the forklift drivers drive around in the factory to search for finished pallets of materials, some garbage that can be transported to the dock or another "thing" to do. If Marabou instead implemented a signal system that was connected to the dock which states the urgency of the problem, it could be easier for the forklift drivers to plan their workload.

Rebuilt the door at Jensen 1

As mentioned in the glossary, J1 is the production line that stands for ⅓ of the production at the company. Today the opening between the warm and cold part of the Jensen 1 factory is not permitted for the forklifts. The storage for packaging materials is on the warm side of the production line and they need to be transported to the cold side, which is done by a detour. This could be great efficiency savings if – after safety improvement if necessary – this route was reopened.

Conclusion

Jensen 1 is the production line with the worst storage locations due to the forbidden passage that separates the cold and warm side of the production line. Because Jensen 1 is of great importance for the factory this problem regarding the passage that separates the warm and cold sides should definitely be looked at. Articles that are being used more frequently, thus the pallets that are in flow everyday should be prioritised and be close to the production line. In summary, a central storage location should be preferable for all production lines but for non-frequent pallets this is not as important. In this report we have given an overview of internal transport within the Marabou factory and made some suggestions for improvements and efficiency savings. We now discuss possible directions for further work building on what was achieved in this report.

7   Future Work

In this section, we discuss further development of the project, subsequent projects that can be based on our master thesis and how it can be linked and utilised with other theories.

Primarily, to make the result more accurate continued work is needed on the Hungarian algorithm. In the future, a more in-depth study of the Hungarian algorithm itself could help achieve a more accurate result. Consequently, a more precise program for implementation needs to be developed so that each pallet can be matched to one storage location.

Furthermore, the program could be used for other matching problem such as matching a forklift driver to jobs. Also, if Marabou would give a linear order of priorities on its production lines, then this kind of data could be used together with a Gale-Shapley algorithm to find a good matching. For example reserving certain storage locations (namely those used for cooling and heating) for certain materials could be prioritised.

Minimise forklift paths

Additionally, minimising the transportation cost could also be done as a master thesis project. For this future project, exact measurements of the paths should be measured by tracking the distances with a GPS-reader and then develop a spaghetti diagram. Thereafter, vertices, which are the storage locations are connected with an arc which will represent the transportation cost, this is a typical travelling salesman problem.

Forklift driving

Considering that some pallets can be driven two by two by a forklift with max weight 1000 kg, there should be a specific implementation and investigation for this case as well. This could be a further development from the travelling salesman problem.

A knapsack problem

This future project could be investigated to find the security level, which is the minimum amount of pallets that have to be stored in the storage. By making a so called knapsack problem, which allows to maximise the capacity of storages and minimising the cost? This problem also shows how to load the materials in the specific storage location.

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Appendix

a. List of the contents and number of pallets of each storage locations

2nd floor	Nr of pallets	Current content and production line
A	436	Packageing material for FbK and J1K
B	434	Packageing material and rawmaterial
C	228	Daim
D	200	FbK
E	300	FbK
F	191	Empty pallets
G	202	Packageing material ObK and empty pallets
H	40	Raw material FbV
I	24	Packageing material Daim
J	24	Raw material FbV J1V J6V
K	41	Empty pool
L	41	Empty pool
M	108	Packageing material J1K
N	66	Packageing material J1K
O	14	Packageing material J1K
P	14	Packageing material TwK
Q	104	Pralines TwV
R	108	Pralines TwV
S	20	Empty pallets FbK
T	689	Pralines TwV
U	11	Packageing NoK
V	21	Packageing ObK
W	75	Raw material
X	18	Packageing material J1K
Y	14	Chocolate shapes
Z	10	Raw material
Sum 2nd floor	3433	
1st floor		
AA	788	Raw material
BB	110	Raw material
CC	202	TwK (not int use)
DD	730	Raw material
EE	726	Raw material NoK
Sum 1st floor	2556	
Sum of all	5989	

b. The different transportation costs from each production line to each storage location. All distances are added with the distance from the production line to the dock. It is in total 30 storage locations (without storage F).

	FBV	FBK	J1V	J1K	J6V	J6K	TwV	TwK	ObV	ObK	NoV	NoK
a	21	18	37,5	51,5	35,5	41	59,5	50,5	30,5	45	39	57,5
b	57,5	63,5	46	82,5	37	42,5	94	84,5	45	80	49,5	92,5
c	58,5	44,7	33	67	30	32	81	72	32,5	67	34,5	79,5
d	26	32,5	50,5	63	47,5	53,5	70,5	61	43	57	51	69
e	22	28	49	61,5	46	52	69	59,5	41,5	55,5	49,5	67,5
f	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
g	24,5	17,5	30	29	27	33,5	46	37,5	23,5	21,5	31	45
h	25,5	18,5	26,5	49	23,5	30,5	56,5	47	20	30,5	27,5	55
i	40,4	33,4	28,5	63	25	31,5	70	61,5	21,5	45	29	70
j	47,7	40,7	27,5	70	24	33,5	77	68,5	28,5	52	28	77
k	64,8	59,8	88	89,5	43,5	43,5	97	88	48	74,5	43	95
l	57,8	50,8	78,5	80	34	34	87,5	78,5	38,5	65	33,5	85,5
m	65	58	34	65,5	37,5	49	51	62	44	71	37	58,5
n	60,6	53,6	31	62	34,5	46	47,5	58,5	41	68	31	55
o	68	56,2	42	68	45,5	55	53,5	64,5	50	77	40	61
p	68,4	61,4	78,4	26,5	72,1	79,2	40,4	27,5	69,5	37,6	92,7	40
q	71,6	64,9	43,4	60,2	47,4	59,6	45,9	56,5	52,8	65	41,7	41,2
r	81,1	74,1	51,4	55,2	57,4	67,3	39,9	51,5	60,1	62,1	49,9	42,5
s	63,5	44	52,2	71	50,2	44,6	66,5	72,8	52,4	69,5	50,9	62
t	53	71,5	50,6	62,4	54,8	64,9	47,2	58,6	59,6	68,4	47,5	48
u	75,7	67,2	47,8	44,5	62,1	52	39,7	40,7	56,8	51,5	45,7	33
v	53,8	46,8	29,3	29,3	59,4	69,5	37,1	28,1	48	19	54,2	35,4
w	47,5	40,5	32,7	67,9	28,5	35,6	48,9	70,4	28,5	66,6	33,8	44,5
x	63,6	56,6	35	66,5	38,5	50	52	63	45	72	38	59,5
y	62,6	55,6	34	64	37,5	49	49,5	60,5	44	71	37	57
z	63,6	56,6	38	66,5	41,5	51	52	63	46	73	36	59,5
AA	42,5	45,7	61,4	47	57,2	77,8	54,8	45,8	53,4	41,9	62,5	53,1
BB	53,5	56,7	72	58	68,2	88,8	65,8	56,8	64,4	53	73,5	64,1
CC	56,1	59,3	75	60,6	70,8	91,4	68,4	59,4	67	55,6	76,1	66,7
DD	52,9	56,1	71,8	57,4	67,6	88,2	65,2	56,2	63,8	52,4	72,9	63,5
EE	61,5	64,7	80,4	66	76,2	96,8	73,8	64,8	72,4	61	81,5	72,1

c. List of the result from the priority method. The storage locations are listed in the correct order.

Production line	Priority method
FbV	A
FbK	A,G
J1V	G,H,I,J,V
J1K	G,P,V
J6V	H
J6K	C,H,I
TwV	G,P,Q,R,T,U,V
TwK	G,P,V
ObV	G,H,I
ObK	G,V
NoV	H
NoK	P,Q,R,U,V