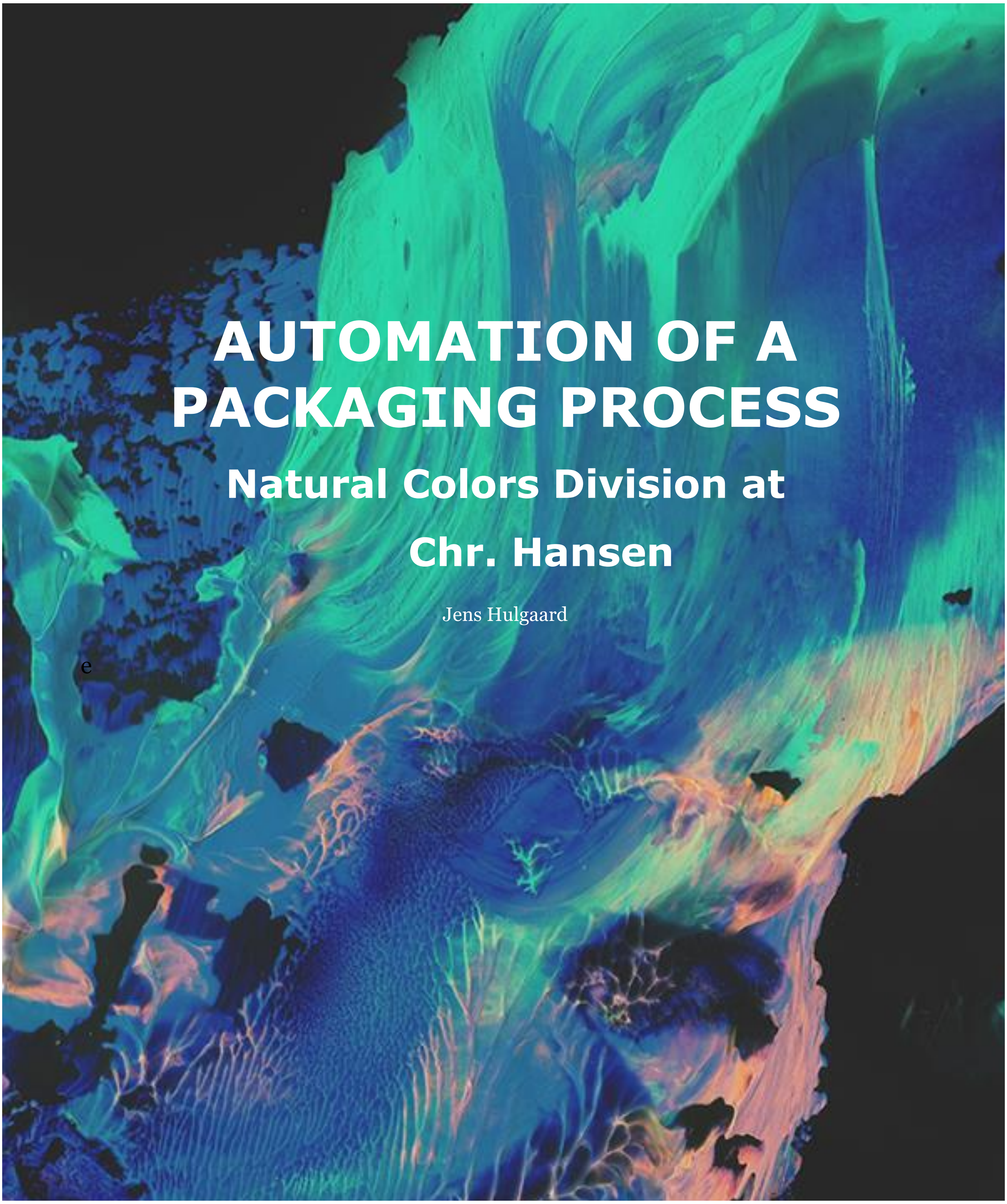
UMEÅ UNIVERSITY



AUTOMATION OF A PACKAGING PROCESS

Natural Colors Division at Chr. Hansen

Jens Hulgaard

Master’s thesis, 30 credits
MSc Industrial Engineering and Management, Logistics and Optimization, 300 credits
Spring term 2020

Abstract

Automation is the future. Sometime in the future, warehouses will be fully automated. Already today, many warehouses around the world have reached a high degree of automation. This master's thesis project aims to evaluate how a warehouse site within Chr. Hansen Holding A/S can take one step further in this direction. Chr. Hansen Holding A/S is a global bioscience company.

The packaging process currently relies primarily on manual labor, and the focus is to investigate methods to improve this process through automation. The process of packing goods on a pallet consists of the following steps; transport to the packing area, label the products, move the products to a new pallet, measure, apply protection, wrap, label the pallet, and transport to temporary storage.

In order to automate a process, some degree of standardization is needed, but many parameters constrain this development. An important parameter is variation in terms of material and packaging, both interior and exterior, such as pallet type. The packaging process can be divided into a number of subfunctions by Function Analysis. Together with Process Activity Mapping, the study suggests that the relevant part of automating is the last part of the packing process, from the step *wrap* mentioned earlier.

The project has developed five different concepts. All of the concepts include a fully-automatic wrapping machine. The five concepts have different methods of transporting finished pallets to storage at the other end of the warehouse. The investigated transport methods are various lengths of conveyor belts, an automated guided forklift (AGV), a combined conveyor belt-AGV solution, and human-operated forklifts.

The study suggests a solution with a fully automated wrapping machine followed by a 9 m conveyor belt followed by transport with a human-operated forklift. The wrapping machine should include modules for labeling and weight and height measuring. The improvement is most likely to reduce cost packing by 460,000 DKK per year calculated in fixed prices of 2019. It requires an investment of 1,500,000 DKK.

The project finds that the wrapping machine is the most beneficial part of the concepts, but an AGV solution could be an interesting addition with a great future perspective. The company should follow the development of AGV technology in relation to warehousing.

Furthermore, the project improves safety in the warehouse by reducing the forklift traffic in the packaging area.

Sammanfattning

Automatisering är framtiden. Någon gång i framtiden kommer lager att vara fullt automatiserade. Redan idag har många lagrar en hög grad av automatisering. Detta examensarbete har som mål att evaluera hur ett lager inom Chr. Hansen Holding A/S kan ta ett steg i denna riktningen. Chr. Hansen Holding A/S är ett globalt bioscienceföretag.

Studien har som mål att utveckla och evaluera metoder för att reducera kostnader i paketeringsprocessen i ett lager. Paketeringsprocessen beror i nuläget primärt på manuellt arbete, och studiens fokus är att undersöka hur denna process kan förbättras genom automatisering. Paketeringsprocessen av varor på en pall innehåller följande steg: transport till paketeringsområdet, sätta label på produkter, flytta produkter till en ny pall, mäta, påsätta skydd, emballera, påsätta label på pall och flytta till tillfälligt lager.

För att automatisera en process krävs någon grad av standardisering, fast många parametrar begränsar detta. En viktig parameter är variationen av material och förpackning, båda inre och yttre som t.ex. typ av pall. Paketeringsporcessen kan indelas i ett antal subfunktioner med hjälp av Funktionsanalys. Tillsammans med Process Activity Mapping rekommenderar studien att den enklaste delen att automatisera är sista delen av processen, från och med steget *emballera* som har nämnts tidigare.

Projektet har utvecklat fem olika concepter. Alla dessa concepten inkluderar en helautomatisk emballeringsmaskin. De fem concepten has olika transportmetoder av färdiga pallar till en plats i andra änden av lagret. De undersökta transportmetoderna är transportband i olika längder, en självkörande gaffeltruck (AGV), en kombination av en AGV och ett transportband och slutligen en människostyrd gaffeltruck.

Studien rekommenderar en lösning med en helautomatisk emballeringsmaskin följd av ett transportband på 9 m följd av transport med människostyrd gaffeltruck. Emballeringsmaskinen bör inkludera moduler för påsättning av label och vikt- och höjdmätning. Förbättringen kommer mest sannolikt att ge en reducerad kostnad på 460,000 DKK per år beräknad i fasta priser för 2019. Detta kräver en investering på 1,500,000 DKK.

Projektet finner att emballeringsmaskinen är den mest fördelaktiga delen i concepten, men en AGV-lösning skulle kan vara en intressant tillkoppling med goda framtidiga perspektiv. Företaget bör följa utveckling inom AGV-teknologin i relation till lager.

Projektet vill dessutom förbättra säkerheten i lagret eftersom gaffeltrucktrafiken i paketeringsområdet reduceras.

Acknowledgments

I would like to thank Carsten Hansen for allowing me to write this master's thesis in the warehouse site Hammerholmen within Chr. Hansen. Further, I would like to thank my supervisor at Chr. Hansen, Thomas Søgaard. He has been an excellent help for brainstorming and in keeping me on the right track. Thanks as well to my supervisor at Umeå University Robert Johansson, who has helped with the more academic details. This thesis would not have been possible to write without the corporation of the warehouse workers at Hammerholmen, which is why I want to thanks all warehouse workers as well.

Contents

1 Introduction

1.1 Introduction to the Company

Chr. Hansen is a global bioscience company and a supplier of ingredients for food, pharmaceuticals, and agriculture. More than one billion people consume Chr. Hansen's products every day. (Chr. Hansen, n.d.)

Chr. Hansen is mainly known for its bacteria cultures for the production of dairy products such as cheese and yogurt. However, the company produces natural colors, e.g., from beetroot and potatoes, as well. The natural colors division accounts for approximately 20 % of the company's sales and ships 16-17 000 tons of natural color a year. This project will concern processes in a warehouse in the natural colors division. (Søgaard, 2020)

The warehouse is located at Avedøre Holme in Copenhagen, Denmark, and supports a factory nearby.

The warehouse handles inbound and outbound goods for the factory, inventory, and packaging of goods for shipping. Pallets with goods are received and shipped by truck, stored, and repacked before shipping inside the warehouse. The warehouse has a very high storage density (99 %), and in addition to this warehouse, the site makes use of three external warehouses to increase the storage capacity. (Hansen, 2020)

1.2 Introduction to the Problem

There are many areas to explore in a warehouse, and I was free to choose almost any project within this warehouse. This project has been selected among many possibilities. The focus in selecting a project has been to find a relevant and exciting project for a master's thesis, which would also add value to Chr. Hansen.

The problem chosen for this project is a project regarding the packaging process. I and the management of the warehouse suspect that the packaging process is a significant bottleneck and that a reduction of this bottleneck will yield the most considerable increase in productivity.

Before starting the project, we need to ensure that it is relevant to optimize the packaging project. The employer requires a brief analysis to prove this argument.

1.3 Problem Description

1.3.1 Main question

How can we reduce the cost of the process from order to shipment by improvements in the packaging process?

1.3.2 Minor questions

What improvements are required to gain a significant effect on the cost?

What is the cost of the required investment of the proposed projects?

2 Background

The reason why the project aims to improve the packaging process lies in the suspicion that this process has the greatest potential in terms of cost-improvement. In order to prove this suspicion, a brief analysis of the whole outbound process has been conducted.

2.1 The entire outbound process

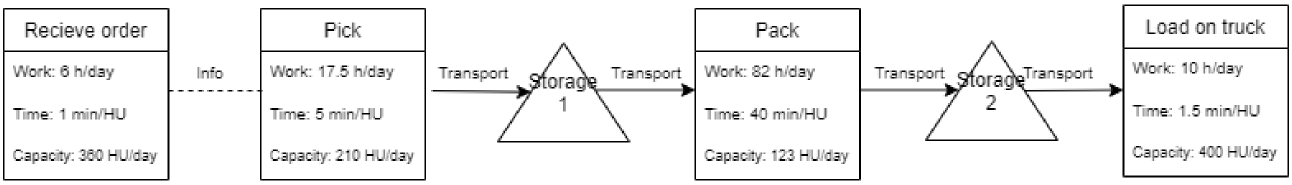


Figure 1. A flow chart of the outbound process

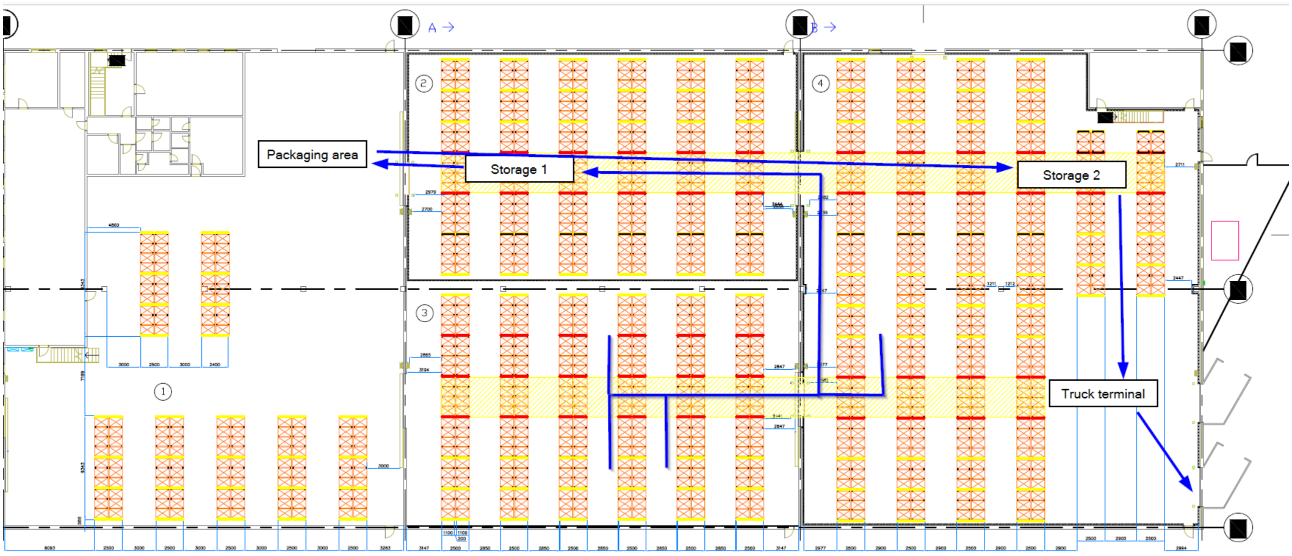


Figure 2. A map of the warehouse. The blue arrows show the process in Figure 1.

The outbound process in this warehouse starts when the warehouse receives an order. The process ends when the order has been shipped. Figure 1 shows the process flow, and Figure 2 illustrates this process in the warehouse.

When the warehouse receives an order from customer service, it is confirmed and added in the warehouse database system, SAP, and will be ready to pick from the warehouse. The employee responsible for receiving orders chooses which item to pick and makes a picking list in SAP.

An order can consist of goods in the range from only one item to an entire container of goods. Small orders are packed in boxes or cartons, while larger orders are shipped on several pallets. The average number of units per order during 2019 was 4.3.

In the step of picking, a warehouse worker selects an order, a location of each item will be shown, and the worker can collect each item by forklift and deliver the items to the pre-packing storage, which is storage 1 shown in Figure 1 and Figure 2.

Workers in the packing process select orders from a monitor showing orders ready to pack and collect them in the pre-packing storage. The order is then packed and sent to the post-packaging storage by forklift.

Finally, workers in the goods reception area pick goods from the post-packaging storage (storage 2) and deliver the goods to the courier or load on a truck.

2.1.1 Bottleneck Detection

According to and (Lawrence & Buss, 1995) and (Wang, et al., 2005) there is no single exact definition of a bottleneck. However, there seems to be a consensus of a bottleneck to be a limiting part of a system.

2.1.1.1 Bottleneck definitions

(Wang, et al., 2005) defines bottlenecks as either based on *Performance in Process (PIP)* or *Sensitivity*.

PIP based definitions are measured in either *Average Waiting Time (AWT)* or *Average Utilization (AU)*. The AW definition refers to the machine or process step with the longest waiting time. It is a suitable definition if there is no or only limited intermediate storage before the process step. In the AU definition, the bottleneck is the machine with the highest utilization ratio, specified as a busy/idle ratio. I.e., the machine that is running the most time is the bottleneck by this definition. I this case, a process step is regarded as a machine.

(Wang, et al., 2005) defines sensitivity based definitions as the machine that has the greatest impact on the overall performance of the system. Thus, if changes are made on this particular machine, it will have the greatest effect on the system in comparison to similar changes on other machines. These bottlenecks are divided into the production bottlenecks and economic bottlenecks.

(Wang, et al., 2005) describes four different production bottlenecks. These four definitions each focus on uptime, downtime, circle time, or production of each machine and its effect on the overall throughput of the production system. The uptime definition looks at the uptime of each machine. The production rate of the system can be described as a function of the uptime of each machine. The question is: if the uptime of a machine is increase by one unit, then what is the marginal change in the production rate of the system? The machine with the greatest effect is defined as the bottleneck. Similarly, the downtime bottleneck is the machine where a decrease in downtime has the greatest effect on the production system.

The economic definition is based on the congestion cost. The machine where a marginal increase in capacity gives the highest decrease in congestion cost is the bottleneck.

2.1.2 Distribution of workload

The current distribution of warehouse workers gives the available working time, as shown in table 1. This distribution is not fixed, and it only shows the workers' priority.

Table 1. Available working hours work per day based on the work schedule.

PROCESS\WEEKDAY	MON	TUE	WED	THU	FRI	AVERAGE (HOURS)	SHARE (%)
ORDER RECEPTION	6	6	6	6	6	6	5%
PICK	17.5	17.5	17.5	17.5	17.5	17.5	15%
PACK	85	85	85	85	70	82	71%
LOAD TRUCK	10.75	10.75	10.75	10.75	7	10	9%
TOTAL	120.25	120.25	120.25	120.25	101.5	116.5	100%

As shown in table 1, the packing process consumes approximately 70 % of the working hours.

2.1.3 Capacity

Table 2. Required work for each process in the outbound process and the capacity based on table 1.

WORK REQUIRED	ESTIMATED AVERAGE WORKING TIME	TIME RANGE	AVAILABLE WORKING HOURS PER DAY	CAPACITY PER DAY
RECEIVE ORDER	1 min	0.25 – 8 min	6	360 units
PICK HANDLING UNIT	5 min	2-20 min	17.5	210 units
PACK HANDLING UNIT ON PALLET	40 min	7 – 120 min	82	123 units
LOAD HANDLING UNIT ON TRUCK / TO CURRIER	1.5 min	1-3 min	10	400 units

An administrative employee handles the first step in the outbound process. Usually, an order only takes a few minutes to treat. Errors occur frequently, but the average time of this process is not more than 4 minutes. During 2019 the average number of handling units was 4.3, which results in an average handling time per unit of 1 minute for this process. Order with mixed materials might as well require more work, which gives a longer handling time. However, the size of the order does not affect handling time.

The work required in the picking and the packing processes mainly depend on the quantity of the order and the variety of materials. These variables generally affect the processes equally, i.e., orders requiring a great amount of work to pick often involves much work to pack. The packing process also depends on the packaging material type, which does not affect the workload in the picking process.

Most units only take a few minutes, but some take up to 20 minutes.

The packing process is the most time-consuming. Small boxes can be packed in a few minutes. However, some goods need old labels to be replaced by new ones, which can require two hours of work per pallet. The average packing time is estimated to be 40 minutes.

The step "load on truck" is handled by the goods reception. This department has four workers on the day shift and one on the night shift. The inbound process requires approximately 75 % of their working times, which leaves 10.75 working hours per day for the outbound process four days a week and 7 hours one day a week.

In table 2, the capacity of each process step is calculated from the estimated average working time and the working hours available. This calculation indicates that the packing is the limiting step with the current distribution of working hours available. As mentioned in section 1.3.1 the schedule is not fixed. The packaging area is limited physically to have a maximum of 8-10 workers working simultaneously. With many workers in the packaging area, the efficiency decreases, and the risk of working accidents increases.

2.2 Assessing the problem – Design Process

Following a creative design process might be advisable to rethink a system and remain open to a wide range of solutions. Various engineering design models exist, but according to (Motte, 2008) they seem to share general principals. According to (Motte, 2008, p. 1), a widely accepted model and the leading representative of the systematic engineering design process is Pahl and Beitz' systematic approach (Pahl & Bietz, 2007) (later referred to as SAPB). On this basis the project will follow the principals of SAPB.

SAPB provides four broad phases in the design process, which are:

- Planning and Clarification
- Conceptualization of design
- Realization of design
- Detailing design

The project needs to ensure that improvements in the packaging process benefit the warehouse in terms of cost and lead time. We believe that a brief analysis is sufficient. The project plan can be regarded as a part of the first phase as well. Ideally, the project plan would be the second step, but in this case, the project plan is the first step. See section 1.3 for an explanation. Thirdly, the requirements for a solution needs to be clarified.

The second phase starts by abstracting the task in order to find the root of the problem. The main function or the desired system is defined in this first step of the phase. In the second step, the main function is broken down into several sub-functions. These sub-functions are reduced until the task of each sub-function is clarified. Hereafter, solutions to the sub-function are generated, and in the next step, the solutions are combined into different concepts. These concepts are then evaluated both from technical and economic criteria.

A final layout for each concept is developed in the third phase. Later in this phase, the function of the system is tested in this phase, which in this project could be by a simulation of the packaging system.

In the last phase, the final layout is detailed further and finally documented.

A social dimension in the evaluation of the design is required as well because it affects the people working in the system. The workers' perception of a potential system has a significant effect on the performance of the system as they are an essential part of it.

3 Clarification and Specification

3.1 Analysis of the Current Packaging Solution

3.1.1 Process Activity Mapping

Process activity mapping one of seven value stream mapping tools described by (Hines & Rich, 1997). In this tool, the process steps are categories into five categories to identify waste. The categories are *Operation, Transport, Inspect, Store,* and *Delay*.

Table 3. The result of the Process Activity Mapping of a packaging process.

	TOTAL	OPERATION	TRANSPORT	INSPECT	STORE	DELAY	OTHER
TIME (MIN)	38.8	23.9	10.3	2.3	0.0	0.0	2.2
SHARE OF TOTAL TIME	**100%**	**62%**	**27%**	**6%**	**0%**	**0%**	**6%**

The table above shows the total time in each category during the process of packing a pallet. *Operation* only accounts for 62 % of the entire time, which means that 38 % is categorized as waste according to the process activity mapping tool. Especially *transport* accounts for a large share of the time with 27 % or approximately 10 minutes on average. The process activity mapping was not carried out in 100 % detail in all processes. Thus, some process steps in the category *Operation* also included some movement that would lie in the category *Transport*. This only states that the potential for improvement might be even higher than what one can read from the process activity mapping.

3.1.2 Spaghetti Diagram

Looking specifically at transports in a process, then a suitable tool from LEAN manufacturing seems to be the spaghetti diagram. (Senderksá & Václav, 2017) demonstrates how a spaghetti diagram can be used to analyzing workers' movement in a production process. Figure 3 shows a spaghetti diagram of the packaging process, illustrating a worker's movement. The actions in the spaghetti diagram are matched with the steps from the process activity map (see appendix A). Storage 2 is located outside the diagram, 60 m to the right in real-world scaling.

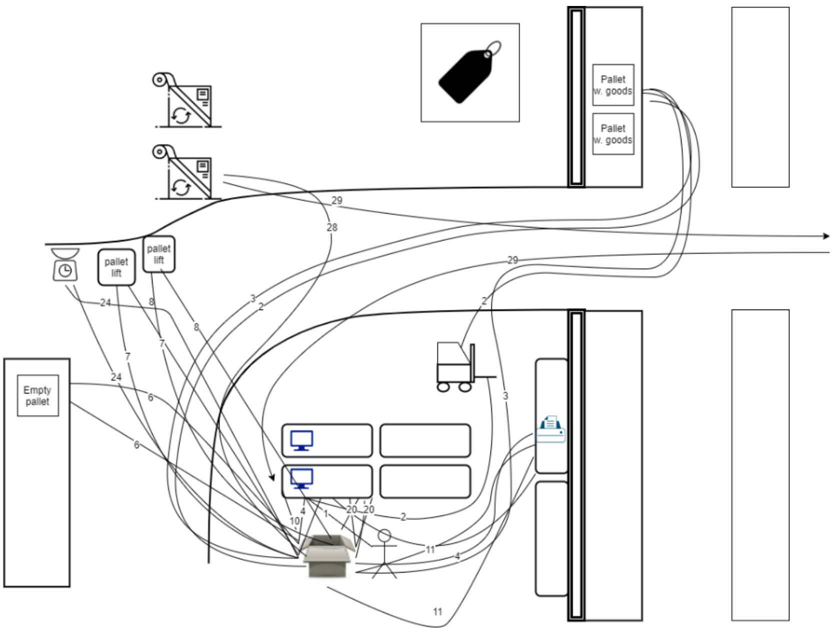


Figure 3. Spaghetti diagram of the packaging process

Further, from the spaghetti diagram, we can derive the distance covered by workers. If we summarize the length of the required movement of all the steps, we get a distance of approximately 450 meters in the particular case. We can divide the process into three phases. The first is picking goods from storage 1 and preparing all equipment. The second phase is the actual packing phase, where products are physically moved from one pallet to another, labeled, and the pallet is secured. The last stage is wrapping and transportation to storage 2.

3.2 Important Parameters

3.2.1 Material Variety

Each product is packed in some kind of packaging. A material number is unique for the given product and packaging, i.e., the same product in different packaging has different material numbers, e.g., beta-carotene in 5kg cans and beta-carotene in 10 kg cans have separate material numbers. We specify this type of packaging as inner packaging to separate it from outer packing or master packaging, which could be a pallet or a box containing several units of, e.g., 5 kg cans. (Chr_Hansen, 2020)

During the year 2019, products with 547 different material numbers have been sent from the warehouse. An ABC-analysis of the material number shows that the 20 % most frequent material numbers account for 68 % of all handling units, and the 50 % most frequent material numbers account for 93 %. Hence, the 50 % least frequent material number only accounts for 7 % of handling units. This analysis does not include handling units with mixed material numbers, which account for 21 % of the total number of handling units. (Chr_Hansen, 2020)

The mixed material number is further a dimension to consider as these units often form odd size pallets as products are combined on one pallet.

3.2.2 Outer Packaging

The warehouse ships product in 24 different types of the outer packaging. This packaging is either a pallet or a kind of box/carton. Smaller handling items are shipped in boxes or cartons, while larger handling items are shipped on pallets. (Chr_Hansen, 2020)

Pallets can generally be categorized into three categories: EUR-pallets, half EUR-pallets, quarter EUR-pallets, industry pallets, and boxes/cartons. A EUR-pallet is a well-known pallet and a general standard with the dimension 80x120 cm. Half EUR-pallets or EUR-6-pallets are simply half the size of the euro pallet with the dimension 80x60 cm. Quarter EUR-pallets are even smaller than half EUR-pallets and have a size of 40x60 cm. Industry pallets are slightly more full than EUR-pallets with a size of 100x120 cm. Finally, the category boxes/cartons contain boxes and cartons that are not shipped on pallets. (Chr_Hansen, 2020)

The chart below illustrates how the number of handling units is distributed in the mentioned categories of the outer packaging. The mixed group of boxes/cartons and quarter pallets are units that are registered as cartons but might have been shipped on a quarter pallet. (Chr_Hansen, 2020)

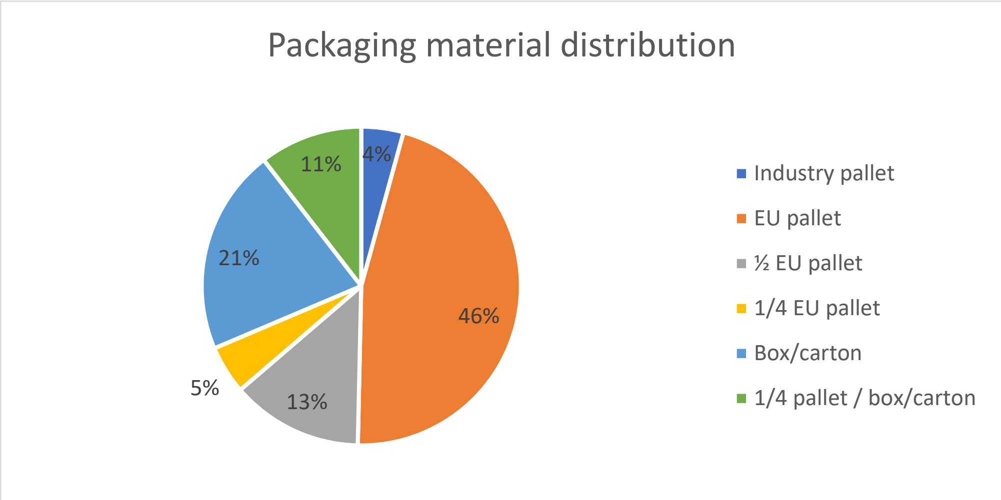


Figure 4. A diagram of the distribution of outer packaging types

3.2.3 Variation in Relation to Process

The packaging process varies depending on the material and the packaging, both interior and exterior. The article itself doesn't affect the transportation method. However, the outer packaging affects the transportation method, both to and from the packaging station. As illustrated in section 3.2.2, there are four different types of pallets and one category of boxes and cartons. A new solution for the transportation process has to consider the variation in the outer packaging.

The primary part packaging process is the operation of moving goods from one pallet to another and labeling the products. This phase varies depending on the material and the inner packaging type. The worker seals the pallet by applying protective corners and bands. This process varies with the size and shape of the pallet, which again is determined by the materials and the inner packaging. More than 500 material numbers make it challenging to standardize this process in detail (see 3.2.1). Even after performing an ABC-analysis, we still have more than 100 material numbers representing 68 % of the frequency.

(Hines & Rich, 1997) describes seven tools of value stream mapping. Among those is the production variety funnel. In this case, the production increase through the packing process as materials and outer packaging are combined. On the other hand, the variety we need to address concerning the handling of them might not be as complicated. While materials are assembled on a pallet or other source of the outer packaging, this outer packaging is practically the only appropriate variety to consider. As goods are packed, both outer packaging and materials need to be considered.

3.2.4 Weight of Units

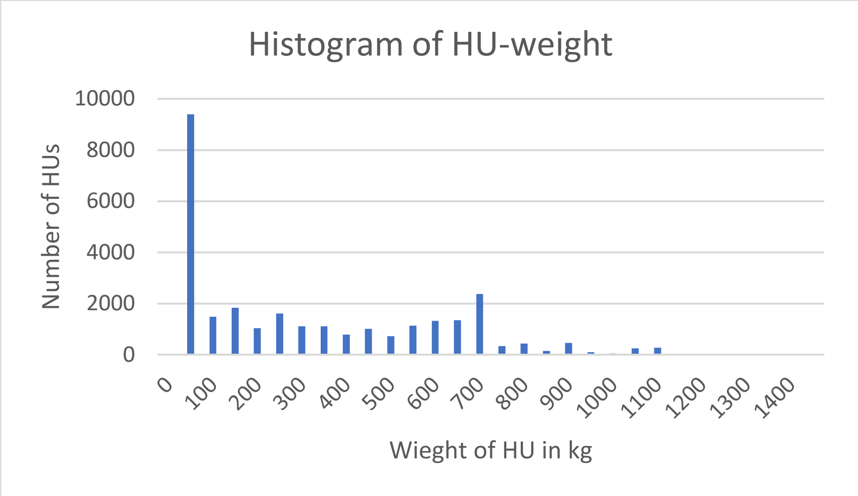
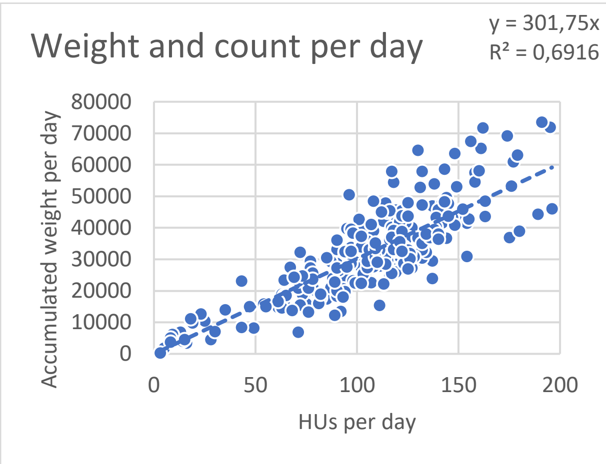


Figure 5. A histogram of the weight of handling units (HU)

Figure 5 is a histogram of the weight of HU. From this figure, we see that units of 50 kg or less represent a large share of all units. The type of outer packaging material corresponds to the weight of each handling unit (HU). 33 % of all HU weigh below 50 kg. These units are typically packed in boxes and sometimes on ¼-pallets.

In order to separate boxes/cartons and pallets, we filter out the unit with a total weight of more than 50 kg. Comparing the total weight packed per day and the number of units, we see that we obtain a better linear fit when filtering the data.



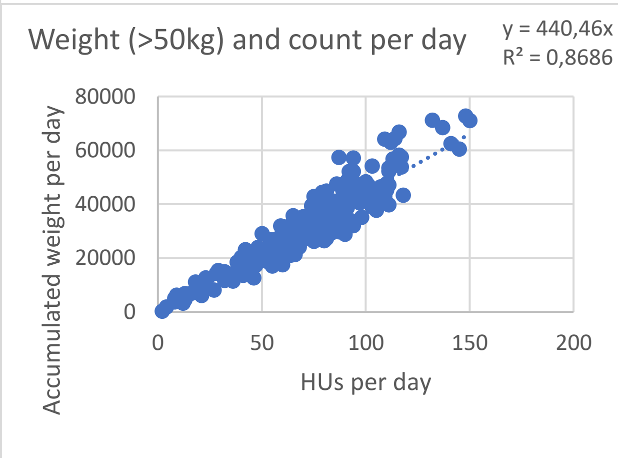


Figure 6. The correlation between count and total weight per day

Figure 7. Count and weight per day for HUs over 50 kg.

The scatter plot, Figure 6. The correlation between count and total weight per day Figure 7, shows a few points with significantly higher weight and count. These points represent days with substantially higher throughput. All days with a count higher than 130 units, they occurred at the end of February, May, and November. The explanation of the high load in these periods is due to the end of each fiscal quarter. I order to deliver and invoice order within the fiscal quarter. Many orders are pushed through by the end of February, May, August, and November.

3.2.5 Demand and throughput

The total amount of HU in 2019 was 28759 units. As mentioned in section 3.2.2, 1/3rd of these units are packed in cartons or boxes, which weigh less than 50 kg. The rest 2/3rds of units are packed on pallets, which was precisely 18963 units in 2019.

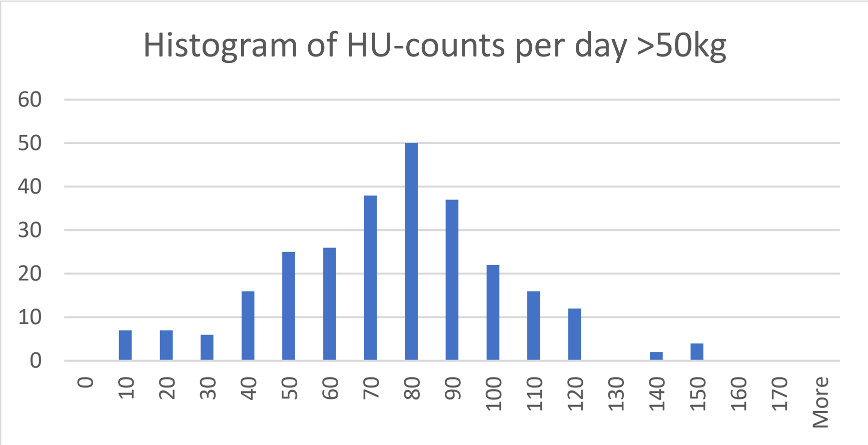


Figure 8. A histogram of HU-counts per day of HU over 50 kg.

Table 4. Statistical analysis of the histogram above.

STATISTICAL MEASURES	
MEAN	70.75746
STANDARD DEVIATION	27.2829
KURTOSIS	0.293997
SKEWNESS	-0.05651

The number of HU a day with a weight above 50 kg form a normal distribution with very little skewness and a kurtosis close to zero. A Chi-test confirms the normality test if the size of the bins in the histogram are increased to 20 units and the number reduced to 7 bins. X^2 is then 8.66, which is lower than the $X^2_{criteria}$ of 9.49 with a significance level of 5 % and 4 degrees of freedom. Since $X^2 < X^2_{criteria}$, the hypothesis that the units per day form a normal distribution cannot be rejected.

3.2.6 Specifications of the building

The warehouse building measures approximately 4000 m^2 with a length of 104 and a width of 41 meters. The packaging area is located in the northwestern corner, while goods are shipped to and from two terminals in the east end of the building. The packaging area measures 28x14 meters, and the goods receptions measures approximately 35x8 m.

Goods are stored on racks in the warehouse. Each rack has four of five stories that measure a total height of 6.6 meters. The ground floor shelf has a height of 1.9 m, the second and third shelf 1.7 m, and the top shelf 1.1 m. The rack with five shelves has the second story split into two shelves. The width of each shelf varies between 2.7 m and 3.575 m.

3.3 Requirement Specification

the requirements are specified in accordance with the management of the warehouse, to ensure that the proposed solution meets the requirements of the company.

Table 5. Requirement specification of a desired solution.

Requirements		**Measurable criteria**
Financial requirements	• The solution has to reduce the cost per handling unit, and the project strives to reach the solution with the highest possible return on investment (ROI)	• A goal of ROI > 25 %
Function requirements	• The solution has to be able to handle EU pallets ½ EU pallets, ¼ EU pallets, Industry pallets, and boxes/cartons • If the pre-packaging storage is organized in a queue, it must be possible to get pallets in the middle of the queue • Goods must not be kept at temperatures above +8°C more than a certain period of time	• Yes/no • Yes/no – if yes, faster than 10 min • < 4 hours
Physical design requirements	• Proposed equipment has to be easily dismountable • The solution must not reduce the number of warehouse slots • Reconstruction of the building is subject to approval by the building owner	• Yes/no • Yes/no • Yes/no
Safety requirements	• The solution must comply with Danish laws of working environment safety • The solution must comply with the current standards set by Chr. Hansen Holding A/S • The solution shall reduce the number of forklift-pedestrian crossings • The solution must not block the emergency exit	• Yes/no • Yes/no • >20% reduction • Yes/no
Production performance requirements	• The solution must reduce the packaging time • The solution must increase the capacity of the packaging system	• >10 min reduction of packaging time of a median order on an EU pallet • >10 % increase in maximum Kg/workday

3.4 Function Analysis

A map of the function analysis can be found in 0 Appendix B – Function analysis.

3.4.1 Main Function

The main function of the packaging process is to prepare an order for shipping.

3.4.2 Subfunctions

The main function can be broken down into several subfunctions. Many preset requirements require separate subfunctions. First of all, the goods are picked from the warehouse. Then they are put in temporary storage. Finally, the goods are delivered to temporary storage before being shipped. This requires some kind of transportation. Thus, two subfunctions in the first tier are the *transportation of goods before the packaging* and *transportation of goods after packaging*. A third subfunction in the first tier would be named *packaging.*

Each of the subfunctions can be further separated in second-tier subfunctions.

A packed unit requires protection to ensure that products won't be damaged. This project will not investigate other methods for protecting the good. Therefore, the currently used bands and corners will be used in by a new system. A subfunction is *apply protection on the handling unit*.

Identification is another necessary subfunction. This subfunction can be reduced further to the identification of an order, a unit (pallet/carton), and each product.

Furthermore, data regarding the weight and dimensions of the unit need to be collected.

3.5 Discussion and Sub-conclusion

The clarification and specifications phase revealed several significant findings. First of all, the function analysis has shown how the process can be reduced into the three subfunctions or phases listed below:

1. Transport from storage 1 to packing area
2. Packing
3. Transport from packing area to storage 2

As described in section 3.2.3, the three stages have different product varieties to consider. The foremost variable to study in the first and the third phase is the variety of outer packaging. In the second phase, both types of material and packaging need to be considered. These considerations make the second phase more complex in terms of variety and thereby more difficult to standardize. However, the processes in the packing phase seem to become more similar at the end of the phase. Once all goods have been moved to a new pallet, then the process is relatively the same for all types of pallets, packaging, and material. Section 0 Appendix A shows that this point has been reached after 19 minutes of the total process time of 38 minutes. Thus, half of the entire packaging time is spent after the primary operation has finished. This part of the process is the main focus of the project.

4 Design Solutions and Concepts

4.2 Possible Solutions

4.2.1 Inspiration from another warehouse

A visit to another warehouse with a very high degree of automation gave an inspiring perspective. The particular has an annual throughput of pallets roughly four times the throughput at Hammerholmen, and the number of employees is approximately 40 % of Hammerholmen. This means that the performance per employee is 10 times as high in terms of packed pallets. However, we need to address a number of factors differentiating the two warehouses. One factor is the variety of pallets. The visited site only has two types of pallets, both with the standard EUR-pallet dimension 80x120 cm, while Chr. Hansen Hammerholmen has 18 types of pallets in the four categories mentioned in section 3.2.2. A second factor is the interior packaging and material. The types of interior packaging at the visited warehouse seems to be quite similar as well, in opposition to Hammerholmen. The goods at the visited site were primarily packed in boxes, while Chr. Hansens also uses both cans and bags. Finally, the products do not need to be relabeled, which reduces the packing time substantially. Many of these factors that differentiate Hammerholmen and the visited needs to be eliminated in order in order to reach the same level of performance. Appendix F – Inspiration from another warehouse contains more information about the visit.

4.2.2 Areas of Interest

The function analysis in section 3.4 illustrates how the packaging process can be generalized into subfunctions. We can divide the process into two parts, develop separate solutions for these parts, and evaluate these solutions separately.

One field of investigation would be the transportation of pallets to and from the packaging station. A second field could be to restructure the packaging area in order to generate a better workflow and minimize the unnecessary movement illustrated in the spaghetti diagram, Figure 3, in section 3.1.2.

The last process step before transporting the pallet to the storage is wrapping the pallet and applying the SSCC-label. This process is currently done with a semi-automatic wrapping machine. The wrapping machine now needs to be assisted in some parts. The idea is to automate and integrate this process step in the transport step. The next session discusses this.

4.2.3 Wrapping Machine

Wrapping a pallet can generally be done manually, semi-automatically, or fully automatically.

Currently, the warehouse uses two semi-automatic wrapping machines of the model GL 300 from the brand Cyklop. To wrap pallets sufficiently, workers assist the wrapper in some parts of the process.

Manual wrapping or wrapping by hand is not the desired solution. For some items, it might be faster than a semi-automatic wrapping machine, because the wrapping machine conducts the same process no matter the size and shape of the pallet. However, if the pallet is on the ground level, the worker has to bend and work in a bad posture when wrapping a pallet by hand.

Fully-automatic wrapping machines are machines that do not need to be assisted by a worker. In addition to wrapping a pallet, different modules can be included in the device, such as putting on top protection, labeling the pallet with SSCC, and adding the PET band. Some wrapping machines operate with an arm while keeping the pallet stationary. Other devices spin the pallet on a plate while keeping the "wrapping arm" stationary. All automatic wrapping machines seem to interact with a conveyor belt.

4.2.4 Pallet Transport Systems

As mentioned in section 3.2.6, the distance from the packaging area to the shipment area, where the goods are loaded on a truck, measures 60 m. Approximately 18 900 pallets are shipped a year.

4.2.4.1 Automated Guided Vehicles

An automated guided vehicle (AGV) is a robot vehicle that operates without a driver. Many types of AGVs exist, and the price of these vary depending on the model. As pallets currently are moved by a manual pallet mover, the obvious substitution is the pallet mover AGV, which is similar to the manual version except it is driverless.

An alternative to the pallet mover AGV is the automated guided cart (AGC), which is simply a cart where the pallet is put on top.

A tugger AGV is a third AGV solution. It can be described as a train with several wagons and is suitable if high capacity is needed.

Finally, the unit load AGV is a solution as well. This AGV is a cart with a conveyor belt on top, which makes it able to receive pallet from one conveyor belt and deliver to another conveyor belt as well.

4.2.4.2 Conveyor Belt

Generally, there are two types of pallet conveyor belts: the roller conveyor and the chain conveyor. Roller conveyors are made with either metal or plastic rollers. Pallet width cannot exceed the length of the rollers, but on the other hand, they are allowed to be narrower than the roller. Chain conveyors consist of two or more chains. Pallets must be wider than the gap between the chains.

To transport pallets from the packaging area to the goods reception, a conveyor with a minimum length of 60 m is required. Since such a belt cannot be crossed by forklift, it has to be placed such that it doesn't interfere with the routes of the forklifts. It could either be placed along one the walls or elevated to make it possible for the forklifts to cross under the conveyor belt.

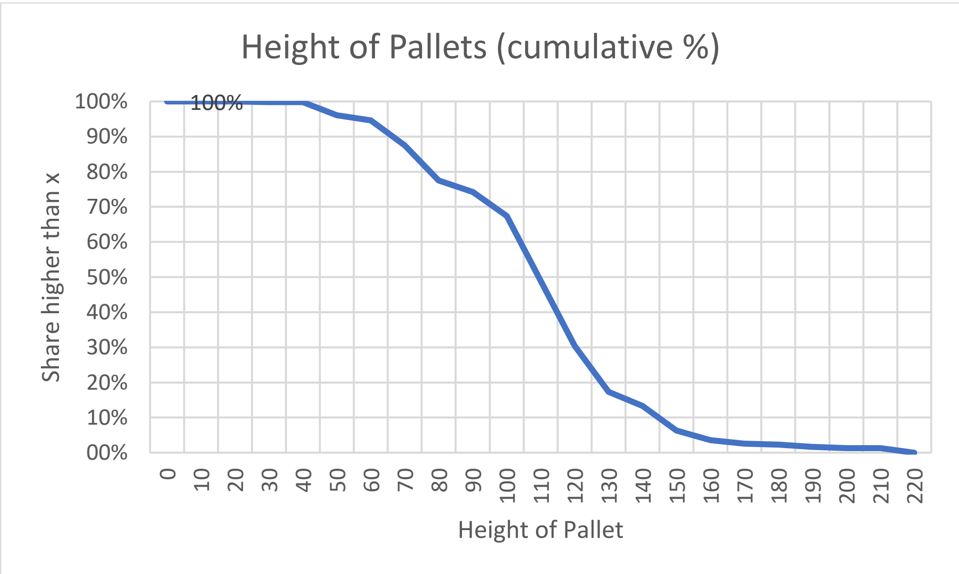


Figure 9. Commutative distribution of pallet height.

Usually, a conveyor belt is lifted above the ground. If the conveyor belt is to pass through the shelf storage, the total height of the conveyor belt and the pallet cannot exceed 190 cm. However, it is possible to change the height of the shelves.

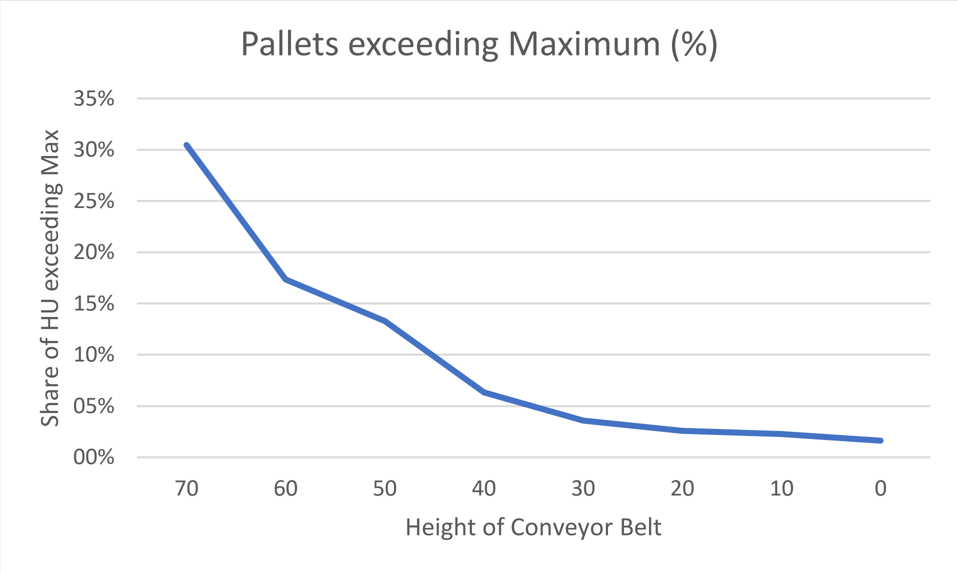


Figure 10. Share of pallets exceeding a given height.

4.2.2.3 Restructuring the Work Process

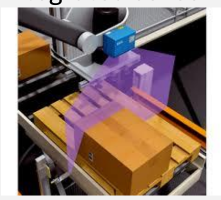
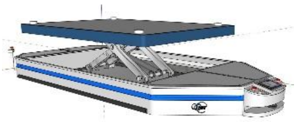
The spaghetti diagram in section 0 shows that the packaging process involves a great deal of movement. Some of this movement might be unnecessary, and therefore it is relevant to investigate whether some of the movement can be eliminated. One solution could be to integrate some of the process steps into an automated system. Currently, weight and height measurements are made manually with a pallet lift that workers have to pick up and return. This process step could be integrated into an automated system.

4.3 Summary of solutions

In this section, the different solutions from section 4.2 are put together in a table. Each row in the table represents a subfunction of the process. The current solution of each subfunction is stated in the column *current.* The column, *other solutions*, has a set of solutions to each subfunction.

Table 6. Overview of solutions to different subfunctions.

SUBFUNCTION\ SOLUTION		**CURRENT**	**OTHER SOLUTIONS**
1	Apply plastic band	Manually on station	
2	Apply corner protection	Manually on station	

3	Apply PET band	 + 	Automatic 	Add Mouse  +  + 	Semi-automatic 
4	Measure the weight	Pallet jack scale 	Integrated scale 		
5	Measure the height	Ruler 	Integrated sensor 		
6	Move to the wrapping machine	Electric pallet mover 	Pallet mover AGV  Conveyor belt 	Conveyor AGV  AGC 	
7	Apply top protection	Manually	Automatic 		

8	Wrap pallet	Semi-auto wrap 	Full-auto wrap		
9	Apply SSCC	Manuel printer 	Automatic printer 		
10	Move to storage	Electric pallet mover  Or Electric Pallet Stacker 	Pallet mover AGV  Conveyor belt 	Tugger AGV  Conveyor AGV 	Forklift AGV  AGC 
11	Storage 2	Pallet racking 245 slots (65 on the floor)	100 floor-spots	Floor slots + slots on the conveyor belt	
12	Move from storage 2 to floor	Electric pallet mover  Or Electric Pallet Stacker 	Eliminate process step		
13	Floor storage	In front of truck terminal	Eliminate process step		
14	Move to truck	Electric pallet mover 	Pallet mover AGV 		

4.4 Combining solutions into concepts

4.4.1 Apply PET-band

The current solution is to apply the PET band manually. Most often, a pallet is strapped with the PET band vertically and sometimes horizontal as well. For the band to be applied vertically, the worker needs to guide the band through the holes in the pallet, which often requires the worker the sit in a kneeling position. In order to improve the working environment, it would be beneficial to improve the handling of the PET band. With the current process, the holes in the pallet need to be open. If the pallet is lifted with a forklift, it blocks the holes in the pallet. However, if the pallet is elevated on a conveyor belt, it might as well be challenging to apply the band as currently done.

Applying the band, automatically might require the pallets to be somewhat similar in size and shape. This method works best in combination with a wrapping machine as an integrated module. If the machine is installed alone, it requires the pallet to be moved back and forth.

4.4.2 Measure height and weight

Measuring the weight of the packed pallet is currently done with a pallet jack scale. The worker has to move from his or her station to get the scale, weigh the pallet, and move the scale back in place. The two current semi-automatic wrapping machines have integrated scales, but these scales need to be calibrated frequently.

The height of the pallets is currently measured manually with a ruler. All workers are equipped with rulers, so there is no movement to get one. However, it still takes time to grab the ruler, unfold it, measure the pallet, and enter the number in SAP. As scales can be integrated, the height can similarly be measured with integrated sensors.

4.4.3 Apply top protection

This process is currently done manually at the station of the semi-automatic wrapping machine. In a fully-automated process, it is advised to integrate the top protection module. If applied manually before the pallet is sent to a fully-automated wrapping machine, the plastic might have to be sealed in order to prevent it from falling off during transport from to the wrapping machine. This an extra process step that is doesn't exist in the current process.

4.4.4 Move to Wrapping Machine

Currently, a warehouse worker moves the pallet from his packing location to the wrapping machine with a pallet mover. This could be done automatically with a pallet mover AGV. With the current layout, the distance is rather short, so this might not make sense. Another solution could be to transport the pallet on a conveyor belt. This would require a different layout of the packaging area.

4.4.5 Wrap pallet

The current wrapping machine is a semi-automatic wrapping machine of the brand Cyklop. The warehouse worker moves the pallet to the wrapping machine through a ramp. When the wrapping machine is running, it still needs to be assisted by the warehouse worker. Hereafter the pallet is moved from the wrapping machine with the pallet mover. Even if the wrapping machine didn't need assistance, the time of the wrapping process would still be too short for the worker to squeeze in anything productive. On the other hand, the time always adds up to a considerable amount of waste during a year. The time on the wrapping machine is, on average, 3 min, excluding transport to and from the station. If transportation by pallet mover is included, the time is 4.5 min.

With 19000 pallets per year and a cost of 30 EUR per working hour, the yearly waste in waiting time is 28,500 EUR compared to a fully automated wrapping machine.

4.4.6 Move to truck

According to Pierre Østergaard from NC Nielsen, it is not yet possible in practice to use their forklift AGV's to load a truck or a container. As their AGV's are guided by reflexes, all trucks would need to have reflexes on the inside for the AGV to navigate. Furthermore, the AGV measures distance on the rotation of the wheels. If the wheels spin, errors could occur, and the AGV might misplaces pallets in the container.

4.5 Concept development

4.5.1 Specification of Internal Transport Solution

Table 7. Requirement specification to suppliers of equipment.

Requirements	
Pallet handling requirements	• Maximum load >1200 kg/pallet • Capacity > 20 pallets/h • Maximum pallet height >160 cm • Able to handle EUR pallets, ½ EUR pallets, and industry pallets as minimum • Handling of ¼ pallet is preferred, but not required
Wrapping machine	• Fully-automatic (able to operate without human assistance) • Able to deliver pallets to a conveyor belt • Possible to operate without a conveyor belt
Conveyor belt	• Required length 60 m • Required speed >0.04 m/s (with 10 pallets on 60 m belt) • Conveyor height < 40 cm (preferred) • Possible to pick pallets from the middle of the belt
AGV	• Able to pick from and deliver to floor • Able to pick from and deliver to a conveyor belt

All concepts are based upon a fully automatic wrapping process. The differences between the concepts lies in the transportation method to and from the wrapping machine. The table above illustrates a number of solutions, which are assembled into concepts.

4.5.2 Concept 1: Long Conveyor Belt

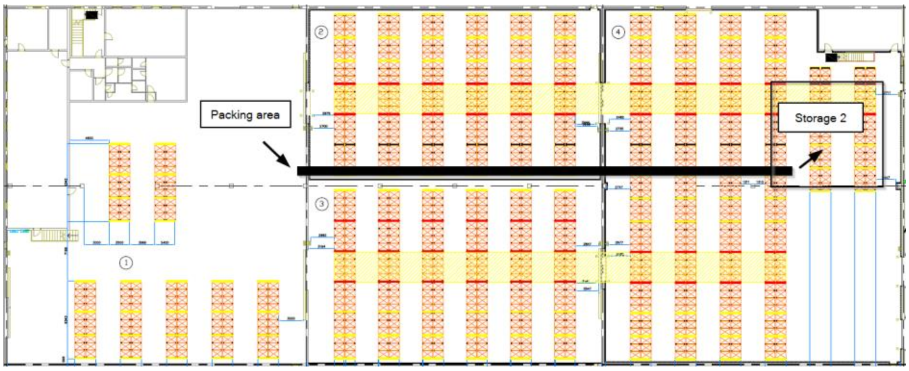


Figure 11. An illustration of concept 1.

Following the table of solutions, the concept consists of the following steps:

STEP	TASK	SOLUTION
3	Apply PET-band	Manual (as current)
4	Measure weight	Automatic
5	Measure the height	Automatic
6	Move to wrap	Pallet mover (man driven)
7	Apply top protection	Conveyor belt
8	Wrap pallet	Fully automated
9	Apply SSCC	Automatic
10	Move to storage 2	Long conveyor + pallet mover (man driven)
11	Storage 2	Racks
12	Move from storage 2 to floor	Forklift (man driven)
13	Floor storage	Floor
14	Move to truck	Pallet mover (man driven)

This concept has a 60 m conveyor belt all the way from the packing area to the storage location. The belt runs through a total of 20 racks. Depending on the width of the belt, the belt occupies one or two slots in each stand, if only the floor shelf is filled and the shelves above are converted to end rack selves.

On the plus side, the space on the belt can be included in the outbound storage. If each pallet requires 1.4 m, a total of 43 pallets can be stored on the belt.

In order to make space for a conveyor belt, two walls would have to be penetrated. Furthermore, the belt would block four aisles. The consequence of these actions has to be investigated. Currently, pallets are moved to storage by workers in the packing area. This solution redistributes this working process to the workers in the goods reception.

The position of the belt has been chosen to be along the middle wall. A belt running along the outer wall would block two emergency exits.

4.5.3 Concept 2: AGV Solution

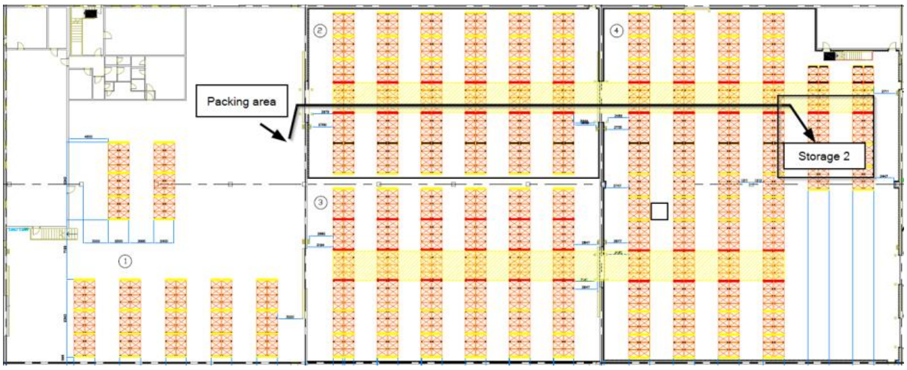


Figure 12. An illustration of concept 2.

An AGV-solution would consist of storage in the packaging area and storage in the goods reception. The distance between these two storage areas is approximately 70 m.

4.5.4 Concept 3: Short Conveyor Belt

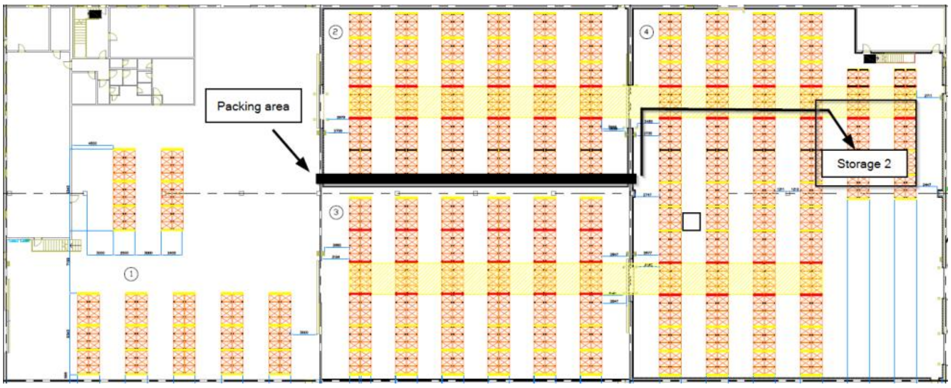


Figure 13. An illustration of concept 3.

The short conveyor belt penetrates the two wall as well and delivers pallets to the middle of the storage room, to avoid blocking the four aisles. The length of the belt is 35 m and runs through 12 racks. Hence, the belt itself would occupy 12 or 24 pallet slots. The capacity of the belt would be 25 pallets.

4.5.5 Concept 4: Short Conveyor Belt + AGV

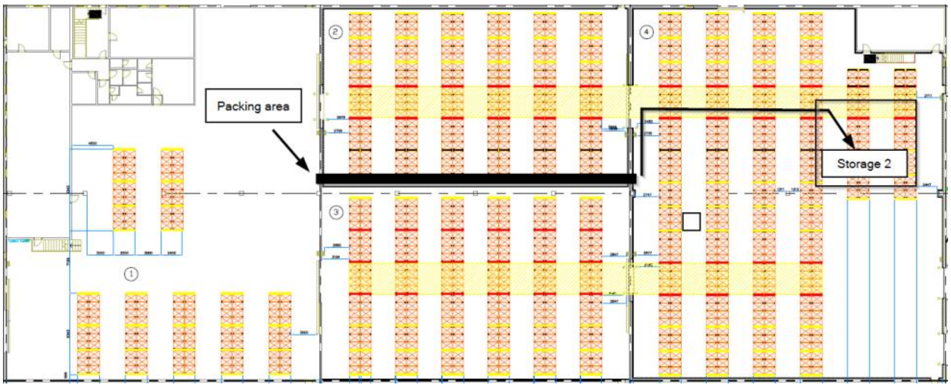


Figure 14. An illustration of concept 4.

A fourth concept is to combine a short conveyor belt and an AGV. The idea is to use the conveyor belt as a buffer storage.

4.5.6 Concept 5: Wrapping machine only

As the evaluation of the four first concept indicates that the significant part of the cost reduction might lie in the implementation of the wrapping machine, a fifth concept has been developed. This concept consists of an application of a wrapping machine followed by transportation of pallets from the wrapping machine to storage 2 by an electric forklift as the current process.

After the wrapping machine, there will be a very short conveyor belt handle a queue of a few pallets. Pallets are picked up by an electric forklift from this conveyor belt and transported to storage 2. This operation would be a task for the warehouse workers to organize.

4.6 Evaluation of the Concepts

4.6.1 Methods of evaluation

There are two main aspects of the assessment of the concepts: technical evaluation and economic evaluation. The technical part evaluates elements such as the capacity of the concept. The economic evaluation considers the required financial investment and the cost reduction of the concept in comparison to the current state.

The reduced cost is calculated based upon the reduced work needed to pack the annual amount of pallets. In Figure 15 in section 4.6.5, the estimated time save of each subprocess is presented. In the same figure, the annual cost save of each subprocess is presented. The figure shows the minimum and maximum of each process as well. This process is either based on observation or an estimate.

The estimated lower and upper range is the estimated range of the average, which is simply a rough estimate based on the minimum and the average. The purpose of the range is not to provide a statically exact interval but simply provide sensitivity analysis.

The average cost save of each concept is calculated by summarizing the cost save of each subprocess. To calculate the upper and lower range for a concept, then the following formula has been used.

The reduced packing time of a pallet in each concept has been calculated and then extrapolated to the annual saved cost.

4.6.2 Methods of cost-saving estimation

The estimated cost-saving is based on the time required time of the work needed for a specific process step. This time is then to estimate the cost-saving of the new implementation.

At the beginning of the project, two entire packing processes were recorded with split times for each process step. Later in the project, the focus is to observe only a number of selected process steps that the project aims to eliminate or substitute. If the new operation eliminates all manual work of a process step, then the estimated time-saving corresponds to the recorded process time. If the new process step still requires some manual labor, then this time is subtracted.

As an example, the operation *Move from wrap, AGV* automates the whole process of transporting a pallet from the wrapping machine to Storage 2. On the other hand, *Move from wrap, 62 m* in Concept 1 does not automate the whole process, as the pallet has to be moved from the conveyor to Storage 2 manually.

When a forklift arrives at a destination to pick up or deliver a pallet, the estimated time to conduct a pick-up or delivery is 20-30 seconds, based on various observations from the warehouse. As a pick-up and a delivery has to be conducted manually plus a few meters of driving, then time-saving of *Move to wrap, 62 m* is 62 seconds less than the time-saving of *Move to wrap, AGV*.

It is vital that the process times are recorded to represent a typical day. Hence, if employees are told that their work is recorded, then they might not follow their routine, and the recorded times would differ from the actual process times.

4.6.3 Methods of investment estimation

Ideally, the estimated price of a given investment is based on an offer from a supplier. If an exact price has not been offered, then an estimated price range from suppliers can be sufficient. The minor investments will be estimated, without contact to suppliers. E.g., it is possible to estimate the price of new racks from the internet prices of a particular product.

4.6.4 Methods of range estimation

In order to get an idea of the sensitivity of the, then the estimated cost-saving or investment can be specified as a range. If the particular estimate represents a series of observations, then the bound is set to be the average of the extreme point and the average of the whole series. E.g., the estimated lower average, in Table 8 in section 4.6.5 is the average of minimum and the average.

The total average time of several process steps is calculated by summarizing the average times of each of the steps. However, this is not the correct method for summarizing the estimated lower and upper bounds of average. The estimated range is meant to represent a confidence interval, except the fact that no significance level is set. If we assume that we have a real confidence interval that correlates to a standard deviation, then the standard deviation of the entire process would be the root of the square sum of variances (Alm & Britton, 2008, p. 246).

(Alm & Britton, 2008, p. 246) describes the square sum as:

$$S_{xx} := \sum_{i=1}^{n} (x_i - \bar{x})^2$$

The variance can be described as:

$$s^2 := \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

Where the standard deviation is $s := \sqrt{s^2}$, $\bar{x}$ expresses the mean, x_i is the value of the observation i, and n is the number observations (Alm & Britton, 2008, p. 245).

The method used to estimate the spread in this project is based on the principles above. The following equation shows the method:

$$Estimated\ lower\ average\ of\ process := \sqrt{\sum_{i=1}^{n} (l_i - \bar{x}_i)^2}$$

where l_i is the lower average time or cost of a process step and $\bar{x}_i$ is the average time or cost of the process step. For the estimated upper average the same equation is used. Further, it is assumed that the times of each process steps are independent variables.

4.6.5 General cost savings

A cost save in time and economic value has been calculated in the table below.

Table 8. An overview of different operations and cost-saving.

COST SENSITIVITY	TIME SAVED PER PRODUCT/OPERATION (MIN)					ANNUAL COST SAVE (DKK)			
PRODUCT/OPERATION	Min	Est. low average	Avg.	Est. upp. avg	Max	Low range	Avg.	Upp. range	Estimation method
WRAP + TOP PROTECTION	**3.19**	**3.33**	**3.47**	**3.80**	4.13	235837	245582	268971	20 observations, different pallets
INTEGRATED WEIGHT + HEIGHT MEASUREMENT	**0.70**	**1.03**	**1.35**	**1.68**	2.00	72647	95681	118716	5 observations
LABELING MODULE	**0.50**	**0.75**	**1.00**	**1.25**	1.50	53156	70875	88594	Own estimate
MOVE FROM WRAP, AGV	**2.17**	**2.63**	**3.10**	**3.58**	4.05	186683	219803	253424	13 Observations
MOVE FROM WRAP, 62 M CONVEYOR	**1.20**	**1.66**	**2.13**	**2.59**	3.05	117830	150609	183389	Own estimate
MOVE FROM WRAP, 35 M CONVEYOR	**1.16**	**1.31**	**1.46**	**1.61**	1.76	92864	103496	114127	Own estimate
MOVE FROM WRAP, 10 M CONVEYOR	**0.86**	**1.01**	**1.16**	**1.31**	1.46	71602	82233	92864	Own estimate

Figure 15

4.6.6 General investment

Table 9. An overview of investment options and their price.

PRODUCT/OPERATION	ESTIMATED PRICE (DKK)	METHOD
WRAPPING MACHINE INCL. TOP MODULE	731000	Offer from supplier
WEIGHT AND HEIGHT MEASUREMENT	74000	Offer from supplier
LABELING MODULE	215000	Offer from supplier
CONVEYOR BELT (62 M)	874000	Estimate from supplier
CONVEYOR BELT (35 M)	559000	Estimate from supplier
CONVEYOR BELT (10 M)	199500	Offer form supplier
RECONSTRUCTING A WALL	50000	Own estimate
NEW RACKS	50000	Own estimate

4.6.7 Concept 1: Long Conveyor Belt

4.6.7.1 Technical evaluation

The conveyor belt replaces the transport of pallets done by warehouse workers. However, the pallets still need to be handled at the end of the conveyor belt. Thus, the concept does not eliminate the operation of handling of the pallets but is just shortens forklift transport distance by installing a conveyor belt. Moreover, the conveyor belt can be used as a storage of pallets after the packing process.

A 62 m conveyor belt has a storage capacity of 46 pallets. As long as the conveyor belt is able to move a pallet one spot in the queue of pallets on the belt faster than the wrapping machine can process one pallet, then the conveyor belt will not be a bottleneck. The factor limiting the conveyor belt is how quickly a worker can unload a pallet from the belt.

The capacity of the conveyor belt is 46 spots. If the belt is set to run through racks, it will occupy columns on every rack. The total number of racks to run through is 20 rack, which means that the number of columns filled is 40. Each column has either four or five stories. If the racks on the end of the wall are installed above the conveyor belt, only the ground floor spots will be lost. Hence, we lose 40 spots on the rack, but on the other hand, we gain 46 places on the conveyor belt.

The conveyor belt would block four aisles, which would increase the distance for forklifts going through these aisles. It is uncertain to what degrees this would be an issue.

4.6.7.2 Economic evaluation

The estimated has cost save been made based on Figure 15. Four processes are included in this cost save:

- Integrated weight and height measurement
- Wrap and top protection
- Move from wrap with 62 m conveyor
- Labeling module

These four processes are estimated to save 7.9 min per pallet, which accumulates to 560,000 DKK per year.

A table of the calculation of cost save and investment can be found in

Appendix L – Economic evaluation.

A supplier of conveyor belts has been contacted, and a rough price estimate has been given. The supplier estimates that a conveyor belt has a cost of 20-23,0000 DKK per unit of 1.35 meters. 46 units are required, which gives a total price of 920,000 to 1.058 mill. DKK, respectively depending on the exact type conveyor belt and the length.

Reconstructing walls and setting up new rack are further investments needed for the project. Rebuilding a wall means making a hole in two walls and insert, e.g., a PVC-curtain. A new rack might require a customized solution due to the width of the conveyor belt. Standard racks have a depth of 110 cm, whereas the conveyor belt occupies 160 cm. An estimate is that such customized solutions could cost up to 100,000 DKK.

4.6.8 Concept 2: AGV Solution

4.6.8.1 Technical evaluation

NC Nielsen has been contacted, and they have made an offer on a solution. NC Nielsen suggests a stacker AGV, which is able to pick and deliver pallets to shelves. The AGV navigates by reflexes installed in the warehouse. The benefit of this solution is that it can fully replace the current operation conducted by warehouse workers.

Overall the AGV is a very agile solution, which is easy to implement and change if needed. However, one concern is if the AGV meets the required capacity.

Let us assume that the average speed of an AGV is 4 km/h, and it spends 40 seconds picking up or delivering a pallet when it has reached the destination. The forklifts cover a distance of 70-80 meters, which would take 64 seconds for the AGV in each direction. The total time of the operation is 244 seconds or 4 minutes and 4 seconds. Thus, the AGV can deliver approximately 15 pallets per hour. During an 8 hour shift, the AGV would be able to handle 120 pallets. The warehouse only has a demand of this scale a few times a year, and these days, the shifts are usually longer than 8 hours. The capacity of the packing process was estimated in section 2.1.3 to be 123 pallets per day. The average time of delivering a pallet in the current process, by human-operated forklift, is approximately 3.5 minutes (see section 4.6.5), which translates to 17 pallets per hour per driver. On a busy day, the delivery time of the current process might be as fast as 2.5 min, which translates to 24 pallets per hour per driver. Thus, the capacity of the subprocess of transporting pallets will decrease with an AGV solution. On the other hand, it would not be a bottleneck if the packaging process if it operates for more than eight hours per day.

If we consider a scenario in which the throughput is increased, the demanded capacity increases as well. According to (Chr_Hansen, 2019), the annual organic growth for the past five years has been 7-12 % per year. If the through increases 10 % annually during the next five years, the through increases by 61 %. Such a scenario will be a challenge to this solution. One solution to solve this issue could be to change the work schedule to give the AGV assistance from workers for a longer period of the day. This might as well be the desired solution to increase the capacity in other areas of the packing process.

4.6.8.2 Economic evaluation

An AGV differs from the solution in concept 1 in the last process step, as the AGV is able to move pallet directly from the packaging area to a shelf in storage 2. Thereby, it saves 8.9 minutes of work per pallet and reaches an annual cost reduction if 630,000 DKK. The required investment is approximately 2 million DKK.

4.6.9 Concept 3: Short Conveyor Belt

4.6.9.1 Technical evaluation

Two issues with the long conveyor belt in concept 1 lead the way to a shorter conveyor belt in this particular concept. This first issue is that the long conveyor belt would block four aisles. The second issue is whether the long conveyor belt reduces work required per pallet as it does eliminate processes. A short conveyor belt might yield the most of the benefit of using the belt storage. The belt 35 meters has a storage capacity of 26 pallets.

4.6.9.2 Economic evaluation

Shortening the conveyor belt affects the cost savings by 0.6 minutes in the last process step compared to concept 1. This is the time it takes for the forklift to drive an extra 50 meters. The annual cost saving of the concept is 520,000 DKK. The financial investment of concept 3 is approximately 2 million DKK.

4.6.10 Concept 4: Short Conveyor Belt + AGV

4.6.10.1Technical evaluation

This solution combines the AGV and the short conveyor belt solution. The idea is to yield the benefits of the AGV while ensuring high capacity and a buffer storage after the wrapping process. As the distance, the AGV has to transport each pallet is shorter, the AGV will probably be able to handle pallet in 3 minutes instead of 4 minutes, which will increase the capacity from approximately 15 pallets per hour to 20 pallets per hour. Furthermore, the conveyor belt adds a buffer to the system, which enables the AGV to operate while the wrapping machine is not being fed with pallets for a longer time.

4.6.10.2Economic evaluation

This concept reduces the work time per pallet by 8.9 min and the annual cost by 630,000 DKK. Combining a conveyor belt and an AGV solution gives the same cost-saving as only having an AGV solution, as long as the AGV solution meets the required capacity, and no waiting time occurs. The financial investment of concept 4 is approximately 3.4 million DKK.

4.6.11 Concept 5: Wrapping machine only

4.6.11.1Technical evaluation

As this concept has only a very short conveyor belt for a buffer of pallets after the wrapping machine, one issue is that the wrapping machine can only operate as long as the conveyor belt after wrapping machine has an empty spot. Hence, warehouse workers must deal with this queue frequently during the work shift. One solution could be to have a worker transporting pallets from the wrapping machine to storage 2. However, if the handling time for each pallet is approximate 3 minutes, then the worker handles 20 pallets per hour. If this is the only task for the worker, much waiting time will occur. On the other hand, jumping between this task and other tasks frequently during the shift could lead to unnecessary movement by the worker. Thus, it might not be possible to reach the theoretical cost reduction.

4.6.11.2Economic evaluation

Only having a wrapping machine and transporting pallets to storage 2 as the current process reduces the work time per pallet by 5.7 minutes. Annually we reach a cost reduction of 410,000 DKK with this concept. The investment required is 1.2 mill. DKK.

It has been discussed not to include the labeling module, as the IT-solution required might be challenging to implement. As labeling the pallet imposes an operation after the pallet has been sent to the wrapping machine, it would be a great advantage to automate this operation. The work-saving through this automation is likely in the range of 0.5-1.5 min per unit, which is equivalent to roughly 150 to 450 working hours or 35,000 to 100,000 DKK per year. Thus, the additional labeling module will most likely increase the profitability of the project. However, the cost of operations by the internal IT department of Chr. Hansen in order to implement the labeling module in the ERP system, has not been considered in this budget.

If the labeling module is not included, then the work-time reduction is estimated to be 4.7 minutes per pallet, and the annual cost savings to be 340,000 DKK. The investment needed is approximately 1 million DKK.

4.6.12 Comparison of Concepts

Table 10. An overview of the cost-saving, investment and ROI of the concepts.

Concepts	Time reduction per unit (min)	Annual cost reduction (DKK)	Investment (DKK)	ROI
Concept 1: long conveyor	7.9	560,000	2,400,000	23%
Concept 2: AGV	8.9	630,000	2,600,000	24%
Concept 3: short conveyor	7.3	520,000	2,000,000	25%
Concept 4: conveyor + AGV	8.9	630,000	3,400,000	19%
Concept 5: only wrap	5.7	410,000	1,200,000	33%
Concept 5: only wrap without labeling	4.7	340,000	1,000,000	34%

In the table above, we see the required investment of the different concepts varies in the range of 1 million DKK to 3.4 million DKK. Concept 5 requires the smallest investment, but still yield a sound cost reduction, which makes it the concept with the highest expected ROI. Concept 1-3 are somewhat similar regarding financial aspects. They all reach a cost reduction in the range 520-630,000 DKK per year and an investment of 2-2.6 mill. DKK. Concept 4 requires the most significant investment but does not yield a significantly higher cost reduction to concept 1-3.

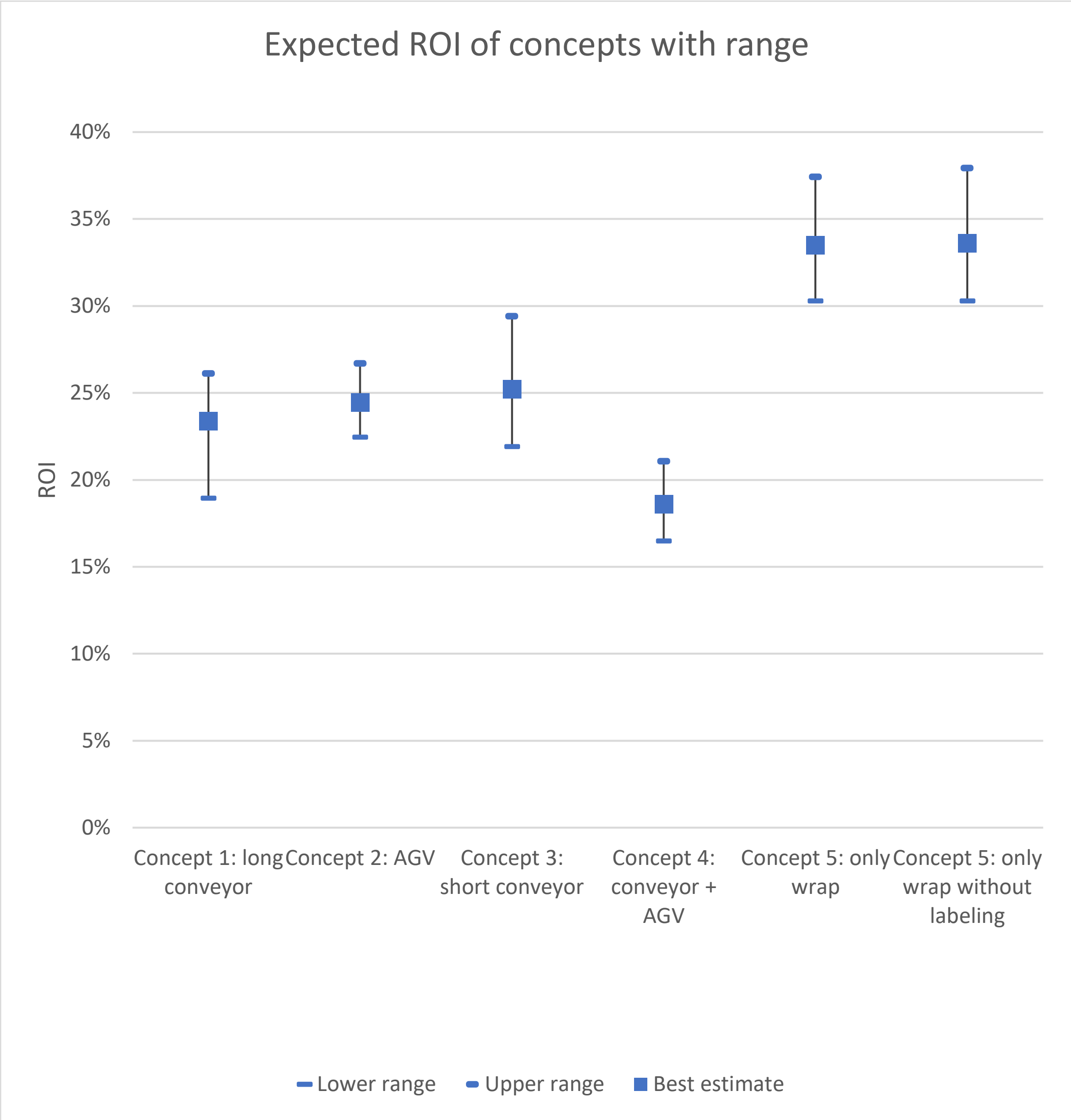


Figure 16. The expected ROI of concepts with the blue square as the best estimate and a line showing the range.

Figure 16 shows that concept 5 seems to yield the highest return on investment. The lower ROI of concept 5 is higher than the upper ROI of all other concepts. Concept 4 seems to have the lowest ROI, while the ROI of concepts 1-3 are reasonably similar.

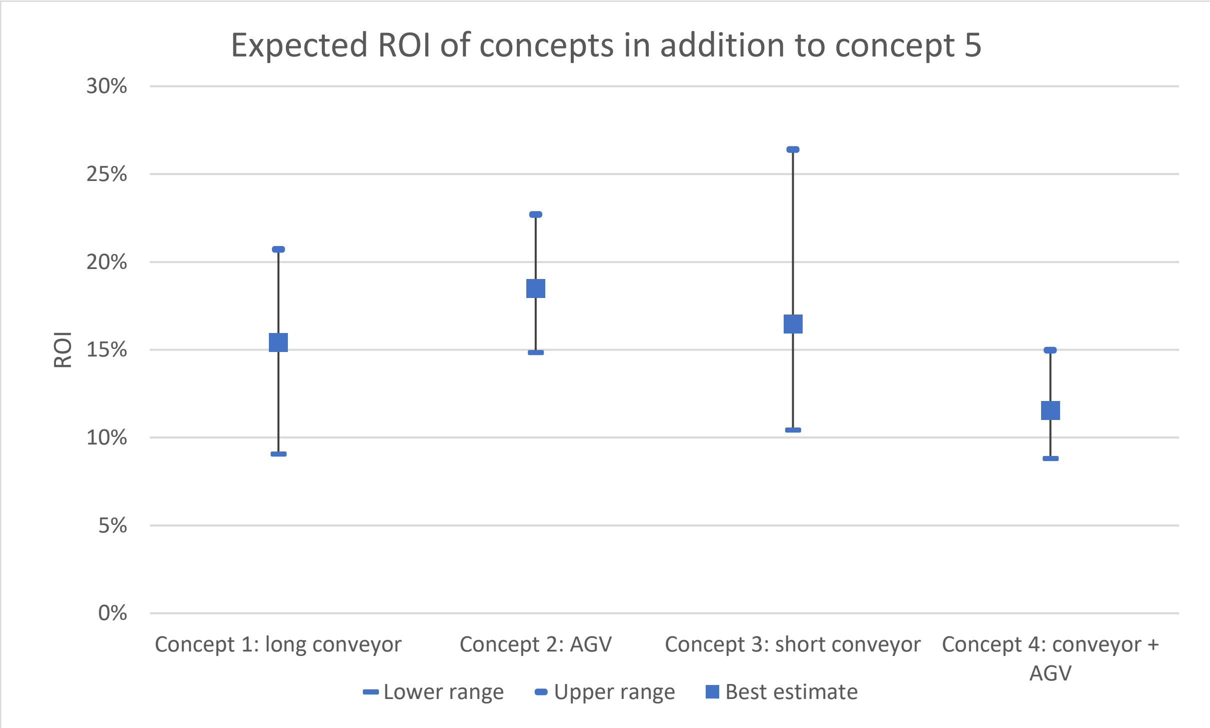


Figure 17. A comparison of concept 1-4 in addition to concept 5.

The fact that concept 5 yields the highest indicates that the central part of the reduced cost lies in the wrapping machine. If we subtract the investment and annual cost reduction of concept 5 in the four other concepts, then we can calculate an ROI of the transport from the wrapping machine to storage 2 using the different methods of concepts 1-4. Figure 17. A comparison of concept 1-4 in addition to concept 5. presents this comparison. The best estimate of the concepts all lies in the interval 12-18 %, which is considered a low ROI.

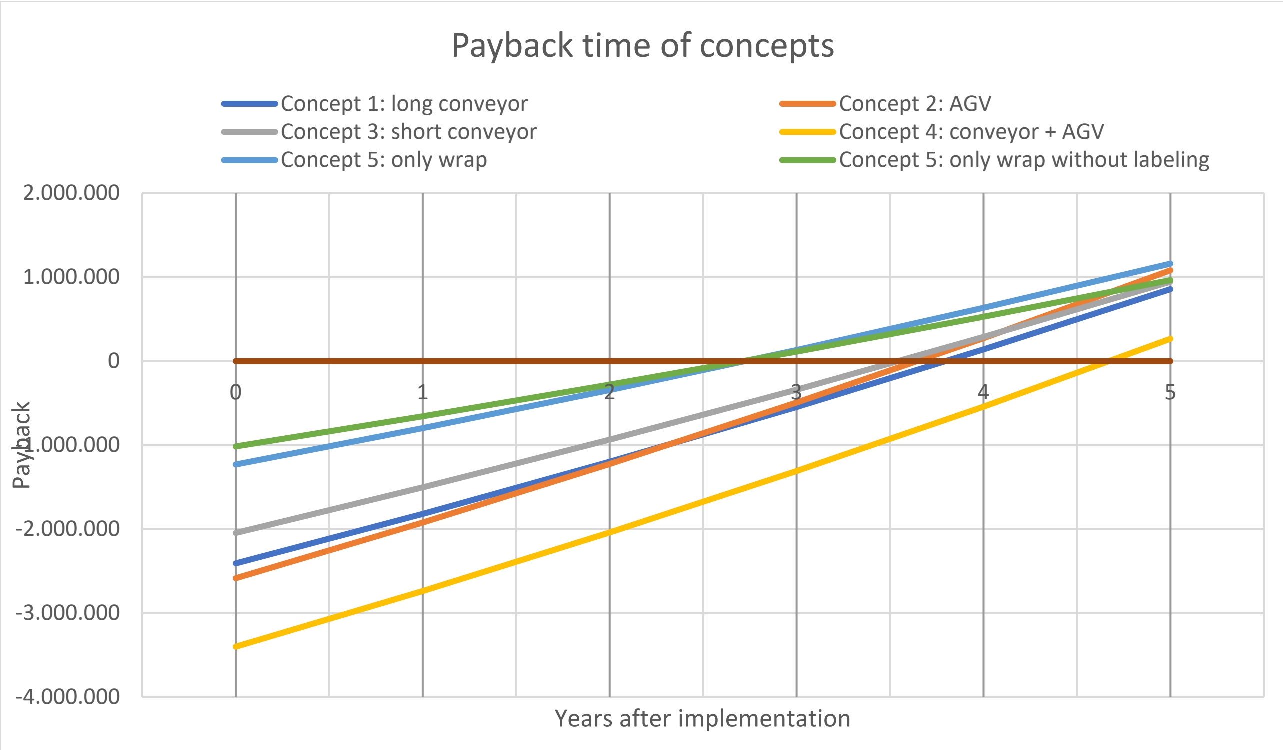


Figure 18. A comparison of the payback time of the concepts.

Figure 18 Shows that concept 5 has the shortest payback time in 2.7 years and requires the smallest investment as well. The payback times of concept 1-3 are all in the range of 3.5-3.8 years. Concept 4 requires the most substantial investment and has the longest payback time, approximately 4.7 years.

4.6.13 Sub conclusion

It seems that the majority of the cost reduction lies in implementing a fully automated wrapping machine. However, concept 5 might not be an optimal solution in practice because it likely increases the unnecessary movement of workers. One solution could be to prolong the conveyor belt suggested by the supplier of the wrapping machine solution. Hence, one focus of the refinement of the final concept determines the required minimum length of this conveyor belt to ensure a productive work process.

5 Refinement of concepts

5.1 The layout of Packing Area

Due to the space occupied by the wrapping machine, the general layout of the packing area needs to be restructured. Two different layouts are suggested. Both of them will be connected to a conveyor belt along the interior wall.

5.1.1 Layout 1

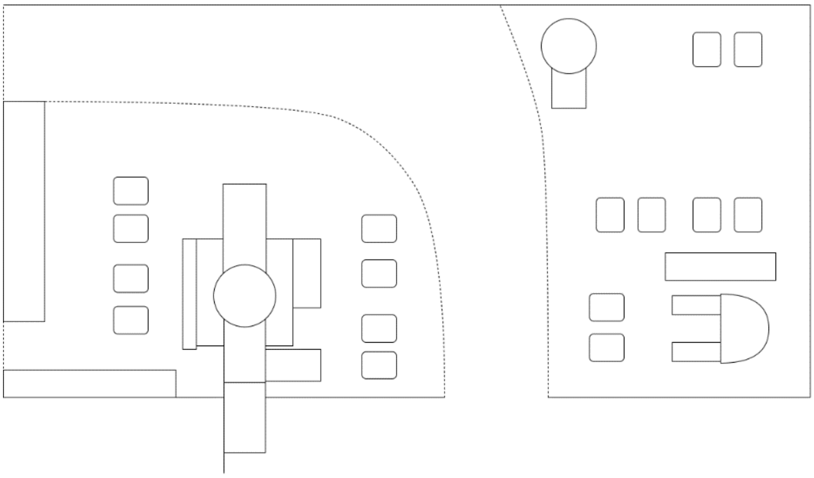


Figure 19. An illustration of layout 1

In this layout, the wrapping machine will be placed in the middle of the packing area. Four packaging stations will be placed around the wrapping machine. On the other side of the forklift driveway, it will be possible to have at least four more packaging stations. At the table for a printer and the necessary equipment is located near the wrapping machine on the right-hand side. Further, two tables for material on the left-hand side of the wrapping machine and one next to the labeling machine.

5.1.2 Layout 2

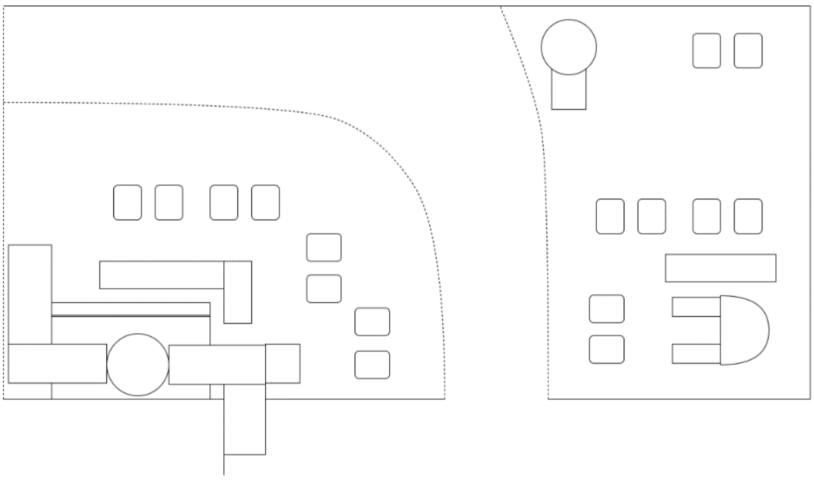
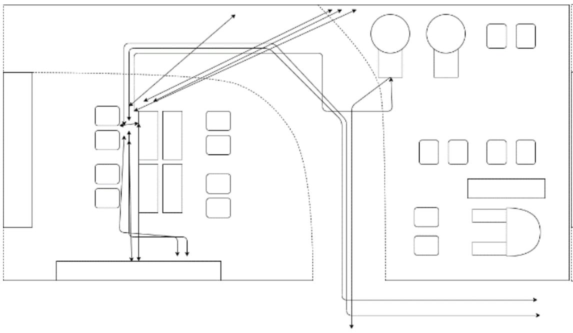


Figure 20. An illustration of layout 2.

5.2 Spaghetti Diagram

A suitable way to compare the two solutions with the current solution could be a comparison of the spaghetti diagrams. The spaghetti diagram of the ongoing process in section 3.1.2 was conducted on the basis of a list of processes in appendix A 0. Due to the COVID-19 situation, it is not possible to physically test a new layout. However, it is possible to compare the worker's movement in terms of distance, as (Senderksá & Václav, 2017) do.

5.2.1 Comparing new and current layouts



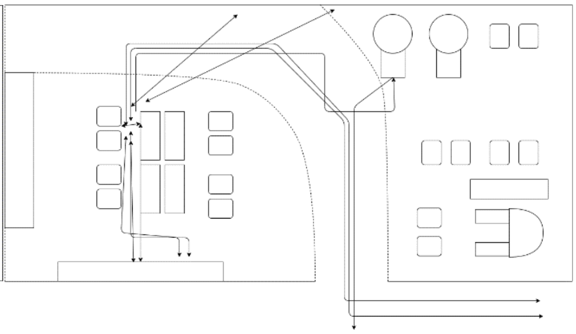
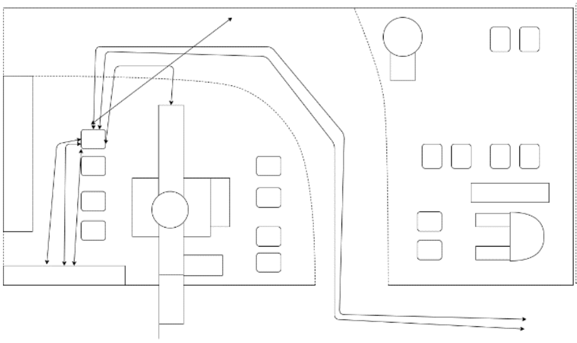


Figure 21. Left figure. Spaghetti Diagram of the current process.

Figure 22. Right figure. Spaghetti Diagram of the adjusted current process.



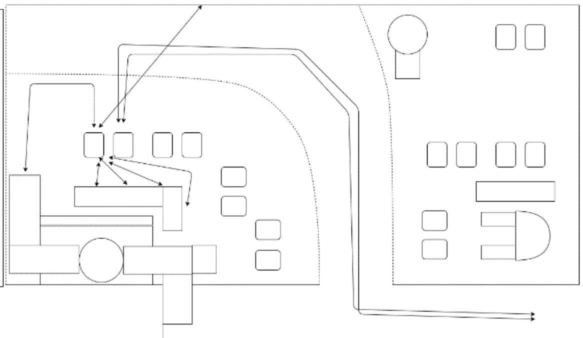


Figure 23. Left figure. Spaghetti Diagram of layout 1.

Figure 24. Right figure. Spaghetti Diagram of layout 2.

As workers do not need to pick up the pallet lift in all packing processes, the spaghetti diagram in figure 5 represents a process without this step.

To compare four scenarios, the accumulated distance complete by a worker has been measure from the spaghetti diagrams. The full table can be found in appendix 0.

Table 11. A summation of the distances in the spaghetti diagrams figures 21-24.

	CURRENT PROCESS	CURRENT ADJUSTED PROCESS	LAYOUT 1	LAYOUT 2
SUM OF DISTANCE (M)	457	413	402	283
WALK	153	109	116	73
FORKLIFT	304	304	286	210

Currently, there are a number of the label printers on the left side of the forklift aisle along, but not printers of computers on the right side of the aisle. Thus, workers on work stations on the right side have to walk back and forth in order to print labels, SSCC-label, et cetera. Furthermore, their workers some times have to pick up a pallet lift next to the semi-automatic wrapping machine. This also implies walking and crossing the forklift aisle. One solution could be to mark the floor at each work station to keep the pallet lifts at the work station. However, this is a minor issue.

5.2.2 Buffer storage after the wrapping machine

Only implementing a short conveyor belt downstream of the wrapping machine as in concept 5 requires a worker to empty pallets from the conveyor belt frequently. However, this task will not be a full-time job as the average number of pallets per day is approximately 70 (see section (see section 3.2.5), and a worker can move 35 pallets per hour (see 4.5.3). Therefore, on or more, workers need to be responsible for this task in addition to other jobs. However, we do not want this responsibility to disturb other jobs and lead to unnecessary movement.

The question is for how long the wrapping machine can keep operating without workers emptying pallets from the conveyor belt? A long conveyor belt requires a larger investment. On the other hand, a very short conveyor belt will lead to unnecessary movement as other jobs will be interrupted.

To answer this question, we need to decide whom to assign this task. The workforce of the warehouse can be divided into three teams. One handles packaging. Another team handles receptions and delivery of goods, and the last team picks orders.

The ideal worker to handle the job is a worker that frequently is near the conveyor belt and whose other jobs are relatively short, such that the worker is able to finish a task without being interrupted.

Workers in the goods reception will mainly be located far away from the conveyor belt. Therefore, they won't be aware of the queue. Packaging workers visit storage 1 every time they start packing a new pallet. They will also be well aware of when to empty the belt and any other issue regarding the pallets. However, they use a pallet mover, that cannot move the pallet to ground floor spots.

The workers who pick orders deliver them to storage 1. They use stacker forklifts as well, which can move pallets to any shelf in the warehouse. If these workers choose a new order in a series without other tasks between them, then they will drive a forklift almost half the time. Figure 25 illustrates this process. The blue line is the transport of a finished pallet from the conveyor belt to storage 2. The two red lines are empty transports. The orange line is the transport of a new empty pallet. The green line illustrates picking pallets to storage 1. The picking process and the process of moving pallets from the conveyor belt to storage 2 are two separate processes in this figure.

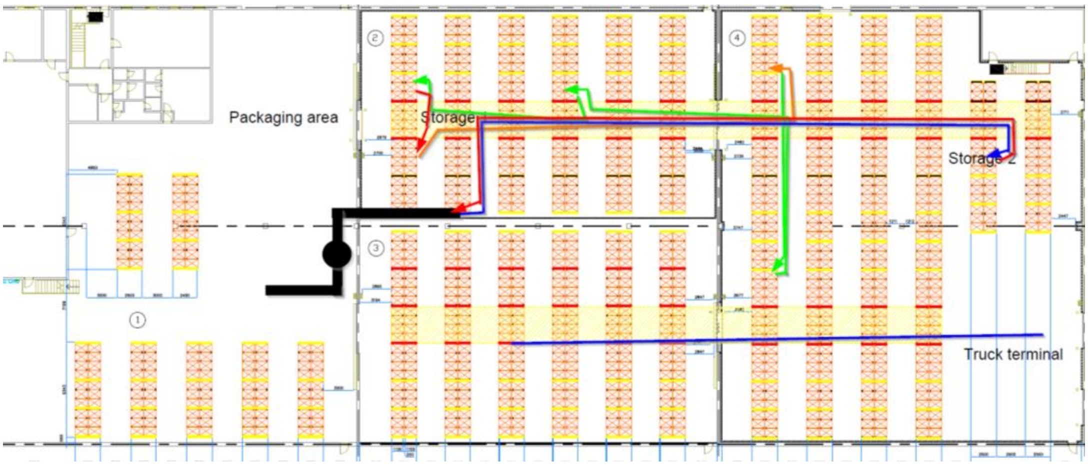


Figure 25. An illustration of the current forklift route.

If they move one pallet from the conveyor belt to storage 2 between their other job, then they only have to drive an empty forklift back from storage 2 to the next pallet to pick. Figure 25. An illustration of the current forklift route. illustrates how the two processes can be merged into one process.

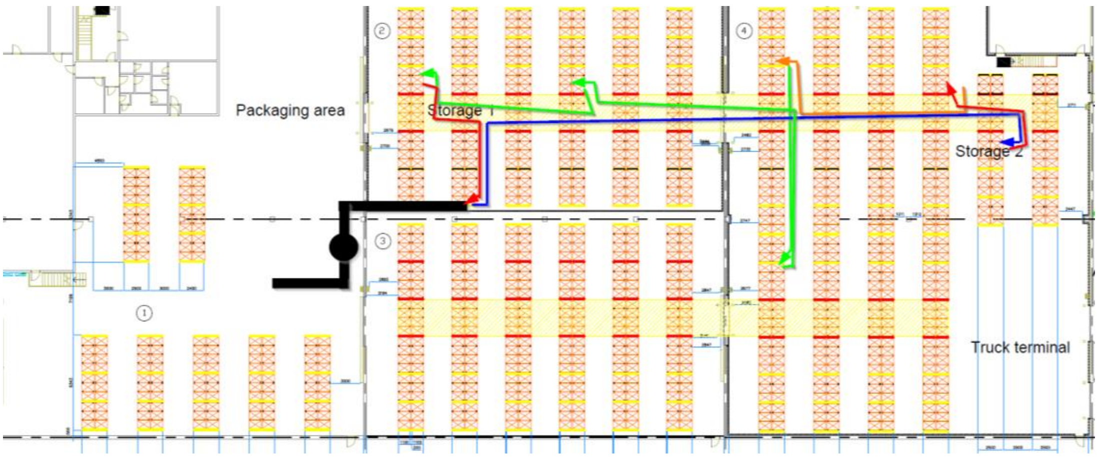


Figure 26. A new forklift route.

The process in Figure 26. A new forklift route. requires the stock of empty pallets to be moved from storage 1 to storage 2. This is considered to be a minor issue.

6 Final Design

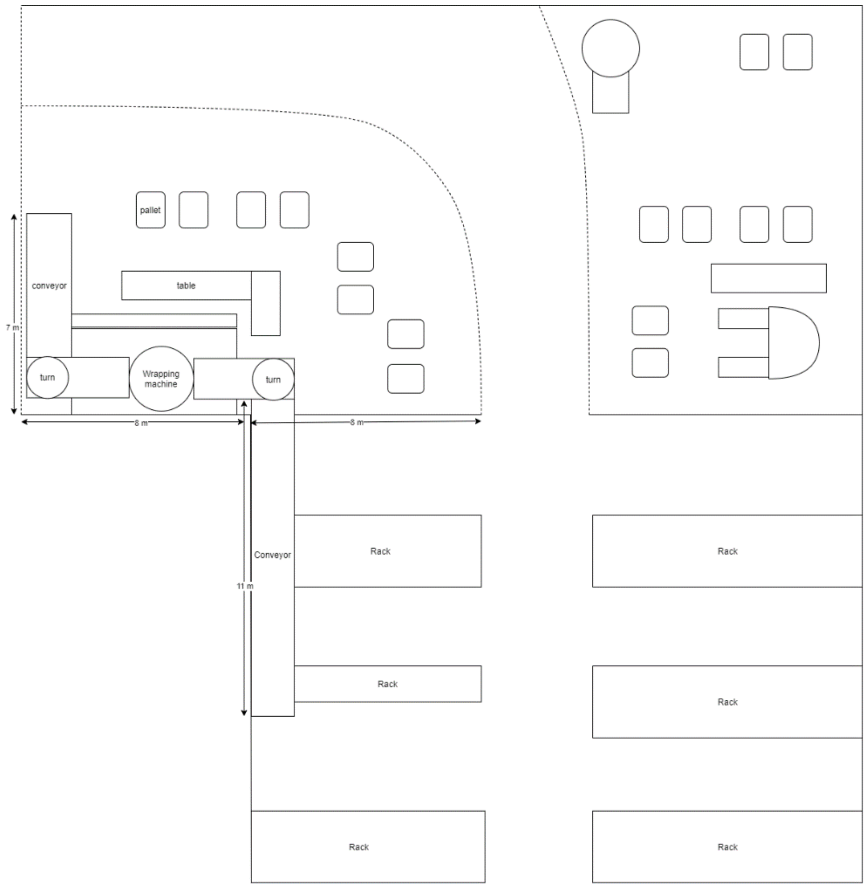


Figure 27. A drawing of the final design.

The final design is based on concept 5 with an additional labeling module and an extra 10 m of the conveyor belt. The suggestion is to follow layout 2 in Figure 20, section Layout 2. This layout requires the conveyor belt to make two 90 degree turns.

The shelves on the rack in the upper left corner in Figure 27, which has been removed, could be conserved by installing a rack above the conveyor belt. The removed rack at the end of the conveyor belt could be kept as well. Each side of the rack has 18 pallet spots. I believe that it is not necessary both rack, a total of 36 spots, but a realistic guess would be to remove one side, i.e., 18 places.

6.1 Technical description

After packing a pallet, the worker will move it to the conveyor belt in the upper left corner in Figure 27. The pallet is then moved automatically on the conveyor belt to the wrapping machine. On the conveyor belt before the wrapping machine, the pallet weight and the height of the pallet are recorded by integrated sensors. The top protection is applied as well before the enters the wrapping machine. After wrapping machine, the pallet is transported into the cold storage on the conveyor belt.

The conveyor belt has three spots before the wrapping machine and eight spots after wrapping machine, which gives a total of 11 spots. If the wrapping time is a minimum of 2.5 minutes, it takes at least 20 minutes for the wrapping machine to process eight pallets. If we consider a case where 12 or more pallets are sent to the wrapping machine, then the wrapping machine will wrap the first six pallets in a minimum of 15 minutes. The next three pallets will be a queue on the conveyor belt before the wrapping machine.

The 12th pallet cannot be sent to the conveyor belt before the wrapping machine if no pallets are removed from the conveyor belt after the wrapping machine. Hence, in the worst case, a worker has to assist the conveyor belt every 20 minutes.

6.2 Investment of the final design

Table 12. The investment calculation of concept 6.

Investment	Price (DKK)
Wrapping machine incl. safety fence, 8 m conveyor belt and installation incl. 12 conveyor units, 2 turn tables, labelling module and weight and height module	1,250,000
Reconstructing walls	50,000
Unexpected expenses	195,000
Price	1,495,000
Rounded price	**1,500,000**

The investment of the wrapping machine is based on an offer from a supplier while reconstructing walls is a rough estimate. Other expenses to new rack and IT-solutions for the label printer must be considered as well. They are included as unexpected expenses.

6.3 Cost-saving

Table 13. Cost-saving of concept 6.

Task	Work saved per unit (min)	Work saved per year (h)	Work saved per year (DKK)
Integrated weight + height measurement	1.4	425.3	95681
Wrap + top protection	3.5	1091.5	245582
Move from wrap	1.2	365.5	82233
Labeling module	1.0	315.0	70875
18 pallets in an external warehouse			-36000
Sum	7.0	2197.2	458371

Table 14. Cost-saving of concept 6, including lower and upper range.

	Annual cost save (DKK)		
Task	Lower range	Average	Upper range
Wrap + top protection	236,000	246,000	269,000
Integrated weight + height measurement	73,000	96,000	119,000
Move from wrap	72,000	82,000	93,000
Labeling module	53,000	71,000	89,000
		-30,000	
Sum or square of sumproduct for range	425,000	458,000	498,000

Rounded sum	**420,000**	**460,000**	**500,000**

6.4 Return on investment and payback time

The final concept has an ROI on 31 % with a cost save of 2019 and a simple payback time of 3.1 years when not encountering any growth nor inflation. Figure 28 illustrates the payback time when a 5 % annual growth rate in throughput but without a discount rate encountered. With these assumptions of the payback time concept, 6 is approximately 2.8 years, which is similar to the payback time of concept 5 and lower than the payback time of concept 3.

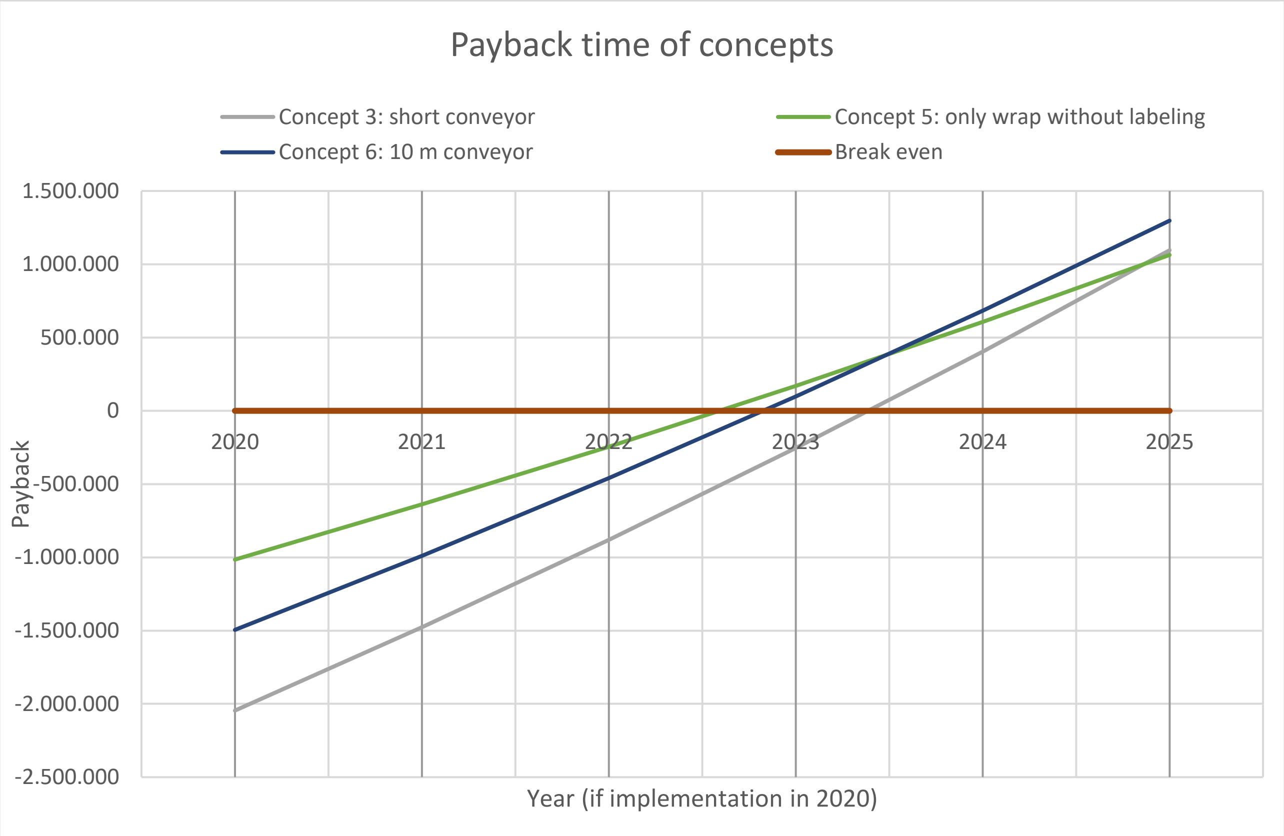


Figure 28. The payback time of concept 3, 5, and 6.

6.5 Sensitivity to the growth rate

The comparison of concepts has based on the throughput of 2019, and perpetual growth is not taken into account. According to the Annual Report 18/19 of Chr. Hansen, the annual organic growth of the whole company, has been 7-12 % annually during the past five years. The natural colors division experienced organic growth of 3 % last year, but the lower growth was primarily due to the impact of prices on raw materials. (Chr_Hansen, 2019)

The COVID-19 situation does not seem to affect the demand of the products at the warehouse site negatively as records in terms of throughput was recorded in April 2019. Therefore, it would be fair the evaluate the concepts in a growth scenario.

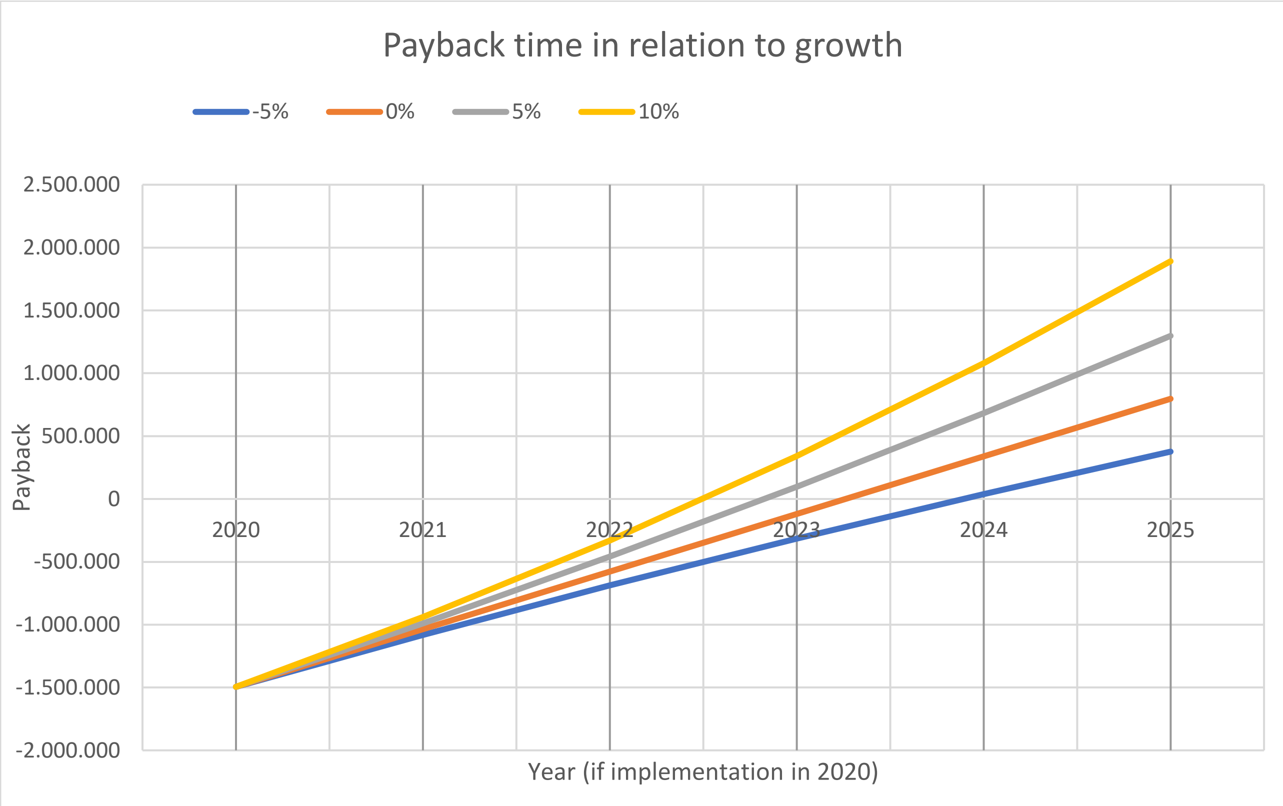


Figure 29. The payback time of concept 6 at different growth rates.

Figure 29 shows how the growth rate affects the payback time of concept 6. We see that the payback time varies in the range of 2.5 to 4 years with a growth rate in the range of 10 % to minus 5 % per year, respectively.

6.6 How does the solution comply with the requirement specification?

This section evaluates the requirement specification, which was conducted in section 3.3. Each bullet point has a requirement and measurable criteria. Green text indicates that the requirements have been reached in the final design. Red indicates that it has not been reached. Finally, blue means that the specification has been left out or not answered. Black text in the column *Measurable criteria* indicates criteria from the requirement specification.

Table 15. Evaluation of how concept 6 complies with the requirement specification in 3.3.

Requirements		**Measurable criteria**
Financial requirements	• The solution has to reduce the cost per handling unit, and the project strives to reach the solution with the highest possible return on investment (ROI)	• Goal of ROI > 25 % • 33 % estimated
Function requirements	• The solution has to be able to handle EU pallets ½ EU pallets, ¼ EU pallets, Industry pallets, and boxes/cartons	• Partly - not ¼ pallet

	• If the pre-packaging storage is organized in a queue, it must be possible to get pallets in the middle of the queue • Goods must not be kept at temperatures above +8°C more than a certain period of time	• Yes/no – if yes, faster than 10 min (not organized in a queue) • < 4 hours Yes, < 20 min
Physical design requirements	• Proposed equipment has to be easily dismountable • The solution must not reduce the number of warehouse slots • Reconstruction of the building is subject to approval by the building owner	• Yes – dismountable • No – might reduce capacity by 18 spots • It should not be a problem.
Safety requirements	• The solution must comply with Danish laws of working environment safety • The solution must comply with the current standards set by Chr. Hansen A/S • The solution shall reduce the number of forklift-pedestrian crossings • The solution must not block the emergency exit	• The supplier handles this issue. • The supplier handles this issue. • >20% reduction • Yes, very likely to do so. • Yes
Production performance requirements	• The solution must reduce the packaging time • The solution must increase the capacity of the packaging system	• >10 min reduction of packaging time of a median order on an EU pallet No, a reduction of 7 min was a better solution. • >10 % increase in maximum Kg/workday Yes, if we keep the workforce the fixed, then the capacity increases by 17 %.

7 Discussion of Concepts

7.1 Work efficiency

During the study, I have noted a difference in the effective process time and the actual process time. Just being present and letting the worker know that processing time is being recorded gives biased results. I have made an effort to reduce this bias as much as possible, but I assume that even my present will have some impact. This is not a critique of the workers. I believe that it is impossible to reach close to a hundred percent efficiency for an extended period of time. I regard it similarly to humans' ability to run faster for 100 m and for a marathon. This also implies that the capacity of eight hours is less than eight times the capacity of one hour. Similarly, the maximal capacity of one day cannot be reach day after day.

7.2 How to realize the cost savings?

The estimated cost saving in this report is a theoretical measure. However, we cannot assume that this cost reduction can be reached without showing how to implement the new process in the current process. This issue has been addressed in section Buffer storage after the wrapping machine.

The suggested working process in Figure 26. A new forklift route. in section 5.2.2 redistributes work from packaging to picking. This makes the forklift drive in similar patterns, which might increase the risk that two forklifts disturb each other. The question is if this will be a significant problem and eliminate the benefit of the working process.

In this project, cost-saving has been calculated on the reduction of full-time equivalents (FTE) required per year to conduct a job. A decrease in FTE is only realized if the workforce is reduced. Otherwise, the freed FTEs can be used to increase the capacity of the outbound processor allocated to other areas in the warehouse. If we encounter a growth scenario, this project can be regarded as a way to meet the demand for increased throughput without increasing the workforce.

As mentioned, the capacity of the outbound process in terms of throughput is not proportional to time, but diminish for a longer period. Hence, capacity cannot be regarded as a fixed number. It is probably possible to reduce the workforce and still manage the same results for a short period of time, but this will create bills in terms of unhappy and stressed employees. Sooner or later, this bill will have to be paid. On the other hand, reducing the required work without reducing the workforce should have the opposite effect. Hence, there must be some equilibrium of the right balancing workers available and the amount of work.

7.3 SSCC-labelling

Automation of the printing and applying SSCC-label, which is the label to put on a packed and wrapped pallet, has not been sorted out. It is an assumption that this process can be automated as it is possible in other companies. The cost of the implementation by the IT-department has not been detailed in this project even though it must be considered significant. Such an application might as well not be unique for this project, but possible to reuse in similar deployments in other warehouses within the Chr. Hansen.

7.4 Implementation to storage 2

Both in the AGV solution and the conveyor belt solution, implementation of the concept in storage 2 needs to be thought through. One relevant question in regard to this issue is the required storage capacity of storage 2.

Currently, the capacity of storage 245 spots, of which 160 are ground floor spots. The rest are found on shelves that require a pallet stacker for handling.

Appendix K – storage 2 illustrates that a reduction of the capacity to 200 pallets would be exceeded only a few times a year.

The current process has a double move as pallets are moved first to racks and hereafter to a place on the floor before they are loaded on a truck. Pallet stackers that are used handling of a pallet on racks cannot load pallet to trucks. I have been discussed to move all pallets in storage 2 to ground floor spots in order to eliminate the double movement of pallets.

7.5 Uncertainty in measurements

The estimates and measurement of the process times have a number of uncertainties. As mentioned in section Work efficiency, work efficiency is a major uncertainty. Another important factor is the variation of material and packaging, which has been investigated in section 3.2.3. In order to get a perfect estimate of the average packaging time, a large sample would be required due to the many variables. It was decided at the beginning of the project that it would time consuming and necessary to obtain a large sample of observations of the whole packaging process. Instead, certain subprocesses, e.g., the wrapping time, have been targeted. Furthermore, the number of measurements possible to conduct has been limited due to the coronavirus pandemic. The estimated new processes that are not present in the currency has been made based on their similarity to the current process. In order to cope with this uncertainty, a sensitivity analysis has been made.

7.6 Conveyor belt before and after the wrapping machine

The final design suggests three spots before the wrapping machine and eight spots after in section Technical description. Initially, it was suggested to have five spots before the wrapping machine and six spots after. Two spots have been moved to make the conveyor belt fit better into the placing of the racks in the warehouse. In section Technical description, I consider the case where an empty system is filled with 13 or more pallets. In order to process the 13th pallet, then the system would need assistance within 20 minutes. Every time we remove a spot after the wrapping machine, we reduce the time to assistance by 2.5 minutes. On the other hand, when we have three spots on the conveyor belt upstream of the wrapping machine, then we can only deliver four pallets immediately. The 5th pallet has to wait to a minimum of 2.5 minutes after the first has been delivered; the 6th has to wait for a minimum of 5 minutes et cetera.

7.7 Aspects in relation to future pandemics

The project has been conducted during the COVID-19 pandemic. In this context, it is relevant to reflect upon the benefits and consequences of the different concepts concerning future pandemics.

One benefit from the suggested process improvement is that packaging workers will be able to stay in the packaging area and at storage 1, just outside the packaging area. Currently picking workers also move pallets from packaging to storage 2. In the suggested solution these pallets will not be located in the packaging area   When packaging workers finish a pallet by moving it to a conveyor belt in the packaging area and not having to deliver the pallet at storage 2

7.8 This project from a broader perspective

It is clear that warehousing, in general, constantly moves towards more automation. This project can be seen as one step in this direction. The suggested solution is compatible with further automation. The AGV solution could be one step further. As an automatic guided vehicle is a fairly new technology in constant development, then the price of an AGV is likely to decrease in the next years. If the price of a new investment decreases, then the incentive to invest increases. Further development of the AGV solution enables it to manage more types of jobs. In the end, it is all about making the AGV substitute manual work, and the more work it can manage, the higher the cost-saving will be.

7.9 Work environment and safety aspects

It is essential to discuss how a proposed solution affects the work environment. When discussing work environment and safety, forklift accidents arise as a particular field of interest. As the suggested concept moves the pick-up point for finished pallet out of the packaging area and into the cold storage area, then forklift traffic in the packaging area decreases dramatically. If the picking process would run as in Figure 26. A new forklift route. in section 5.2.2, then most of the stacker forklift traffic in the packaging area would disappear. On the other hand, the wrapping machine and the conveyor belt impose a risk to the work environment. However, these are not new solutions, and they comply with safety standards.

All in all, I believe that the proposed solution brings a significant improvement in the work environment due to the reduced forklift traffic in the packaging area.

7.10 Did I choose the right project?

My main objective was to find a project, which Chr. Hansen can implement and add value to the business. I cannot answer whether or not I could have chosen another project, not concerning the outbound process, and reached this objective in a better way. However, I can evaluate whether or not my focus on the packing process was the right decision. We assume that the average packing time is 40 minutes, and the workforce available is 82 FTEs in the packing process on an average day. The time reduction of 7 minutes is a 17.5 % reduction in the work required for packing. 17.5 % of the 82 FTEs equals 14 FTEs. Of the other processes in the outbound process, only the picking process, which is 17.5 h/day, consumes more time per day than the 14 h/day. In order to yield a more significant reduction in work time from reducing the time of the picking process, we would have to improve the picking process by 82 %. Thus, choosing to focus on the packing process seems to be the right choice.

8 Conclusion

The cost of the packaging process can be reduced by implementing a wrapping machine, followed by a transportation system. Out of five investigated concepts, a sixth concept has been developed.

The final suggestion, concept 6, described in section 6, consists of a wrapping machine followed by an 8-10 m conveyor belt. The concept is a refinement of the concept 5 and has a short conveyor belt, yet long enough to eliminate waiting time. The estimated investment required is 1.5 million DKK, and annual cost saving is expected to be approximately 460,000 DKK in 2019 throughput. The simple return on investment (ROI) is 31 %. If we assume an expected growth of 5 % per year in throughput, the payback period of the investment would be approximately 2.8 years.

Concept 5, where pallets are wrapped in a fully automated wrapping machine, was evaluated to yield the highest ROI (33 %) of all concepts. Concept 1-3 yield have somewhat similar ROIs of 22, 24, and 26 %, which represented two versions of a conveyor belt and an AGV solution. Concept 4, which represented a combined AGV and conveyor belt solution, had an even lower estimated ROI of 20 % due to the more considerable required investment.

The estimated ROI of each concept lies in the assumption that the estimated cost saving can be realized. Due to the missing buffer after the wrapping machine, a worker needs to assist the wrapping machine. As this is not a full-time job, there would be a significant amount of waiting time. This realization led to the development of concept 6.

The investigation indicates that the central part of the cost reduction lies in implementing a wrapping machine with build-in modules such as weight and height measurements and labeling. Minimizing the distance to transport finished packed pallets does not necessarily yield high-cost savings compared to the investment. Instead, the focus should be to reduce the number of times a pallet is lifted and put in place.

The AGV, in concept 2, is an exciting solution with a great perspective and could be an addition to concept 6. The AGV a very agile solution that can be implemented to manage other jobs. As the AGV technology develops continuously, I suggest following the development carefully. The capacity of such a solution is sufficient, but it needs to be coordinated with the work schedule.

A long conveyor belt is an excellent solution to handle a large throughput. According to a supplier of conveyor belts, the throughput of this warehouse is in the lower range of their projects. Further, the long conveyor belt, concept 1, would block four aisles, and all implications as a result of this have not been investigated.

The work environment could be significantly improved with the proposed solution due to the elimination of forklift traffic in the packaging area. The action of sending pallets by conveyor belt to the cold storage moves the pick-up point for the forklifts out of the packaging area. This action reduces the risk of forklift accidents.

9 References

6.1 Verbal references

Søgaard, Thomas; Head of Supply Chain Development, Chr. Hansen. 2020. Meeting 6 January.

Hansen, Carsten; Senior Manager - Site Manager, Chr. Hansen. 2020. Meeting 6 January.

Romoeke, Kristian; Sales manager – Cyklop Emballering. 2020. Phone meetings and email.

Larsen, Preben; Project manager – Cyklop Emballering. 2020. Phone meetings and email.

Werenberg, Flemming; Sales manager – Interoll. 2020. Phone meetings and email.

Mårup, Kristian; Project manager – Interroll. 2020. Phone meetings and email.

Østergaard, Pierre; AGV product specialist – NC Nielsen. 2020. Phone meetings and email.

6.2 Written references

Alm, S. E. & Britton, T., 2008. *Stokastik.* 1st ed. Stockholm: Liber AB.

Chr_Hansen, 2019. *Annual Report 2018/19.* [Online]
Available at: https://www.chr-hansen.com/en/investors/reports-and-presentations
[Accessed 5 May 2019].

Chr_Hansen, 2020. *Chr. Hansen's SAP database: Handling Unit Monitor,* Copenhagen: s.n.

Hines, P. & Rich, N., 1997. The seven value stream mapping tools. *International Journal of Operations & Productions Management,* 17(1), pp. 46-65.

Lawrence, S. R. & Buss, A. H., 1995. ECONOMIC ANALYSIS OF PRODUCTION BOTTLENECKS. *MPE,* Volume 1, pp. 341-363.

Motte, D., 2008. A review of the fundamentals of the systematic engineering design process models. *Proceedings of the 10th International Design Conference - DESIGN'08,* DS 48(1), pp. 199-210.

Senderksá, K. & Václav, S., 2017. Spaghetti diagram application for workers' movement analysis. *U.P.B. Sci. Bull., Series D,* 79(1).

Wang, Y., Zhao, Q. & Zheng, D., 2005. BOTTLENECKS IN PRODUCTION NETWORKS: AN OVERVIEW. *Journal of Systems Science and Systems Engineering,* 14(3), pp. 347-363.

Appendix

Appendix A

Table 16. The process steps of a packaging process.

STEP	PROCESS	ACCUMULATED TIME	ACCUMULATED TIME	SPLIT TIME	SPLIT TIME (S)	PROCESS TYPE
1	Pick order	0	00:00:15	00:00:15	15	I
2	Get pallet 1	00:01:00	00:01:15	00:01:00	60	T
3	Get pallet 2	00:02:15	00:02:30	00:01:15	75	T
4	print order	00:03:53	00:04:08	00:01:38	98	O
5	check order	00:04:45	00:05:00	00:00:52	52	I
6	get empty pallet	00:05:10	00:05:25	00:00:25	25	T
7	get pallet lift	00:05:50	00:06:05	00:00:40	40	T
8	get pallet lift	00:06:25	00:06:40	00:00:35	35	T
9	remove plastic from pallet	00:07:25	00:07:40	00:01:00	60	O
10	print labels	00:08:55	00:09:10	00:01:30	90	O
11	get labels	00:10:10	00:10:25	00:01:15	75	T
12	check barcode	00:10:20	00:10:35	00:00:10	10	I
13	label 5 cans	00:12:10	00:12:25	00:01:50	110	O
14	scan 5 cans	00:12:50	00:13:05	00:00:40	40	O
15	move 5 cans to pallet	00:13:30	00:13:45	00:00:40	40	O
16	label 7 cans	00:17:45	00:18:00	00:04:15	255	O
17	scan 7 cans	00:18:00	00:18:15	00:00:15	15	O
18	move 7 cans to pallet	00:18:32	00:18:47	00:00:32	32	O
19	apply corners	00:19:22	00:19:37	00:00:50	50	O
20	apply band	00:20:00	00:20:15	00:00:38	38	O
21	apply corners	00:20:40	00:20:55	00:00:40	40	O
22	apply band	00:23:08	00:23:23	00:02:28	148	O
23	tidy things	00:25:21	00:25:36	00:02:13	133	Ot
24	weigh pallet	00:25:50	00:26:05	00:00:29	29	I
25	move back weight	00:26:30	00:26:45	00:00:40	40	T
26	measure	00:27:00	00:27:15	00:00:30	30	I
27	print SCC	00:30:15	00:30:30	00:03:15	195	O
28	wrap	00:34:00	00:34:15	00:03:45	225	O
29	move pallet to storage	00:38:30	**00:38:45**	00:04:30	270	T

Figure 30. Process Activity Map of the Packaging Process. O=operation, T=transport, I=inspection, Ot=other

Appendix B – Function analysis

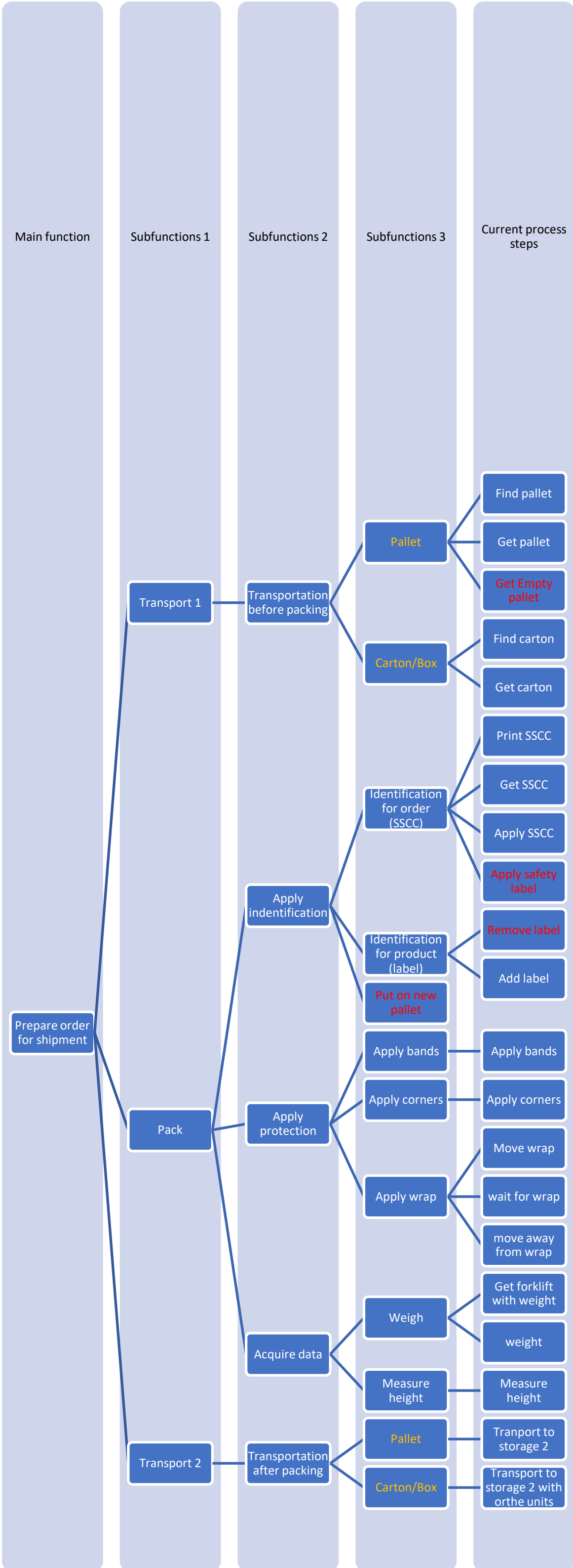


Figure 30. Boxes with yellow text indicates a decision choice between two or more boxes. Boxes with red text are not necessary in all orders. Boxes with white text are standard procedures.

Appendix C - Meeting with Pierre Østergaard from N.C. Nielsen A/S

N.C. Nielsen is a Danish supplier of AGV solutions. I have presented Pierre Østergaard from N.C. Nielsen the current situation and asked how N.C. Nielsen is able help as part of concept 2.

Pierre Østergaard suggested a pallet mover AGV as the best and cheapest solution to the project. The name of the model is N 24.

The pallet mover AGV from N.C. Nielsen navigates with reflexes and an indoor GPS-system. It requires a WIFI connection in the warehouse building, which will be installed as a separates network. An employee from Chr. Hansen will be taught how to operate the AGV, e.g., change routes and correct simple errors.

The pallet mover AGV can move a pallet from a floor position to another floor position. I can be programmed to pick and deliver to multiple floor positions, and it is possible to pick or deliver to a conveyor belt as well. In fact, it is preferred for the AGV to pick from a conveyor belt because the pallet on the conveyor belt is positioned more accurately.

As a pallet mover AGV runs more smoothly and slower compared to a human driver, the wear and tear of an AGV are lower. The speed of the pallet mover AGV is 7 km/h compared to 14 km/h for a human-operated pallet mover. The AGV is a bit slower in picking and delivering pallets as well. A rough worst-case estimate will be that the AGV spends twice the time the desired operation. On the other hand, it is more consistent, since it is not interrupted by colleges for chatting.

The price of the suggested AGV solution is in the range 1,1 to 1,2 mill. DKK.

Appendix D - Meeting with Flemming Werenberg and Kristian Mårup from Interoll

Interoll is a supplier of conveyor belts and of the warehouse solutions. I have presented Interoll for two conveyor belt solutions. One solution with a long conveyor belt of approximately 60 meters, named as concept 1 and the second solution of a shorter belt of 35 meters, called concept 3.

Interoll has two types of conveyor belts. One is a belt based on roller, and the other is a belt based on chains. The chain belt comes with either two or three chains. A major concern to Interoll is the type of the pallets because the chain conveyor with two chains cannot handle pallet smaller than standard EUR pallets. As 19 % of pallets are half-euro pallets, it is desirable to have a conveyor belt that is able to handle this type of pallet. Thus, we need a chain conveyor with three chains. Quarter pallets are not compatible with any of the conveyors because they do not have skids underneath.

The price of the conveyor belts is measured in units of 1.35 meters, which is equivalent to a storage slot of one EUR-pallet. Concepts 1, which is a 62 meter conveyor belt, needs 46 of these units. Concept 3, a 35 meter belt, requires 26 of these units.

The price of two different types of conveyors is 9-10,000 DKK and 14,000 DKK for a chain conveyor and a roller conveyor, respectively. However, a chain conveyor has one engine to a whole belt, which makes the price of a short belt a little more expensive per meter and the long one a little cheaper per meter. Installation and additional costs make the total price to be in the range 20-23,000 DKK for both solutions.

Appendix E – Meeting with Kristian Romyeke from Cyklop-Emballering A/S

Cyklop is a Danish supplier of wrapping machines for pallets and supplied Chr. Hansen with several products. Currently Chr. Hansen Hammerholmen has two semi-automatic wrapping machines.

Generally, there are two types of wrapping machines. One consists of a plate that will spin and an arm that is fixed. The two semi-automatic wrapping machine at Hammerholmen are of this type. The other type is to have the pallet fixed and arm spinning around the pallet. This type seems to require a bit more space because of the rotating arm.

Kristian Romyeke has been briefed about the current situation. His recommendation among the different models of fully automated wrapping machines is the model GL-1000, which meets the capacity requirement. This model operates with a conveyor belt. A pallet is loaded on to a conveyor belt and sent to the wrapping machine through the conveyor. This required some length of the conveyor belt before and after the wrapping machine in order to have a buffer. The capacity of this wrapping machine is 70 pallets per hour, which translates to a lead time of the wrapping machine of 51 seconds per pallet. This capacity is sufficient for the needs of the warehouse site.

It is possible to module adding top protection to the pallet, which is a desired feature.

Kristian Romyeke estimates that implementation of a system with the model GL-1000 and a top protection module will cost 5-600,000 DKK.

Appendix F – Inspiration from another warehouse

X is a global company with a production site located in Denmark. At this site X build a new warehouse with a fully automated warehouse, which was put into action a decade ago. The storage capacity of the warehouse is 6600 pallet units. The annual throughput is approximately 80000 pallets measured in pallet units. Warehouse workers work in two daily shifts in the time period 7 am to 11 pm. The warehouse has three terminals, both handling in- and outbound of good.

The internal transport system at the warehouse is based on the conveyor belts. Pallets are picked from the high-rack by a machine and place on a conveyor belt. The pallet is then transported to the packaging area where a packaging worker moves packages from one pallet to another, labels the pallet, and returns the pallet to the conveyor belt. The system is conducted such that unnecessary movement has been minimized and the packaging worker works is lead to work in an ergonomically gentle position.

Product variety

In terms of pallet variety, the warehouse has standardized their pallets in order to fit the pallets to the automatic system. Hence, the warehouse only handles two types of pallets: one standard EUR pallet in wood and one plastic pallet with similar EUR pallet dimensions (80x120 cm).

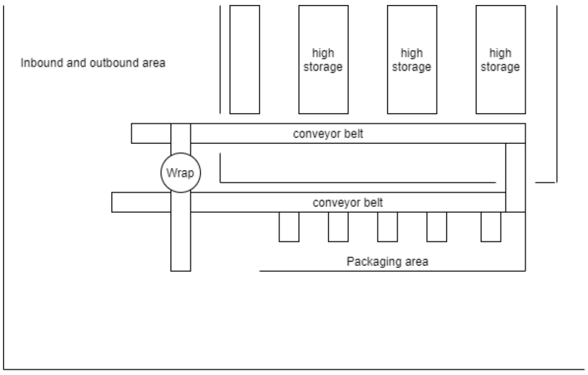


Figure 31. A map of a warehouse.

Table 17. A comparison of Hammerholmen and a visited warehouse.

	Chr Hansen Natural Colors, Avedøre, Denmark	Visited company
Handling Units per year	19000 pallet + 10000 cartons	80000 pallets + x cartons
Packaging Variety	18 different pallets types + cartons	2 different pallets types + cartons
Terminals for trucks	2	3
Storage Capacity	2657 slots (cold permanent) + ≈300 (storage pre and post pack) + external storage	6600 slots
Storage Density	99 % + external storage	< 80 %
Packaging Area	14 x 23 m	Larger than Hammerholmen
Loading Area	12x10 m + racks 245 slots	Smaller than Hammerholmen
Distance Pack-Load area	60-70 m	0 m
Shifts per day	2 (3)	2
Workers	25	10
Investment cost		≈100 mill. DKK

Appendix G – Cost save scheme

Table 18. Cost sensitivity scheme.

COST SENSITIVITY	TIME SAVED PER PRODUCT/OPERATION (MIN)			ANNUAL COST SAVE (DKK)			METHOD
PRODUCT/OPERATION	Lower range	Average	Upper range	Lower range	Average	Upper range	Estimation method
WRAP + TOP PROTECTION	2.9	3.15	3.75	205538	223256	265781	20 observations, different pallets
INTEGRATED WEIGHT + HEIGHT MEASUREMENT	1	1.5	2	70875	106313	141750	2 observations
ADDITIONAL OPTION: LABELING MODULE	1	1.5	2	70875	106313	141750	Own estimate
MOVE FROM WRAP, AGV	2.07	3.285	4.5	146711	232824	318938	2 Oberservations + own estimate
MOVE FROM WRAP, 62 M CONVEYOR	1.2	2.35	3.5	85050	166556	248063	Own estimate
MOVE FROM WRAP, 35 M CONVEYOR	0.6	1.175	1.75	42525	83278	124031	Own estimate

Appendix H – Investment scheme

Table 19. Investment sensitivity scheme

INVESTMENT SENSITIVITY		PRICE (DKK)		METHOD
PRODUCT/OPERATION	Lower range	Average	Upper range	Estimation method
WRAPPING MACHINE INCL. TOP MODULE	731000	731000	731000	Offer from supplier
WEIGHT AND HEIGHT MEASUREMENT	74,000	74000	74,000	Offer from supplier
ADDITIONAL OPTION: LABELING MODULE	215000	215000	215000	Offer from supplier
CONVEYOR BELT (62 M)	920000	874000	828000	Estimate from supplier
CONVEYOR BELT (35 M)	520000	559000	598000	Estimate from supplier
RECONSTRUCTING A WALL	25000	50000	75000	Own estimate
NEW RACKS	25000	50000	75000	Own estimate

Appendix I – Expected ROI of concepts

Table 20. ROI calculation and sensitivity.

	Investment (DKK)			Cost save (DKK)			ROI		
	Lower range	Best estimate	Upper range	Lower range	Best estimate	Upper range	Lower range	Best estimate	Upper range
Concept 1: long conveyor	1,925,000	1,994,000	2,063,000	361,463	496,125	655,594	18%	25%	34%
Concept 2: AGV	2,033,000	2,033,000	2,033,000	423,124	562,393	726,469	21%	28%	36%
Concept 3: short conveyor	1,475,000	1,514,000	1,553,000	318,938	412,847	531,563	21%	27%	36%
Concept 4: conveyor + AGV	2,653,000	2,692,000	2,731,000	423,124	562,393	726,469	15%	21%	27%
Concept 5: wrapping only	855,000	855,000	855,000	276,413	329,569	407,531	32%	39%	48%
Concept 5 + labeling	1,070,000	1,070,000	1,070,000	347,288	435,881	549,281	32%	41%	51%

Appendix J – Packaging material

Table 21. Distribution of packaging material types of 2019.

PACKAGING MAT. TYPE	EURO PALLET	½ EURO PALLET	Z-TYPE PALLET	INDUSTRY PALLET	BOXES
1000	0	0	0	440	0
½EUR	0	3816	0	0	0
A1CA	0	0	0	0	501
AUPA	0	0	0	774	0
B1CA	0	0	0	0	530
BOXA	0	0	0	0	6
BOXB	0	0	0	0	23
BOXC	0	0	0	0	362
BOXD	0	0	0	0	124
C1CA	0	0	0	0	1470
DCAR	0	0	0	0	712
ECAR	0	0	0	0	829
EURP	12501	0	0	0	0
FBOX	0	0	0	0	12
FCAR	0	0	0	0	205
FT	0	0	0	12	0
GCAR	0	0	0	0	1
HCAR	0	0	0	0	354
NCAR	0	0	0	0	53
PLAP	336	0	0	0	0
X6CA	0	0	0	0	5
YBOX	0	0	0	0	5
ZPAL	0	0	4667	0	0
ZPLP	0	1021	0	0	0
SUM	12837	4837	4667	1226	5192
		Total count ex. boxes and Z-type pallets:			18900

Appendix K – storage 2

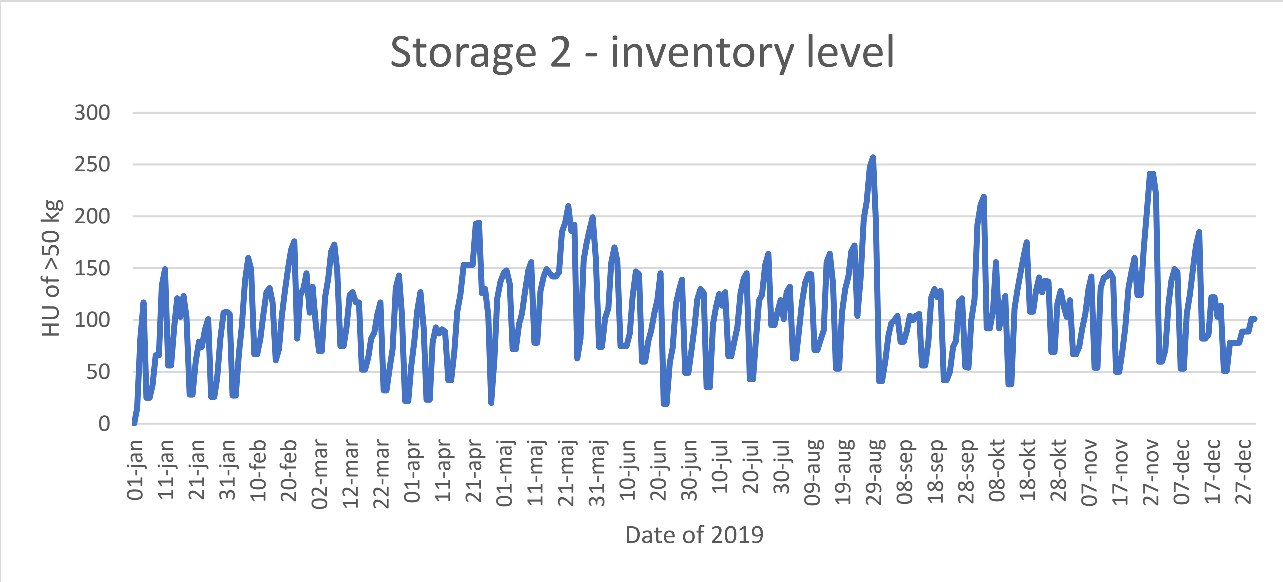


Figure 31. Inventory level of storage 2 in 2019

Appendix L – Economic evaluation

Concept 1

Cost save

Task	Work saved per unit (min)	Work saved per year (h)	Work saved per year (DKK)
Integrated weight + height measurement	1.4	427.5	96,188
Wrap + top protection	3.5	1097.3	246,881
Move from wrap, 62 m conveyor	2.1	672.9	151,406
Labeling module	1.0	316.7	71,250
Sum	7.9	2,514	565,725

Financial investment

	Price (DKK)		
Investment	Lower range	Best estimate	Upper range
Wrapping machine incl. top module	731,000	731000	731,000
Weight and height measurement	74,000	74000	74,000
Labeling module	215000	215000	215000

Conveyor belt (62 m)	920000	874000	1058000
Reconstructing walls	50,000	100000	150,000
New racks	50,000	100000	150,000
Unexpected expenses	306,000	314,100	356,700
Sum	2,346,000	2408100	2,734,700

Concept 2

Cost save

Task	**Work saved per unit (min)**	**Work saved per year (h)**	**Work saved per year (DKK)**
Integrated weight + height measurement	1.4	427.5	96188
Wrap + top protection	3.5	1097.3	246881
Move from wrap, AGV	3.1	982.1	220966
Labeling module	1.0	316.7	71250
Sum	8.9	2823.5	635285

Financial investment

	Price (DKK)		
Investment	Lower range	Average	Upper range

Wrapping machine incl. top module	731000	731000	731000
Weight and height measurement	74000	74000	74000
Labeling module	215000	215000	215000
Reconstructing a wall	25000	50000	75000
AGV stacker	1178000	1178000	1178000
Unexpected expenses	333,450	337,200	340,950
Sum	2,556,450	2,585,200	2,613,950

Concept 3

Cost save

Task	Work saved per unit (min)	Work saved per year (h)	Work saved per year (DKK)
Integrated weight + height measurement	1.4	427.5	96188
Wrap + top protection	3.5	1097.3	246881
Move from wrap, 35 m conveyor	1.5	462.4	104043

Labeling module	1.0	316.7	71250
Sum	7.3	2303.8	518362

Financial investment

	Price (DKK)		
Investment	Lower range	Average	Upper range
Wrapping machine incl. top module	731000	731000	731000
Weight and height measurement	74000	74000	74000
Labeling module	215000	215000	215000
Conveyor belt (35 m)	520000	559000	598000
Reconstructing a wall	50000	100000	150000
New racks	50000	100000	150000
Unexpected expenses	246000	266850	287700
Sum	1,886,000	2,045,850	2,205,700

Concept 4

Cost save

Task	**Work saved per unit (min)**	**Work saved per year (h)**	**Work saved per year (DKK)**
Integrated weight + height measurement	1.4	427.5	96188

Wrap + top protection	3.5	1097.3	246881
Move from wrap, AGV	3.1	982.1	220966
Labeling module	1.0	316.7	71250
Sum	8.9	2823.5	635285

Financial investment

	Price (DKK)		
Investment	Lower range	Average	Upper range
Wrapping machine incl. top module	731000	731000	731000
Weight and height measurement	74000	74000	74000
Labeling module	215000	215000	215000
Conveyor belt (35 m)	520000	559000	598000
Reconstructing a wall	50000	100000	150000
New racks	50,000	100,000	150,000
AGV stacker	1178000	1178000	1178000
Unexpected expenses	422,700	443,550	464,400
Sum	3,240,700	3,400,550	3,560,400

Concept 5

Cost save

Task	Work saved per unit (min)	Work saved per year (h)	Work saved per year (DKK)
Integrated weight + height measurement	1.5	475	106,875
Wrap + top protection	3.15	997.5	224,438
Move from wrap	0	0	0
Labeling module	1	316.6666667	71,250
Sum	5.65	1789.166667	402562.5
without label	-1	-316.6666667	-71250
Sum	4.65	1472.5	331312.5

Financial investment

Investment	Lower range	Average	Upper range
Wrapping machine incl. top module	731000	731000	731000
Weight and height measurement	74000	74000	74000
Labeling module	215000	215000	215000

New racks	25000	50000	75000
Unexpected expenses	156750	160500	164250
Sum	1,201,750	1,230,500	1,259,250
Without label	-215,000	-215,000	-215,000
Sum with labeling module	986,750	1,015,500	1,044,250

Concept 6

Cost save

Task	Work saved per unit (min)	Work saved per year (h)	Work saved per year (DKK)
Integrated weight + height measurement	1.4	425.3	95681
Wrap + top protection	3.5	1091.5	245582
Move from wrap	1.2	365.5	82233
Labeling module	1.0	315.0	70875
18 pallets in an external warehouse			-30000
Sum	6.6	2197.2	464371

	Annual cost save (DKK)		
Task	Lower range	Average	Upper range
Wrap + top protection	235837	245582	268971
Integrated weight + height measurement	72647	95681	118716
Move from wrap	71602	82233	92864
Labeling module	53156	70875	88594
18 pallets in external warehouse	-30000	-30000	-30000
Sum	431929	464371	503160

Financial investment

	Price (DKK)		
Investment	Lower range	Average	Upper range
Wrapping machine incl. safety fence, 8 m conveyor belt, and installation incl. 12 conveyor units, 2	1,250,000	1,250,000	1,250,000

turntables, labeling module, and weight and height module			
Reconstructing walls	25,000	50,000	75,000
Unexpected expenses	191250	195000	198750
Price	1,466,250	1,495,000	1,523,750