A Case Study of Alternative Pallet Solutions at Tetra Pak Additional Materials

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October 3, 2019

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Abstract

Pallets are the most common tertiary packaging solution with over 80% the world trade currently being carried out using pallets. The most widely used pallet type is the four-way wood pallet which accounts for 86% of the pallet production worldwide and the most common pallet size is the Euro Pallet. A department at Tetra Pak called Additional Materials (AddMat) is mainly using Euro Pallets, which have a low fill rate in containers, and almost all their pallets are made of wood, which could potentially have higher environmental impact and costs, as well as a lower food safety, compared to alternative materials. The purpose of this study was to analyse what pallet sizes and materials were best suited for each of AddMat's product areas and to calculate the resulting savings, in terms of cost and CO_2e emissions, from using alternative pallet solutions. A case study with a single-case design was chosen as the research method. Qualitative data was gathered through interviews and a literature review. Quantitative data was gathered from internal data sources and from pallet suppliers.

To analyse pallet sizes currently used, the deck-area coverage of all pallet sizes in all means of transport was calculated and visualized with the help of a software called StackBuilder. New pallet sizes were invented, and these sizes were analysed in the same way. The study found that the invented size OP1 (1200 x 770 mm) performed the best, met all requirements from factories, and was the best substitute to the Euro Pallet. Switching the Euro Pallet to OP1 was calculated to give a 7,86 % reduction in transport costs and a 7,2 % reduction in CO_2e emissions from transport. This change was mainly recommended for the product areas Closures and Straws. The product area Strips is recommended to keep using the Strips pallet (1200 x 750 mm). Rack compatibility and box adaptability are the most important factors to research before implementation.

The pallet materials chosen for comparison were wood, plastic, and paper. The recommended material for AddMat was paper, mainly due to the low price, the low tare weight, and the high food safety. Switching from wood pallets to paper pallets could lead to a 70,5 % reduction in pallet purchasing cost and a yearly reduction of 230 447 kg CO_2e emissions from the transport phase, due to a lighter pallet weight. The safe racking load, durability, and water resistance of the paper pallet must be tested further.

Keywords: *Case study, Pallets, Pallet Sizes, Deck-Area Coverage, Pallet Materials,* CO_2e *emissions*

Acknowledgement

This master thesis was started in May 2019, finished in October 2019, and is the final step of my Master of Science in Industrial Engineering and Management. The thesis was written at Lund University at the Department of Packaging Logistics. First, I would like to thank my supervisor Henrik Pålsson for the support, the inspiring discussions, and the valuable feedback. I would like to thank all the people working at AddMat for making my time pleasant and fun through lunches and Friday Fika. I am thankful to Markus Hansson and Diego Garvas for providing valuable information through interviews and Anna Ramberg for giving me feedback on my presentation. I also want to thank my girlfriend Wynnette Yip Mann for always being there for me. Finally, I would like to give my heartfelt thanks to Daniel Hedvall, my supervisor at AddMat, for his unyielding support and his devotion in helping me succeed with this project.

Lund, October 2019

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Contents

1. Introduction

1.1. Company description

Tetra Pak is a multinational food packaging and processing company under the Tetra Laval group and Tetra Pak Additional Materials (AddMat) is a department at Tetra Pak which develops and manufactures additional materials for beverage cartons. Additional materials are all primary package consumables supplied to Tetra Pak's global customer base, except carton material. The additional materials are divided into three product areas: Closures, Straws, and Strips & Films. Closures manufacture different types of caps. Straws manufactures different types of straws. Strips & Films manufacture strips that are used to seal the layers of the cartons, and films that are used inside the cartons to protect the beverages, especially for acidic beverages that corrode the carton. AddMat has over 1100 employees and 35 production sites, producing 30 billion straws, 24000 tons of strips & films, and 35 billion closures annually, making them one of the largest suppliers of additional materials for beverage packaging's in the world (Tetra Pak, 2019). Over 550 000 pallets were used by AddMat in 2018, mainly wooden Euro Pallets. AddMat's goals include having zero waste, lowering their environmental impact throughout the supply chain and achieving lowest system cost possible at specified quality (Tetra Pak, 2019). Compliance with industry standards regarding quality and food safety is crucial.

1.2. Background

Pallets are one of the most basic building blocks of the supply chain. They enable goods to be handled, stored and transported in a seamless, efficient manner, and facilitate the unitisation of goods into unit loads, which in turn enables economy of scale benefits. Unit loads are often heavy, but pallets allow the goods to be handled efficiently with the help of material handling equipment. Pallets are the most common tertiary packaging solution with over 80% of all world trade currently being carried out using pallets. The usage of pallets worldwide has constantly been growing and in 2017 pallet sales climbed to nearly 5.1 billion units, from under 3.7 a few years earlier. (Kočí, 2019)

Historically, pallets were made of solid wood. Wood continued to be the dominating material after World War II when the pallet production grew dramatically (Bush & Araman, 1998), and currently accounts for more than 90 percent of the pallets being used worldwide (Carrano, Thorn, & Woltag, 2014; Clarke, 2004). However, this could change, as there are several global trends that could increase the use of alternative materials for pallets. These are trends such as a demand for lower environmental impact of the supply chain, increased reusability of pallets, higher standardisation, and pest regulation (Clarke, 2004). Examples of alternative materials used for pallets are plastic, corrugated paper, metal and presswood. According to a paper by Bush and Araman (1998), plastic and corrugated paper were the materials with most potential to impact the use of pallets. The pallet material was not the only aspect of the pallet that was undergoing a change. Pallet dimensions were becoming more standardised in industries and across geographic regions due to globalisation (Clarke, 2004).

1.3. Problem formulation

The need for efficient pallet solutions grows larger as supply chains are becoming more and more complex. The increased complexity is due to several factors, for instance, the expansion of global markets, an increase in the number of storage-keeping-units, an increase in the variety of distribution and shipping modes, and higher expectations from customers on service levels and delivery times (Bilbao, Carrano, Hewitt, & Thorn, 2011). At the same time, companies are striving to lower costs, while making their supply chains more efficient and sustainable. Since large quantities of pallets are used for transportation and storing of goods, even a small change to the pallet design can lead to a considerable change in costs and environmental impact.

Despite globalisation, pallet dimensions are still different for different regions, which is problematic for companies operating globally (Clarke, 2004). For example, the Euro Pallet, which is the pallet type most commonly used in Europe, does not fit well in the ISO standardized containers, which were originally designed in the U.S. This leads to a low fill rate of the container, which leads to higher transport costs and a higher environmental impact of the transport.

Companies have also experienced problems with wood as a pallet material. Disadvantages include forest depletion and a high environmental impact, degrading of the wood due to environmental factors, and an unreliable performance of the pallet (Soury, Behravesh, Esfahani, & Zolfaghari, 2009). These disadvantages along with other issues such as a growing concern regarding pest migration has led to an increase in the use of alternative materials (Bush & Araman, 1998; Clarke, 2004). It can be difficult to analyse the environmental impact of pallets made from different materials. Kočí (2019) states that relatively little information has been published on life cycle assessments of pallets. The published life cycle assessments (LCAs) are generally focused on wooden pallets and sometimes plastic pallets, but there are barely any papers on cardboard pallets. Compared to life cycle assessments of pallets, even less information has been published on pallet dimensions and how they affect the fill rates of transports, which in turn affects the costs and environmental impacts of transports. In the literature review, no information was found on fill rates of pallets in means of transport.

1.4. Purpose and research questions

Theory describes different factors affecting the choice of pallet material and suggest which factors are crucial. However, it is very difficult to quantify the performance of certain factors, e.g. supply chain impact. Even if the performance could be quantified, it is impossible to decide on the importance of the factors in relation to each other. This is because the importance varies depending on the situation. For example, the high strength of wooden pallets might be redundant for a company shipping light products. The fill rate of pallet sizes in Europe is easier to quantify and generalise, due to standardised means of transport. Nevertheless, companies use different means of transport to different degrees, which makes the total performance of a pallet sizes impossible to generalise. One way to research how factors relate to each other is to analyse a specific case where theory can be applied, which was the approach for this thesis. The specific case analysed was AddMat's supply chain.

AddMat is mainly using Euro Pallets, which have a low fill rate in containers, and almost all their pallets are made of wood, which could potentially have a higher environmental impact and cost, compared to alternative materials. Therefore, AddMat wish to investigate how their pallet solution can be improved for each of their product areas. The purpose of this thesis was to identify, analyse, and describe alternative pallet solutions for AddMat, in terms of pallet dimensions and pallet materials, and find the solutions best suited for AddMat's product areas, mainly with regards to minimising costs and CO_2e emissions. The sizes analysed should be the ones currently used by AddMat, the ones standardised by ISO for Europe, and any pallet sizes invented in this project. The sizes will be analysed with regards to how they affect fill rates of pallets in trucks and containers, which in turn affects cost and CO_2e emissions. Pallet sizes in this project will also be analysed with regards to additional factors like rack compatibility, the effect on box sizes, and new loading patterns. The materials analysed should be wood, plastic, and corrugated paper. The pallet materials should be analysed on factors affecting the pallet material choice, most importantly strength, cost, and CO_2e emissions. Other important factors are durability, supply chain impact, weight, and sanitization. The alternative pallet solutions will be compared to the current pallet solution AddMat is using and differences in performance on the different factors will be assessed. The research questions were:

RQ1: Based on truck and container fill rates, as well as the additional factors like rack compatibility, box adaptability, and stacking patterns, what pallet dimensions are best suited for each of AddMat's product areas?

RQ2: Based on the factors affecting the pallet material choice, e.g. price, strength, weight, pallet entry height, and sanitization, what pallet materials are best suited for each of AddMat's product areas?

RQ3: What are the costs and CO_2e -emissions of the alternative solutions for pallet dimensions and materials and how does compare to the current solution AddMat is using?

1.5. Delimitations

Several delimitations were made to make this project feasible in the given time and to increase the reliability of the results.

- Only shipments that originated in Europe will be analysed when assessing the current situation, due to that trucks are standardized in Europe, while many different trucks are used for the rest of the world.
- Only shipments with a shipment date during 2018 will be analysed when assessing the current situation, since this is the most up-to-date data, which increases reliability and best reflects AddMat's current shipments.
- Since rail and air freight make up less than 2.1% of total transport, these transport modes will not be investigated.
- The only quantitative data that will be used for assessing environmental impact is data on CO_2e. CO_2e is the most important factor to take into consideration, due to the high impact of CO_2e emissions from shipments and from the pallets' life cycle. There is also more information on CO_2e emissions than on any other factor.
- Cost and CO_2e savings from more effective material handling and storing will not be calculated, since these savings would make up a small part of the total savings, and since it would be complicated to calculate, which would lead to high uncertainties.
- Only pallets will be considered, not other tertiary solutions like loading ledges and slip sheets, since AddMat is not interested in investing in new material handling equipment to handle loading ledges or slip sheets.
- The product area Films will not be considered, since films are "packaging materials" not "additional materials" and the pallets used for films are difficult to change, due to that boxes are adapted to the films (films are stored in rolls).
- No information will be acquired on how customers use or dispose of pallets due to restrictions on contact with customers. This will lead to that the wooden pallets currently used will be considered single use, however, this will be discussed further in chapter 7 and 8.

1.6. Report structure

The report consists of the following 11 chapters:

1) **Introduction** – *explains the background and purpose of the project*
2) **Methodology** – *describes and motivates the methods used in the project*
3) **Theory** – *presents the findings from the literature review*
4) **Life cycle assessments** – *discusses three papers on life cycle assessments for different pallet materials*
5) **AddMat's supply chain** – *presents empirical data collected about AddMat's supply chain, mainly shipment data*
6) **AddMat's requirements on pallets** – *describes the requirements on pallets from AddMat and Tetra Pak*
7) **Pallet Materials** – *presents empirical data collected about three pallet materials, namely plastic, wood, and paper*
8) **Analysis** – *the analysis is divided into two parts; first different pallet sizes are analysed, then different pallet materials are analysed*
9) **Discussion of results** – *Discusses results and compares them with theory*
10) **Conclusions** – *presents conclusions, recommendations, contributions, and suggestions for future research*
11) **Appendix**

2. Methodology

2.1. Research strategy/approach/method

There are five major research methods: experiments, surveys, archival analyses, histories, and case studies (Yin, 2014). Since the research questions are tied to a unique case it seems natural to use case study as the research strategy. The research questions are "what" questions and they are exploratory in nature. For exploratory "what" question, like research question one and two, it is justifiable to use a case study (Yin, 2014). According to Voss et al. (2002) a case study lends itself to "early exploratory investigations where variables are still unknown". This is true for this project since there is not much theory on alternative pallet materials and pallet dimensions. Another strength of using case studies is that a phenomenon can be studied in its natural setting (Voss et al., 2002), which is necessary for this project. For the reasons previously stated, the chosen research method was a case study. There are also disadvantages with case studies and these are discussed in section "2.5 Quality of the study".

To answer the research questions, a single-case design was adopted. According to Yin (2014) single-case designs can incorporate sub-units of analyses, so that a more complex design can be developed. This was the main reason for choosing a single-case design, since an in-depth analysis on the factors affect the choice of pallet is necessary to answer the research questions. Multiple-case designs are considered more compelling but can require extensive resources and time, and it is also important to replicate the study for each case (Yin, 2014). A multiple-case design was not viable, due to limited time and due to the uniqueness in the case, which would have made replication challenging.

2.2. Literature review

The initial step in this research was to conduct a literature review. Literature was found by extensively searching through various databases. Theory on pallets is somewhat limited, especially with regards to different pallet materials and pallet dimension analysis. Therefore, the literature review was conducted until there were no more relevant sources to be found in the databases. Theory was used to verify information collected in the empirical study and to underpin the results from the analysis. Theory was also useful to generalize the results of the thesis, which is characterized as analytic generalization by Yin (2014). The literature was scrutinized, especially with regards to how theory have changed since the papers were published. Papers on life cycle assessments were often sponsored by pallet manufacturing companies and any potential impartiality will be discussed throughout the theory segment

2.3. Data collection

After a theoretical base had been established, empirical data was collected. According to Yin (2014), one principle of data collection is to use multiple sources of evidence. Qualitative data about the current pallet solution, product assortment, and transports was derived from AddMat's internal data sources. The data was reviewed critically; faulty data was corrected or excluded, and missing data was corrected when possible, otherwise excluded. The exclusion of data could increase uncertainty and reduce generalizability, and this issue is discussed throughout the paper. Information about different pallet materials was mainly acquired from pallet suppliers. Yin (2014) states that one of the strengths of case studies is the opportunity to use many different sources of evidence, which broadens the researcher's perspective and allows triangulation to be used. Data triangulation was used by comparing data from suppliers with theory, by comparing data collected by AddMat with data on suppliers' websites, and by comparing the methods and results of different papers to one another.

Interviews were conducted to acquire mainly qualitative data, but also quantitative data on several topics. Saunders, Lewis, and Thornhill (2009) describe three ways to carry out interviews: structured interviews, semi-structured interviews, and unstructured interviews. For this thesis the semi-structured approach was chosen, due to that both specific questions, and more general themes were required to be covered in the interviews, and because both qualitative and quantitative data had to be collected. In semi-structured interviews the researcher has a list of questions and themes to be covered and deviations in question order are allowed. Yin (2014) presents four weaknesses of interviews: i) bias due to poorly articulated questions, ii) response bias, iii) inaccuracies due to poor recall, and iv) reflexivity – interviewee gives what the interviewer wants to hear. These weaknesses were counteracted by preparing and documenting the interviews thoroughly, by following the prepared line of inquiries while remaining unbiased, and by using triangulation to compare the answers with theory and data from pallet suppliers.

2.4. Data analysis

In their paper on quantitative data analysis, Miles and Huberman (1994) describe three activities for analysing data: data reduction, data display, and conclusion drawing and verification. Data reduction is the selection and transformation of empirical data into a correct and simplified form. For this research project, data reduction was done in steps. First errors and missing data was identified, and the faulty data was corrected or excluded. Then, different data sources were connected, which resulted in two main sources of data in the form of two Excel sheets. One sheet includes data on the different products and information relating to pallets for each product. The other sheet includes shipping data.

Data display is the representation of data in a condensed and organized fashion, which makes it easier for conclusions to be drawn from the analysis. This was done by displaying data in tables and charts, which made it easier to compare the performance of pallet sizes and pallet materials for the different product areas and to find the areas with the highest improvement potential. Calculations were done with verified methods from theory and from trusted organizations. The process of displaying data is described in detail in chapter 4 and 5.

Conclusion drawing and verification is about generating meaning from the findings in a way that is valid and unbiased. Conclusions were drawn based on data and information from theory and from the empirical study. A more detailed description of this process can be found in chapter 6. To keep the conclusion drawing valid and unbiased, delimitations were kept consistent, assumptions and uncertainties were clearly presented, and conclusions were verified with sanity checks through calculations and comparison with theory.

2.5. Quality of the study

Regarding the quality of the study, there are several disadvantage of case studies that must be taken into consideration. Critics of case studies often point out that generalization may be difficult (Bell, 2010). However, Bell preferred to use the term relatability rather than generalizability. Even though the case is unique for Tetra Pak, there are other companies that could benefit from doing similar case studies on their pallet systems and then the methods and results from this thesis could be beneficial. There is also a concern about the possibility of selective reporting and the difficulty for researchers to cross-check information (Bell, 2010). To decrease the risk of selective reporting the data collection was methodical, e.g. delimitations were used to standardize empirical data and to maintain consistency of the study at comparable levels. Cross-checking was done when possible. Different sources of empirical data were compared to each other, e.g. information from one pallet supplier was compared to other pallet suppliers. Sources in theory were also cross checked, especially for LCAs on different pallet materials, where three different sources were compared extensively, and rivalling theories and results were addressed. Lastly, information from the empirical study was compared to information from theory, to make sure that theory was up to date and that pallet suppliers were not exaggerating the benefits of their pallets. To increase the validity of the case study, interviewees and other providers of empirical data were asked to review a draft of the case study report.

3. Theory

In this chapter relevant theory acquired from the literature review is presented. Current research states that the key to reduce cost and environmental impact is to apply a systems approach (Pålsson, 2018)*. The first step in applying a systems approach is to understand how the packaging system functions and interacts with the supply chain, which is described in the section "packaging logistics". To understand the packaging system for pallets, theory on "pallet management strategies" is presented. The next step is to understand the interaction and trade-offs between packaging functions; this is explained in the section "factors affecting pallet choice". The sections "pallet design" and "freight transport efficiency" are connected to RQ1 and the sections "pallet materials" and "Environmental impact of a pallet's life cycle" are connected to RQ2.*

3.1. Packaging logistics

Packaging is strategically important for reducing costs and environmental impact of the supply chain. According to Pålsson (2018), packaging can be viewed as a system with three interrelated packaging levels. The first level is the primary package, which is the package closest to the product. The secondary packaging, most often a box, holds several primary packages. The tertiary packaging, e.g. a pallet, holds several secondary packages. Pålsson defines six basic functions of packaging:

1. Protection: to safeguard the content.
2. Containment: to hold and maintain the content.
3. Apportionment: to reduce large-scale and high-volume production to manageable sizes.
4. Unitization: to modularize the packaging levels to obtain material handling and transport efficiency.
5. Communication: to identify the packaging in the supply chain and provide product information.
6. Convenience: to simplify the use of products.

In addition to these functions, packaging also affects the logistics and environmental efficiency in the supply chain, for example it interacts with material handling equipment, information systems, means of transport, and waste management (Pålsson, 2018). Due to the many interactions, Pålsson emphasizes the importance of viewing the physical flow of goods as one integrated system.

3.2. Pallet management strategies

Carrano et al. (2015) states that there are three main type of pallet supply chain management strategies. The first one is called single-use expendable pallet strategy and is based on an open-loop approach where the ownership of the pallets is transferred from the supplier to the end user upon delivery of the pallets. The pallets are usually made of softwood, paper or other inexpensive materials. Typically, the pallets are used one or a few times and then disposed. Buy/sell programs are an alternative strategy, in which pallets are repurchased after use through a pallet depot or recycling facility, which handles repair, reuse and proper disposal. The third strategy involves a closed loop system where pallets are reused and usually leased from a pallet pooling company. After pallets are used, they are collected in return depots where the pallets are inspected, sorted and washed or repaired if necessary. The pallets are then prepositioned for further use upstream in the supply chain (Carrano, Pazour, Roy, & Thorn, 2015). Pallet leasing can be good for companies who wish to avoid dealing with pallet management, since pallet refurbishing and disposal is taken care of by the pooling company. Another benefit is that the cost is known and predictable, which reduces the perceived risk. (Bush & Araman, 1998)

3.3. Factors affecting pallet choice

According to Clarke (2004) there are five parameters that should be taken into consideration to achieve a balanced pallet design:

- Strength: the load carrying capacity
- Stiffness: the resistance to deformation under load
- Durability: the ability to withstand the rigors of shipment and handling
- Functionality: the pallet's compatibility with the packaging and material handling equipment
- Purchase price: price for purchasing or leasing the pallet

Clarke (2004) emphasizes the importance of balancing the five parameters depending on the situation and not only focusing on purchasing cost, since this can lead to increased costs in the long haul. Bilbao et al. (2011) mentions additional parameters in their discussion on pallet materials, e.g. weight, sanitization, and stackability. They also emphasize that the trade-off between cost and strength greatly influences the choice of pallet material. Beyond these parameters there are environmental aspects which are becoming more and more important for the choice of pallet solution (Bilbao et al., 2011). Members of the Electronic Industry Pallet Specification Task Group wrote a document called Electronic Industry Pallet Specification with the objective to "establish standardized parameters and for usage by pallet designers and manufacturers when specifying and building material handling pallets for use in the electronics industry" (The EIPS Task Group, 2002). In this document they address the environmental considerations with the environmental hierarchy of "reduce, reuse, recycle". In concert with this hierarchy their recommendation is that pallets should incorporate recycled material if possible, they should be reusable, and the design should consider recycling and disposal. Permanent mixing of materials should be avoided if it inhibits recycling.

A summary of factors from theory:

- Strength
- Stiffness
- Durability
- Functionality
- Purchase price
- Environmental impact
- Pallet weight
- Sanitisation
- Stackability
- Recyclability
- Disposal

3.4. Pallet dimensions

Despite the world becoming increasingly globalised, pallet dimensions are different for different regions. There are trends towards standardisation and ISO has recognized 6 pallet footprints, which can be seen in table 1 (Clarke, 2004). As mentioned before, the difference in pallet standardization in different regions is problematic for companies operating globally. The Euro Pallet which is 1200 x 800 mm does not fit well in the ISO standardized containers. This leads to a low fill rate of the container, which leads to higher transport costs and a higher environmental impact of the transport. Usually extra protection like dunnage bags are required in the empty space between the pallets to prevent the pallets from moving in the containers. In the 60's and 70's, the US grocery industry began converting towards the 48x40" (1219 x 1016 mm) standard footprint, and today this footprint has become standard in many industries in the US (Clarke, 2004). In 2002 the EIPS Computer Industry Pallet Task Group recommended a similar measurement, the 1200 x 1000 mm standard, as its primary global footprint (The EIPS Task Group, 2002). The size was selected due to its recognition in ISO, its metric dimensions, the high fill rate of containers and trucks and the similarity to the 48x40-inch US footprint. The footprint also has the same length as the Euro Pallet which can lead to further standardization (Clarke, 2004). Euro-pallets are standardized by EPAL, the European Pallet Assiociation, and they are the most widely used pallets in the world. Around 450-500 million are currently in circulation (EPAL, 2019).

Size (mm)	Region
1200 x 1000	Europe, Asia
1200 x 800	Europe
1219 x 1016	North America
1140 x 1140	Australia
1100 x 1100	Asia
1067 x 1067	North America, Europe, Asia

Table 1: Six pallet footprints recognized by ISO 6780

3.5. Freight transport efficiency

Euro pallets do not fit well in standardized containers, which is an example of how pallet dimensions impact the freight transport efficiency. Measuring the efficiency of freight transport can be done by measuring ratio of the actual capacity used to the total capacity available (McKinnon, 2010). McKinnon defines the following five utilization measures for truck transports, which are also applicable for container transports:

1. <u>Level of empty running:</u> the proportion of truck-kms run empty.
2. <u>Weight-based loading factor:</u> the ratio of the weight of goods carried to the maximum weight that could have been carried on a laden trip.
3. <u>Tonne-km loading factor:</u> the ratio of the actual tonne-kms moved to the maximum tonne-kms that could have been moved if the vehicle had been travelling at its maximum legal weight.
4. <u>Volumetric loading factor:</u> the proportion of cubic space in the vehicle occupied by a load. It is a 3-dimensional view of vehicle fill.
5. <u>Deck-area coverage:</u> the proportion of the vehicle floor (or deck) area covered by a load, representing a 2-dimensional view of vehicle loading.

The expressions loading factor and vehicle fill rate are interchangeable and in this report the expression fill rate will be used.

3.6. Pallet materials

Pallet dimensions is not the only factor of the pallet that is undergoing a change. Alternative pallet materials are becoming more popular due to factors like environmental impact and sanitization (Bush & Araman, 1998). However, wood remains the most common pallet material which will likely not change for many years to come (Kočí, 2019).

3.6.1. Wood

The reason wood is the most common pallet material is mainly because it has been around for long and because the material is relatively cheap. The most widely used pallet type is the four-way wood pallet which accounts for 86% of the pallet production worldwide (Kočí, 2019). Many systems for material handling and packaging are built around the performance of wood pallets (Clarke, 2004). Wood pallets are made from hardwood or softwood. The names hardwood and softwood do not necessarily reflect the density of the material; however, hardwood tends to be slower growing and is therefore usually denser. Hardwood comes from deciduous trees which loses their leaves annually, and softwood comes from confiers, that usually remains evergreen (NZWood, 2019).

Wood has several advantages as a pallet material. It has a good balance of the five design parameters that Clarke (2004) mentions, and wood pallets are easy to prototype and customize. There is also a large and reliable supply of wood pallets, since the wood pallet industry has matured over several decades. Disadvantages with wood include forest depletion, the performance of the pallet may be unreliable due to that it consists of several pieces held together by screws and nails, and the wood degrades due to environmental factors (Soury et al., 2009). Other disadvantages are that wooden splinters or nails can harm goods or the humans handling the pallets, and that wood gives of moisture and can harbour bugs and mould (Clarke, 2004). This is extra problematic in industries with high hygiene standards, e.g. the food and beverage industry.

3.6.2. Plastic

Plastic pallets can be produced with a variety of manufacturing processes and resin formulations. Some of the manufacturing processes are structural foam moulding, injection moulding and profile extrusion. Common resin formulations used for pallets are HDPE, PP and PVC (Clarke, 2004). Non-plastic materials can be mixed in the formulations, e.g. sawdust or paper (Bush & Araman, 1998). Plastic pallets are mainly used in closed loop systems since they are too valuable to be discarded quickly and since they are durable enough to be reused many times. Plastic pallets are common within the food, beverage, dairy, automotive and pharmaceutical industries, especially in Asia. (Clarke, 2004)

Advantages of plastic pallets are that they are strong, relatively lightweight, water resistant, and bug free (Clarke 2004; Kočí, 2019). Other advantages are that no fasteners like nails are required, their cleanliness, and the design potential (Clarke, 2004; Soury et al., 2009). Plastic pallets are at a disadvantage compared to wood on several criteria. The most obvious one is the purchasing price, which is about three to five times more than that of a wood pallet (Soury et al., 2009), though the higher price can be offset by reusing the pallets. Another important disadvantage is the non-biodegradability of plastic. Recycling is the remedy to this problem, although expensive. Other disadvantages are low friction (which can cause unwanted movement of pallets or of goods on the pallets) lack of repair options, and low stiffness (Clarke, 2004). Low stiffness is connected to problems with racking. Some designs are not stiff enough to hold higher weights when the pallet is supported along two edges (racking), which can lead to an intolerable deflection. This problem is prevalent at higher temperatures due to a higher creep deformation (strain accumulated as a result of long-term stress). The problem is solved with new designs of pallets and racks (Bush & Araman, 1998).

3.6.3. Cardboard

In some ways cardboard pallets are the opposite of plastic pallets. Plastic pallets are mainly used in closed loop systems at the high end of the market and are reused for as long as possible. Cardboard pallets have instead found a niche at the low end where purchase prices are important and in open systems where the pallet purchaser does not maintain possession of the pallet and where the pallet is usually disposed after a few or a single use (Bush & Araman, 1998).

Cardboard pallets are lightweight, resulting in increased handling safety and reduced transportation cost. It is also easy to manufacture paper pallets in customized sizes (Edge-Environment, 2017). Many companies desire a pallet which appears and disappears when needed and with as low cost and effort as possible. Cardboard pallets come closer than wood to achieving this ideal, as they are usually cheaper than wood pallets, are easily disposed to existing corrugated recycling systems (Bush & Araman, 1998), and their weight is low which reduces total disposal. Other advantages are that the pallets have a smooth deck surface and are bug free (Clarke, 2004). General disadvantages are that the pallets are susceptible to moisture, have a lack of stiffness which can cause deflection, and a low durability which can lead to product damage (Clarke, 2004).

3.6.4. Metal

Metal pallets have similar benefits as plastic pallets and are used in similar situations. However, metal pallets are heavier than plastic pallets and can be susceptible to rusting. They can have better durability than plastic pallets, which can make them a better choice in certain situation, but according to Bush and Araman (1998) plastic and corrugated paperboard hold the highest potential to impact the use of wood. In addition to this the global supply of metal pallets is relatively small and Tetra Pak has no intentions on using metal pallets in the future. Therefore, metal pallets will not be investigated further.

3.6.5. Summary

Wood remains the most common pallet material due to that wooden pallets have dominated the, they have a relatively low cost, a large and reliable supply, are easily customizable, and have a good balance of the five design parameters that Clarke (2004) mentions. Alternative pallet materials are becoming more popular e.g. due to better safety and sanitization and a lower weight, but this has not been enough to change the current domination of wooden pallets on the market. Table 2 shows a summary of the pros and cons for each pallet material.

Table 2: Summary of pros and cons for each pallet material

Material	Pros	Cons
Wood	• Relatively low purchase cost • Large and reliable supply • Can be repaired	• Can harbour pests, fungi, and bacteria. • Difficult to clean • Inconsistent performance on durability • Can cause handling injuries and damage to goods (splinters, nails) • Heavy
Plastic	• Can be reused many times • High durability • Hygienic and easy to clean • Can be manufactured from recycled plastic • Relatively light weight	• High purchasing cost • Difficult to repair • Manufactured from non-renewable material • Low friction • Can deflect under high temperatures
Cardboard	• Low purchasing cost • Very lightweight • Easily recycled • Can easily be customized	• Low durability and can be damaged by moisture. Needs to be treated with chemicals to prevent this. • Can only be used one or a few times • Cannot handle heavy loads
Metal	• Can be reused many times • High durability	• High purchasing cost • High weight • Susceptible to rusting

3.7. Environmental impact of a pallet's life cycle phases

A pallet life cycle includes the following five phases: materials, manufacturing, transportation and use, refurbishing, and end-of-life disposal (Carrano et al., 2015). All pallets follow these phases except single-use pallets which are usually not refurbished.

Materials phase

There are large variations between the contribution to emissions for the different phases. Generally, the materials phase stand for a major part of emissions. The materials phase includes the sourcing of raw materials (e.g. harvesting and mining) and the primary manufacturing (e.g. turning ore and wood into steel and lumber boards). (Carrano et al., 2015).

Manufacturing phase

The manufacturing phase includes emissions from transportation of materials to the pallet factory and emissions related to fabrication, design and assembly activities. Pallets manufactured for pooling companies are usually produced in large quantities and manufacturing is done with a higher degree of automation, leading to lower emissions. (Carrano et al., 2015).

Use phase

The emissions from the use phase are mainly related to how the pallet design affect the fill rate in terms of volume and weight utilization. The weight of the pallet is one of the most important aspect in this phase. (Carrano et al., 2015).

Refurbishing phase

This phase includes impacts related to the repair and replacement of pallet components. It also includes the emissions from transports of pallets to the refurbishing point and transports to reposition the pallets back into use after refurbishing has been done. Severely damaged components for wood pallets are replaced with components from dismantled pallets. (Carrano et al., 2015).

End-of-life disposal phase

There are many ways in which a pallet can be disposed of. In a life cycle assessment on wooden pallets conducted by Carrano Et al. (2015), four scenarios are considered for wooden pallets: landfilling, mulching (for landscaping, livestock bedding and poultry litter applications), incineration with energy recovery, and incineration without energy recovery. It is rare for solid wood pallets to end up in landfills (Bengtsson & Logie, 2015), but more common for softwood pallets. Landfilling does not lead to energy recovery and wood can decompose anaerobically and can generate methane, a potent greenhouse gas, which can lead to a lower environmental impact if the methane gas is recovered, which is possible in modern landfill systems (Bilbao et al., 2011). Mulching wooden pallets requires grounding equipment which is generally powered by diesel. It enables steel nail and fasteners to be recovered and recycled. Incineration with energy recovery requires pallets to be mulched and then burned. The energy can then be used to replace electricity or other fuels e.g. for heating. Incineration without energy recovery is often done in the open air and no recovery of material or energy is possible (Carrano et al., 2015). For cardboard and plastic pallets, the pallet material can be recycled. This is a so called "downcycling" process because the polymer chains in the plastic and the paper fibres are shortened, resulting in a lower material quality. Landfilling plastic pallets does not lead to any energy recovery, due to plastic being non-biodegradable, and incinerating plastic pallets will liberate toxic chemicals (Bilbao et al., 2011).

4. Life cycle assessments

A literature review was conducted to gain understanding of the environmental impact, in terms of CO_2e emissions, for the entire life cycle of the different pallet materials. Six relevant papers with LCAs on pallets were found and three of these papers had calculated and summarized CO_2e emissions for the entire life cycles. A summary of each of these three papers will be presented with the following data for each LCA:

- Context of the LCA:
  - Year published
  - Summary of purpose
  - Geographical context
  - Pallet materials evaluated
  - Pallet designs evaluated
  - Definition of functional unit or reference unit
- Summary of results concerning CO_2e emissions

There are many methodologies on how to conduct LCAs. Different LCAs have different contexts and functional units, which makes them unique. It is therefore complicated to compare different LCAs in terms of absolute values on CO_2e emissions. By looking at the relative difference of CO_2e emissions between pallet materials and management strategies for each paper respectively, a comparison between the results of the papers can be made without including absolute values that are bound to the context of the case. Some LCAs take biogenic carbon into consideration. The biogenic carbon cycle is the cycle of carbon that is absorbed into trees from the atmosphere through photosynthesis but can later be partly or full re-emitted to the atmosphere at different stages in the tree's lifecycle. By burning wood, the carbon that was once absorbed from the atmosphere is released back into atmosphere, which could be considered CO_2e neutral (Tellnes, o.a., 2017). However, this depends on how the land is used and there can be shifts in the carbon stock in soil and biomass that should be taken into consideration (Edge-Environment, 2017).

4.1. Paper 1: Life cycle assessments of one way and pooled pallet alternatives

In a paper published in 2015, Bengtsson and Logie analysed the environmental impact of one-way and pooled pallet alternatives by conducting cradle-to-grave LCAs on hardwood, softwood, plastic and cardboard pallets, manufactured in China and Australia. The analysis was conducted by Edge Environment, a consultancy that helps clients become more sustainable (Edge, 2019) , on behalf of China Merchant Loscam's, a plastic and softwood pallet manufacturer (Loscam, 2019). This could lead to questions about the impartiality of the papers. However, ISO standards were followed, and the paper was peer-reviewed under responsibility of the scientific committee of the 22nd CIRP conference on Life Cycle Engineering. Edge is a large company with many large clients, and they have received several awards from third parties for their work on LCAs and sustainability (Edge Environment, 2019), which increases their reliability. For Australia the hardwood and softwood pallets were manufactured from timber sourced from Victoria and South Carolina, and for China the timber was sourced from Australia, North America, and New Zealand. The softwood one-way pallets were assumed to be sourced from low quality pine and the plastic pallets were made of virgin HDPE in China and 100% locally recycled HDPE in Australia. Cardboard pallets were manufactured from 80% recycled cardboard material. The pallet dimension investigated was 1165mm x 1165mm in Australia, and 1200mm x 1000mm in China. The reference unit was 1000 customer trips carrying the same load. For this number of trips, the following number of pallets were assumed to be required:

- 12/22 wooden pooled pallets
- 16/16 plastic pooled pallets
- 500/500 simple/one-way softwood pallets (i.e. reused once on average)
- 1,000/1,000 compressed cardboard pallets (i.e. single use)

In figure 1 the results on global warming potential can be seen. The results show that pooled alternatives perform better than one-way alternatives, and wood performs better than plastic or cardboard. The one-way cardboard pallets perform substantially worse than any other pallets. However, the paper states that only limited data on cardboard pallets was available, especially for manufacturing, so there is a high degree of uncertainty to this. The main reason the one-way cardboard pallets perform poorly is that the number of usage cycles is much lower than for wood or plastic pallets.

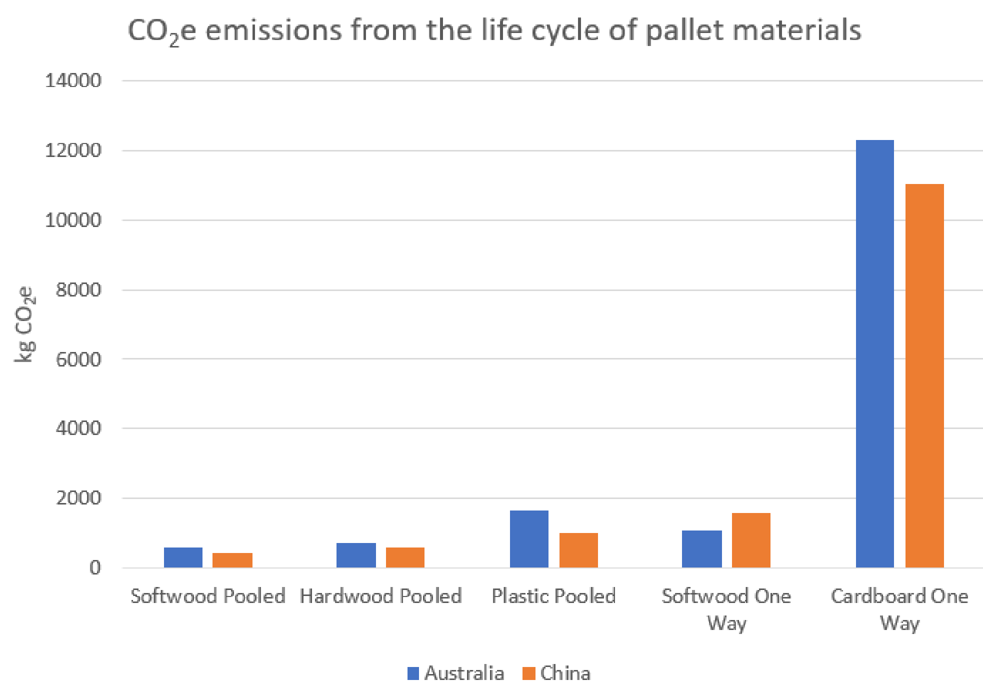

Figure 1: Life cycle impact in terms of kg CO_2e emissions from Australian and Chinese pallets.

4.2. Paper 2: Comparison of environmental impacts between wood and plastic transport pallets

A paper written by Kočí on the "Comparisons of environmental impacts between wood and plastic transport pallets" was published in May this year. The data used in the LCAs was obtained from two pallet manufacturers in the Czech Republic. For wooden pallets, 24 kg pallets made of spruce trunk wood or pine wood was analysed, and for plastic pallets, 25 kg pallets made of polypropylene (PP) or recycled plastic was analysed. The standard Euro Pallet dimension (1200 x 800 mm) was used and the reference unit was a 20 000 km ocean shipping transport by bulk commodity carrier, plus a 1000 km road transport by trailer truck. Wood pallets and plastic pallets were said to be used on average 15 times and 100 times respectively. Cradle-to-grave comparisons were carried out based on ISO 14040 and the ReCiPe 2016 characterization method for harmonized LCA at midpoint and endpoint level was applied. CO_2e emissions were calculated both with and without including biogenic carbon.

An evaluation was made on the contribution of CO_2e emissions from the extra weight of the actual pallet in transports. The evaluation showed that a large part of CO_2e emissions from pallets can be attributed to the pallet weight. The pallet weight leads to 53-133% extra CO_2e emissions during the life cycle of a wood pallet (excluding biogenic carbon) and 80-89% during the life cycle of a plastic pallet. Weight is therefore one of the most important factors to consider when assessing CO_2e emissions, according to this paper. The results from the LCAs show that wood pallets have lower CO_2e emissions (excluding biogenic carbon) even when wood pallets are used less than 15 times and plastic pallets are used more than 100 times. Wood pallets with energy recovery have negative CO_2e emissions, due to the exclusion of biogenic carbon.

4.3. Paper 3: Pallet life cycle assessment and benchmark

In a report from 2017, Range International, a plastic recycling and manufacturing company, commissioned Edge Environment to compare environmental credentials of various pallets using ISO 14040 and 14044 compliant LCAs. The paper was peer reviewed by prof. Wouter Achten from Université Libre De Bruxelles. A cradle-to-grave analysis was made on different types of wood and plastic pallets produced and dispatched in Australia and South East Asia. These pallets were compared with the Range International Re<Pal pallet which was made from recycled plastic. The pallet dimensions analysed were 1200 x 1000 mm and 1090 x 1090 mm. The reference unit used was 1 trip made by the pallet without considering the load. A table with the typical number of pallets per trip and pallet types can be found in the paper.

The Re<Pal pallet had substantially lower CO_2e emissions than any other pallet type. However, Re<Pal pallets are only manufactured in Indonesia, which is too far from Europe to consider. Regarding CO_2e emissions per trip for non-heavy-duty pallets without repairs, tropical mixed hardwood pallets had the lowest emissions, followed by conventional plastic pallets, and softwood pallets. For heavy duty pallets, plastic pallets performed better than tropical mixed hardwood pallets. Repairing timber pallets barely changed the emissions per trip.

5. AddMat's supply chain

This chapter starts with a brief introduction of AddMat's supply chain. Then shipment data is presented, which was collected from AddMat's internal data sources, mainly in the form of Excel files with shipment data for 2018 and master data for products. This data was used in the analysis to analyse pallet sizes and to calculate fill rates, costs, and CO_2e *emissions. Lastly information on requirements from AddMat on pallets is presented. This information was necessary to understand which requirements a new pallet solution had to follow.*

5.1. General AddMat supply chain information

The supply chain of AddMat is global and complex. They have 18 in-house factories around the world, including 8 factories in Europe, and their products were shipped with 374 940 pallets in 2018 (shipments originating in Europe, Films excluded), resulting in around 6 053 ton CO_2e emissions. A typical example of the supply chain of an AddMat product is depicted in figure 2. About half of AddMat's products are shipped straight to customers and the other half is shipped to packaging material factories, where AddMat's products are shipped together with packaging material.

AddMat never retrieves pallets from customers. Wooden pallets can be used several times and since AddMat only use their pallets once, it is assumed that most customers make use of the pallets for other purposes after the pallets are received and depalletized. Considering this, AddMat's wooden pallets should not necessarily be regarded as single-use pallets. The problem with regarding them as multiple-use pallets is that there is no information on the extent to which the pallets are used by customers. This will be discussed further in the analysis. No information was acquired on how customers use or dispose pallets due to restrictions on contact with customers.

AddMat's products are generally made to stock and the means of transport is usually unknown when palletizing is done. This leads to that pallet dimensions cannot be chosen to fit only one means of transport. Instead, the fill rate of a pallet in all means of transport should be taken into consideration for each pallet.

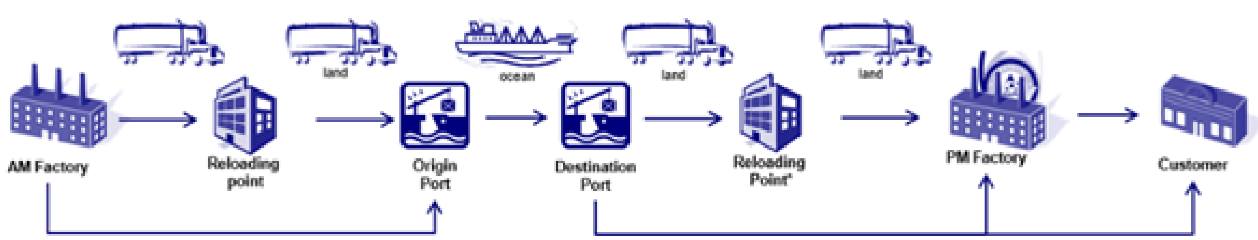

Figure 2: An illustration of a typical supply chain for AddMat.

5.2. Shipment data

Shipment data was gathered from AddMat's internal data sources in the form of Excel sheets. For the shipments logged in AddMat's internal data system, 28 282 shipments had shipment dates during 2018 and 22 967 of these originated in Europe. After delimitations on transport modes and exclusion of Films, 21821 shipments remained. This data was "cleaned" by standardizing the format, fixing errors, and adding missing data. Figure 3 shows the distribution per product area of the 374 940 pallets shipped on the 21 821 shipments. Closures stand for most of the pallets shipped, followed by Strips, and lastly Straws.

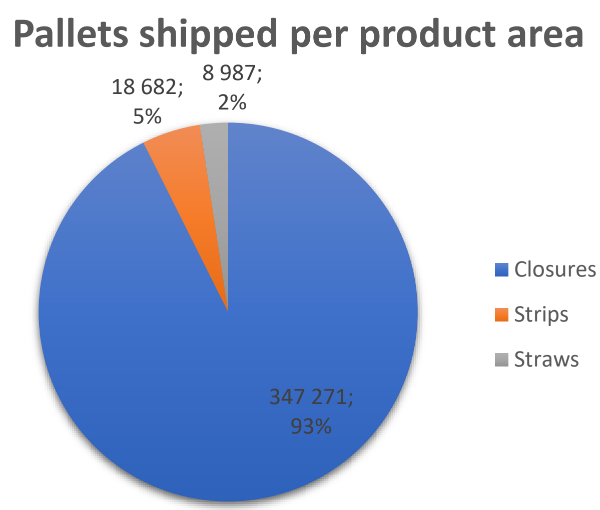

Figure 3: Distribution of the 374 940 pallets shipped in 2018 over product areas.

5.2.1. Pallet weight

Table 3 shows the maximum laden pallet weight of all products in each product area. Laden weight is the tare weight of the pallet plus the weight of the goods on the pallet. This table will be useful when pallet materials and designs that have different maximum safe working loads are analysed.

Table 3: The maximum laden pallet weight of all products in each product area.

Closures	Straws	Strips
385 kg	176 kg	900 kg

5.2.2. Pallet sizes

To acquire data on pallet sizes, the transport data (with delimitations and removal of errors) was connected to the master data, with information about pallet sizes, from each product area. The connection was done using either the article code, SKU ID, product name, or a combination of the prior, as a unique identifier. In figure 4 the distribution of the pallet sizes used for shipments can be seen. This is based on the 374 940 pallets shipped by AddMat in 2018 (Shipments originating in Europe, Films excluded). Euro Pallets stand for 82% of the pallets shipped and therefore the focus will lie on finding a substitute for Euro Pallets when optimized pallet sizes are conceived. The figure also shows that 15 different sizes are used, which is a lot. Using a lot of different pallet sizes leads to lower standardization. Whether lower standardization is problematic or not will be discussed in the analysis. Several of the sizes are very similar, e.g. 1200 x 900, 1200 x 880, and 1200 x 870, as well as 1150 x 790 and 1150 x 800. These sizes only differ one or two centimetres in width. In figure 5, the distribution of pallet sizes is shown for each product area. Strips are unique in that they do not use Euro Pallets. Instead they mostly use the 1200 x 750 mm pallet, which is called the “Strips pallet” by AddMat.

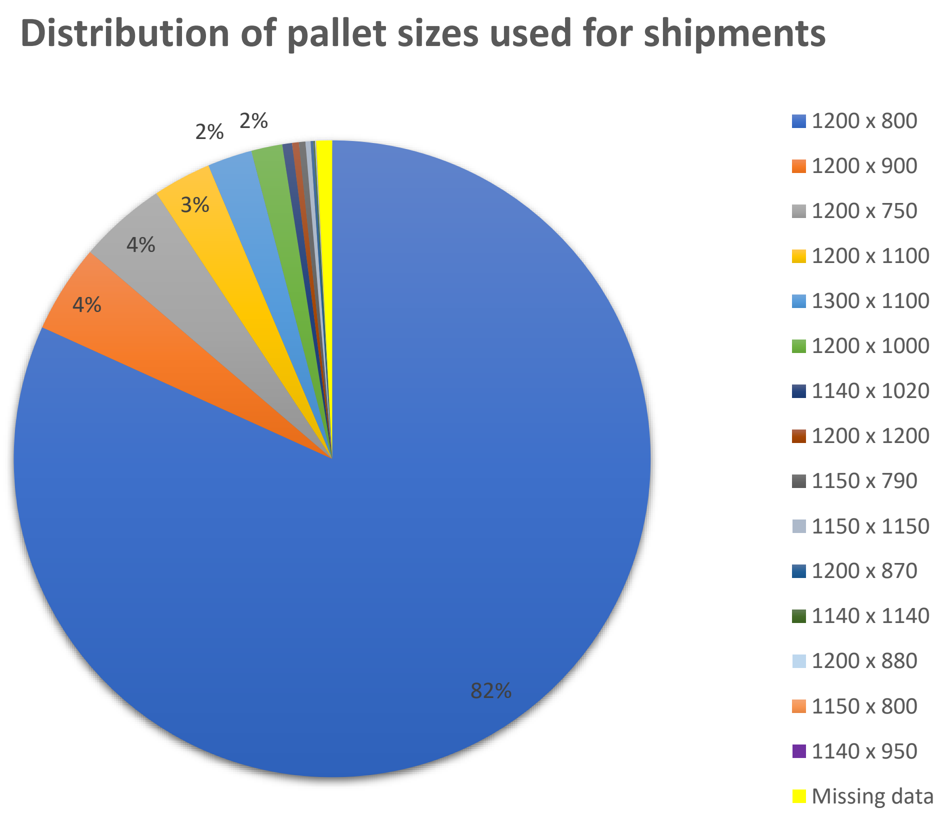

Figure 4: A chart over the distribution of pallet sizes used for shipments. The data is based on the 374 940 pallets shipped by AddMat in 2018 (Shipments originating in Europe, Films excluded). The pallet sizes are in order according to the number of uses. Some products did not have any information on pallet sizes used, hence the “Missing data”.

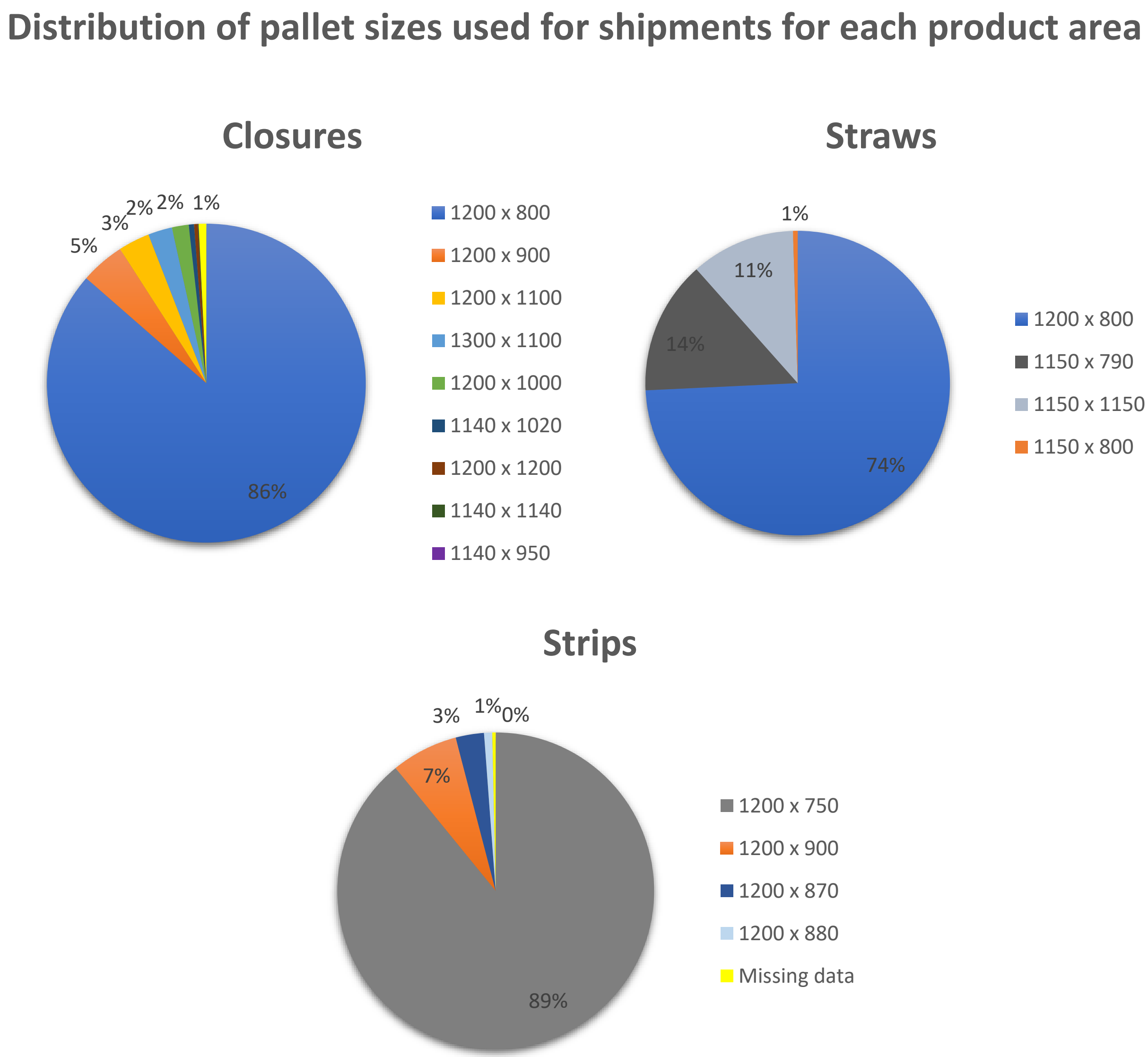

Figure 5: Charts over the distribution of pallet sizes used for shipments for each product area. The data is based on the 374 940 pallets shipped by AddMat in 2018 (Shipments originating in Europe, Films excluded). The pallet sizes are in order according to the number of uses. Some products did not have any information on pallet sizes used, hence the "Missing data".

5.2.3. Means of transport

AddMat uses standard European trucks (Euro Trucks) for their road transports in Europe and a mix of 20' and 40' containers for their sea transports. Some of the 40' containers are so called high cube containers, meaning they are higher than the standard 40' container. Information about the different means of transport can be seen in table 4. In figure 6, the distribution of pallets to the means of transport can be seen. Euro Trucks stand for most of the pallets shipped, but that does not necessarily mean that Euro Trucks is the most important means of transport to focus on when analysing fill rates. To understand the importance of each means of transport we need to look at allocated shipment costs and CO_2e emissions.

Table 4: Data on containers and trucks used by AddMat. Tare weight is the weight of the vehicle or container when it is empty. Max structural weight is the sum of the tare weight and the max payload. Sources: containers - (Hapag Lloyd, 2019), trucks - (Poferrymasters, 2019)

Description	Max Structural Weight (kg)	Tare weight (kg)	Max Payload (kg)	Interior Length (mm)	Interior Width (mm)	Interior Height (mm)	Interior volume (m3)
40' Standard Sea Container	32500	3750	28750	12032	2352	2395	67,8
40' High Cube Sea Container	32500	3900	28600	12032	2352	2700	76,3
20' Standard Sea Container	32500	2350	30150	5900	2352	2395	33,2
Standard European Truck	39000	7100	31900	13620	2480	2650	89,5

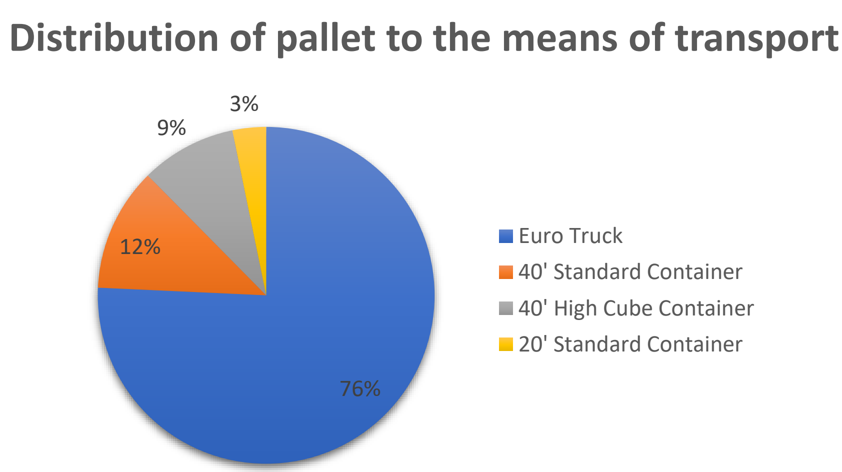

Figure 6: The distribution of pallets (used for shipments in 2018 originating in Europe excluding Films) to the different means of transport.

5.2.4. Shipment costs

This thesis will not mention any costs in absolute values. This is due to the sensitive nature of costs and prices, for pallet suppliers and for Tetra Pak. As can be seen in table 5, road shipments stand for more than half of the total shipment costs and 40’ containers stand for more than three quarters of the total shipment costs for sea shipments. The most important means of transport with regards to cost is therefore road, followed by 40’ container, and lastly 20’ container. Table 5 also shows the distribution of costs over the means of transport for each product area. It can be noted that Straws have most shipment cost allocated to road, while Strips have most shipment costs allocated to sea, and Closures lies somewhere in between the two.

Table 5: The allocation of shipment costs for each means of transport and for each product area. The allocation cost under “sea not specified” is due to missing data on container sizes and should be allocated to either 40’ or 20’ containers.

Product area	Road	40'	20'	Sea not specified
Closures	54,5%	34,9%	8,9%	1,7%
Straws	87,2%	8,6%	1,9%	2,2%
Strips	33,0%	26,2%	28,9%	12,0%
Total	53,7%	33,4%	10,3%	2,6%

5.2.5. Shipment CO_2e emissions

Tetra Pak have calculated factors on CO_2e emissions in gram per ton and kilometre for each transport mode, which can be seen in table 7. This data is based on emission factors by the Network for Transport Measures (NTM), which can be seen in table 6. NTM is a non-profit organization that aims to establish a common base of values on how to calculate the environmental performance for all various modes of traffic (Network for Transport Measures, 2019). Tetra Pak’s emission factors are calculated for each transport mode (road and sea) by multiplying NTM’s emission factors with the usage in percent of the different vehicles/vessels for that transport mode and summing up the results. The usage in percent of the different vehicles can be seen in table 7, as well as Tetra Pak’s emission factors.

3 272 of the 21 821 shipments had missing data on transport distances. Almost all the missing data was for sea transports. To estimate the actual CO_2e emissions the missing data for each shipment was replaced with the average distance from the data available, 704 km for road shipments and 5 637 km for sea shipments. The average distance was assumed to represent the missing data well, since the average was based on thousands of shipments. Replacing 3 273 data rows, or 15 % of the total shipments after delimitations, leads to that results from analyses on CO_2e emissions have a higher degree of uncertainty, which must be taken into consideration. The cause of the missing data should be examined further.

The CO_2e emission for each transport was calculated by multiplying the relevant emission factor in table 7 (58 for road and 12 for sea) with the tare weight of the transport in tons and the distance of the transport in km. The answer was then converted from grams to kgs. The total CO_2e emissions from the 21 821 shipments previously mentioned, given the previous estimation, was **6 052 515** kg CO_2e. If the missing data is not replaced with averages, the total CO_2e emissions would be 4 514 208 kg CO_2e, which shows the uncertainty of this assumption. As can be seen in figure 7, road shipments stand for 55 % and sea shipments stand for 45% of the total CO_2e-emissions from transport. It is therefore more important to increase road transport efficiency than it is to increase sea transport efficiency, for lowering CO_2e-emissions.

Table 6: Emissions factors for different vehicles/vessels. Data is retrieved from the Network for Transport Measures. TEU is the twenty-foot equivalent unit, based on the volume of a standard 20' container.

Vehicle/Vessel	Description	CO_2e [g/tonkm]
TT 60 [40 ton]	Truck and Trailer	49
TST 34-40 [26 ton]	Tractor and semi-trailer	58
SEA 10'	Container ship, 10 000 TEU	10,5
SEA 7'	Container ship, 7 000 TEU	11,9
SEA 1'	Container ship, 1 000 TEU	20,7

Table 7: The usage in percentage of the different vehicles/vessels and the resulting emission factors for each transport mode.

Mode	TT [40 ton]	TST [26 ton]	SEA 10'	SEA 7'	SEA 1'	CO_2e [g/tkm]
ROAD	2 %	98 %	0 %	0 %	0 %	**58**
SEA	0 %	0 %	70 %	18 %	12 %	**12**

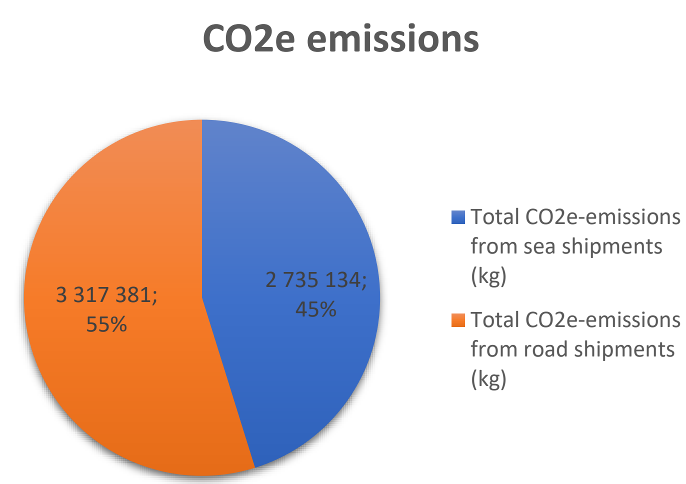

Figure 7: The distribution of the 6 052 515 kg CO_2e emissions over the transport modes.

5.2.6. Summary of shipment data

A summary of the key take-aways about AddMat's shipment data:

- AddMat uses a lot of different pallet sizes, some of which are very similar, and this leads to a lower standardization.
- The Euro Pallet stands for 82 % of pallets shipped.
- Strips use the Strips Pallet (1200 x 750 mm) instead of the Euro Pallet.
- Costs and CO_2e emissions have a similar allocation to transport modes, about 55 % for road and 45 % for sea.
- 40' containers stand for more than three times the allocated cost of 20' containers.
- AddMat's transports results in over 6000 tonnes of CO_2e emissions.

5.3. AddMat's requirements on pallets

The choice of pallet is highly dependent on the supply chain environment. Pallets are handled by different forklifts, hand pallet jacks, and automated guided vehicles. Pallets can be palletized, wrapped in wrapping machines, transported on conveyors, and stored on the floor or on racks. The many ways a pallet interacts with the supply chain leads to requirements and constraints. AddMat is also following environmental regulations and they have goals to reduce their environmental impact and reach zero safety and environmental incidents and zero customer issues. A new pallet solution must follow the environmental regulations and work towards the goals, which leads to requirements on different aspects of the pallet. This section investigates these requirements and constraints so they can be taken into consideration when evaluating new pallet solutions.

5.3.1. Questionnaires

In order to assess AddMat factories' requirements on pallets, questionnaires were sent out by AddMat to 11 AddMat factories, 9 of which are in Europe. The questionnaires were used for this project to understand requirements on measurements and other parameters of the pallets, e.g. minimum entry holes for forklifts. These requirements are assumed to be relatively representative of the requirements from AddMat's entire supply chain. Further research is needed to verify this assumption and evaluate potential additional requirements from customers.

The fork height of different forklifts, hand pallet jacks, and automated guided vehicles ranged from 30 - 60 mm, except for one factory having hand pallet jacks with 80 mm fork height. Hand pallet jacks are relatively easy to change, so the hand pallet jacks with 80 mm high forks were not taken into consideration. Conveyors and palletizers are used by most factories and for one factory in Seville this led to constraints on pallet sizes. The answers to the questionnaires showed that the conveyors in the factory have a constraint on pallet width being max 900 mm and the palletizer has a constraint on pallets being max 900 mm in width and 1200 mm in length. A substantial investment would likely be required to change these constraints so it is necessary for a new pallet size to comply with these constraints if it should be used in the factory in Seville. Pallets are stored differently in different warehouses. Racking along the long side or the short side of the pallet is used depending on the factory and sometimes the racking is supported by nets or bars. Floor stacking is also used. Pallets are stored in conditions with temperatures ranging from 10-40 °C and a relative humidity up to 80%. Pallets are sometimes handled outside, and they should therefore be able to resist inclement weather well.

5.3.2. Environmental regulations and goals

Tetra Pak complies with ISO 9001 and ISO 14001. The ISO 9001 family sets criteria for the quality management system and provides tools and guidance for companies who want to ensure that their products and services consistently meet customer's requirements, and that quality is consistently improved (ISO, 2019). The ISO 14001 family provides tools for companies to manage their environmental responsibilities. It also sets out criteria for an environmental management system. Since Tetra Pak complies with these standards and have these two management systems in place, they strive to constantly improve quality and reduce their environmental impact. A new pallet must therefore be in line with these standards.

AddMat wants to increase safety and lower the environmental impact. Their "Zero Aspiration 2020" (Tetra Pak, 2019) include:

- Zero safety and environmental incidents
- Zero defects and customer issues
- Zero climate impact increase
- Zero waste

A new pallet solution must be in line with these goals. Tetra Pak's motto "Protect what's good" further points out the importance of food safety. Pallets must be sanitary, pest free, and not impair products with splinters or nails.

5.3.3. Summary of requirements

A summary of the requirements on a new pallet solution:

- Pallet openings should be at least 60 mm high.
- Pallet dimensions should preferably comply with the 1200 x 900 mm constraint from the Seville factory.
- Pallets should be able to rack the required load, shown in table 3**,** along both short and long side, with assisting nets or bars if necessary.
- Pallets should retain their quality in temperatures ranging from 10-40 °C and a relative humidity up to 80%.
- Pallets should be able to resist water and inclement weather.
- Pallets should be safe to handle.
- Pallets should not be defect or break under any circumstance.
- Pallets should be sanitary and not impair products.
- Pallets should have as low climate impact as possible.

6. Pallet materials

This chapter presents information gathered about different pallet materials. The information was collected from pallet suppliers, through interviews, and from AddMat's internal data sources. First, factors affecting the pallet material choice are presented, then information based on these factors is presented for each material.

6.1. Factors affecting pallet material choice

Many of the factors affecting the pallet material choice were mentioned in the theory section, the most important of which can be summarized as cost, strength, durability, and environmental impact. Sanitization and pest regulation are also very important for AddMat, since Tetra Pak's is in the food and beverage industry. One factor which was not mentioned much in theory is the handling safety and efficiency, which first and foremost is connected to the pallet weight, but also to parameters like design and friction. In addition to the factors mentioned, the impact a pallet material choice has on the supply chain is critical. It is also important to note that suppliers of different pallet materials have different ranges of pallet sizes. Here is a list of the most important factors affecting the pallet material choice:

- Strength
- Durability
- Sanitization
- Weight
- Available sizes
- Supply chain impact
- Purchasing/leasing cost
- Environmental impact

Quantitative data on maximum safe working load (Strength), dimensions, weight, and purchasing/leasing cost is presented for the pallets of each material. Unfortunately, pallet suppliers were not able to share any quantitative data on CO_2e emissions. Relevant qualitative data on e.g. supply chain impact, sanitization, durability and recyclability is also presented. Every qualitative factor was not evaluated for every material, since some factors are already mentioned in theory, and since some factors are only relevant for certain materials.

6.2. Wood

AddMat is currently using wooden pallets in various sizes for nearly all their shipments. The pallets come from various suppliers and pallet data can differ between suppliers.

6.2.1. EPAL data

In general, the wooden pallets used by AddMat is certified by EPAL or they are similar to pallets certified by EPAL. EPAL, or "The European Pallet Association", is an association that is responsible for the world's largest open pallet pool, and awards licenses to carefully checked producers and repairers of pallets (EPAL, 2019). Data for the three most important EPAL pallets can be seen in table 8. Data on the Euro Pallets used by AddMat is assumed to be similar to the data on the EPAL Euro Pallet.

Table 8: Data on three EPAL pallet designs (EPAL, 2019)

Pallet design	EPAL Euro Pallet	EPAL 2	EPAL 3
Dimensions (mm)	1200 x 800 x 144	1200 x 1000 x 162	1200 x 1000 x 144
Maximum safe working load (kg)	1500	1250	1500
Weight	25	35	30
Pallet entry height (mm)	100	100	100

One single untreated wooden pallet could endanger the tree population of a country and threaten a whole eco-system, due to the spreading of pests. To prevent this from happening, all EPAL licensed production and repair operations use ISPM 15 heat treatment to eliminate harmful organisms from their pallets (EPAL, 2019). ISPM 15 was adopted by the international Plant Protection Convention (IPPC), which is an organization initiated by the Food and Agriculture Organization (FAO) of the United Nations. ISPM 15 stands for International Standard for Phytosanitary Measures No 15 and it lays the foundation for harmonizing international phytosanitary measures by specifying treatments permitted for exterminating organisms that are harmful to forests (Secretariat of the International Plant Protection, 2016). The ISPM 15 treatment does not use any chemicals, but it requires energy for heating a room until the core temperature of the wood reach a minimum of 56 °C for at least 30 minutes. This eliminates all harmful organisms likely to attack standing plants (Secretariat of the International Plant Protection, 2016).

Data about the pallet purchases of six AddMat factories in Europe was acquired. This data showed the purchase price for a total of 228 330 pallets of varying sizes that had been purchased in 2018. To compare the price of wood pallets to the price of pallets made of other materials, without revealing the actual price for each pallet supplier, a price index was used. The average price for Euro Pallets was set as index 100 and all other pallet prices were related to this index. The average price for the 228 330 pallets was then calculated to be index 110,6, i.e. 10,6 % higher than that of only Euro Pallets.

6.3. Plastic

The following information on plastic pallets, closed loop systems, and third-party pallet providers, was acquired through an interview with Markus Hansson, a value chain business specialist at Tetra Pak.

6.3.1. In-house solution

Tetra Pak use reusable plastic pallets in two of their supply chains, one in Finland and one in East Asia. The supply chain in Finland is highly unique in its simplicity and is one of the only supply chains where an in-house reusable pallet system is viable for Tetra Pak. The reason why plastic pallets are used in the supply chain in East Asia is because Japan does not allow the use of wooden pallets for the food and beverage industry. In this supply chain Tetra Pak's laden pallets are shipped from Taiwan to Japan, then the unladen pallets are shipped to Korea for cleaning and then they are shipped back to Taiwan. The total leasing fee per pallet is more than double the cost of using a wooden pallet. The East Asian supply chain is an example of how costly it can be to have in-house systems for reusable pallets. Logistics, warehouse and administration management, washing, and lost and damaged pallets are all driving the costs. The supply chains of Tetra Pak and AddMat is usually long and complex, since Tetra Pak is a global company that ships products all over the world. Therefore, it would never be a viable option for AddMat to implement an in-house reusable pallet system for several of its supply chains. Pallet management is not Tetra Pak's core business, and in the case of reusable pallets it is better to leave pallet management to a third-party company with a global pallet pooling system, according to Hansson.

6.3.2. PolyPool

The only company with a global pallet pooling system that can meet the needs of Tetra Pak is a company that will be called PolyPool throughout this report (the real company name is excluded on request of the company). The company will be called PolyPool because they provide plastic pallets and specialise in pallet pooling. Pallet pooling can increase efficiency in the logistics of reusable pallets, one reason being that the shipment of unladen pallets can decrease significantly. After a pallet has been used in a shipment from point A to point B, it enters the pallet pool and can be used from a location near point B, instead of being shipped back unladen to point A. PolyPool is operating in more than 50 countries, has 115 million pallets in circulation in Europe, and more than 315000 delivery points in Europe. Pallet deliveries, washing, transport of pallets to service centres, pallet repairs, and replacements of lost pallets are included in the leasing price. Most of AddMat's larger customers are customers at PolyPool. which would facilitate the handling and return of the pallets to PolyPool's pallet pool.

6.3.3. PolyPool pallet data

PolyPool provides three designs for plastic pallets, excluding display pallets, which can be seen in table 9. The first two designs are 1200 x 800 mm Euro Pallets with or without top-deck lips. Top-deck lips are heightened edges on the pallets that prevent sliding of merchandise during pallet movement. The last design is a 1200 x 1000 mm UK pallet with top-deck lips. Trials were made by Tetra Pak for the first two PolyPool pallet designs by testing automatic loading, wrapping, and storing of the pallets. The trail went well, except for a few problems with the AGV (automated guided vehicle). Top-deck lips did not add any value, but they did not present any issues either. The maximum safe working load of the pallet designs is sufficient for the laden pallet weight of all AddMat's products. The max temperature without deflection for the first design is only 25°C, which does not meet the requirements from AddMat's factories. However, the max temperature without deflection is calculated for a 1000 kg load which is higher than the load of any AddMat product. The plastic pallets in PolyPool's pallet pool are made of 100% virgin

HDPE, i.e. no recycled material is used. This could change in the future, since PolyPool is currently looking into using recycled material in their plastic pallets.

Table 9: Data on the three plastic pallet designs PolyPool provides.

Pallet design	Plastic Pallet - 1200 x 800 mm With Top-deck Lips	Plastic Pallet - 1200 x 800 mm	Plastic Pallet – 1200 x 1000 mm With Top-deck Lips
Dimensions (mm)	1200 x 800 x160	1200 x 800 x160	1200 x 1000 x 160
Top-deck lips	Yes	No	Yes
Maximum safe working load (kg)	1250	1000	1000
Weight (kg)	19	22	22
Pallet entry height (mm)	100	100	100
Max temperature without deflection exceeding 21 mm, for racking a pallet along the longer sides, with 1000 kg load, for a month.	25°C	40°C	40°C

6.3.4. Service price

The price index will not be used for PolyPool, due to the sensitive nature of pricing. PolyPool did a case study for Tetra Pak with PolyPool for countries in Europe, which resulted in an average cost for PolyPool's plastic Euro pallets with top deck lips which was higher than the average price of wooden Euro Pallets purchased by AddMat. PolyPool could provide their service to most of the countries in Europe that Tetra Pak is operating in, but not all. It is worth noting that the average price for renting a PolyPool pallet varies a lot between countries. If disposable pallets are used in countries with a high average cost and PolyPool pallets are used in countries with a low average cost, the average cost for PolyPool pallets would go down, however it would still be higher than the average cost of wooden Euro Pallets. The design without top deck lips has a higher max temperature without deflection, but a higher average cost.

6.4. Paper

AddMat is currently evaluating if paper pallets could be a viable option to wood pallets and they have collected data from four paper pallet suppliers. A description of IKEA's experience with implementing paper pallets is presented in section X in appendix.

6.4.1. Paper pallet data

All four paper pallet suppliers have capacity to meet the demands of AddMat. Table 10 shows that the pallet entry height of Saica Pack does not meet the requirement of 60 mm. However, Saica Pack has communicated that they can create a higher pallet for AddMat. For Saica Pack the maximum safe working load covers all closures and straws products, but not strips products (see table 3). For Smurfit Kappa the maximum safe working load covers all of Closure's and Straw's products, and about half of Strip's products. The pallet weights of the different paper pallets are much lower than the weight of an EPAL wooden Euro Pallet.

AddMat is currently collecting information from the paper pallet suppliers on several factors, including durability, wet strength, and recyclability. Paper pallets are heat treated so there is no risk for pests. Paper pallet recyclability is affected by repulping time, if chemicals are used for water proofing, and if the paper pallets contain hot-melt adhesives or other glues. The paper pallet suppliers currently do not have reliable studies on recyclability, but it is assumed that paper pallets can be recycled in the same way corrugated boxes are recycled. AddMat is also interested in knowing whether it is possible for the suppliers to produce pallets with used beverage carton (UBC) content. Saica Pack already produce pallets containing UBC-fibres. The purchase price is lower than index 100 for three of the suppliers. Saica Pack has the lowest purchase price and Blue Box partners has a purchasing price higher than index 100.

Table 10: Data from four paper pallet suppliers.

Pallet company	DS Smith	Saica Pack	Blue Box Partners	Smurfit Kappa
Dimensions (mm)	1200 x 800 x 141	1200 x 800 x 55	1200 x 800 x 123	1200 x 800 x 112
Maximum safe working load (kg)	Needs to be tested	400	600	Needs to be tested
Weight (kg)	3,6	2,2	6,9	2,4
Pallet entry height (mm)	75	50	86	75
Price per pallet (EUR)	5,2	2,2	8,14	5
Price per pallet (index 100 based on current price of Euro Pallet)	69,8	29,5	109,3	67,1

7. Analysis

In this chapter data and information from the empirical study is analysed. The analysis is divided into two parts based on the two first research questions. Firstly, pallet sizes are analysed, both the pallet sizes currently used, and pallet sizes conceived through optimization, mainly through calculations of deck-area coverage. Secondly, pallet materials are analysed and compared.

7.1. Pallet sizes

The choice of pallet size depends on how well the secondary packaging fits on the pallet, how well the pallet fits in the means of transport, and other factors like standardization and compatibility with racks and material handling equipment. In this thesis the boxes' fit on the pallets was not analysed, the reason being that AddMat can change box and pallet sizes, but they cannot change container and truck sizes. Therefore, an optimal fill rate can only be obtained if the pallets are adapted to the trucks and containers, and the boxes are adapted to those pallets. Another reason is that analysing all combinations of all box sizes and pallet sizes would require a considerable amount of time. In the beginning of this section, the process of inventing new pallet sizes is explained. Then the deck-area coverage of pallet sizes currently used, and pallet sizes conceived through optimization, is analysed for each means of transport. After that additional factors that affect the pallet size choice are taken into consideration. Finally cost and CO_2e emission savings from using optimized pallet sizes are calculated.

7.1.1. Optimized pallet sizes

To find the best pallet size for AddMat, the ideal process would be to optimize one pallet size for each means of transport. However, the products are generally made to stock and the means of transport is therefore unknow when the products are palletized, so the optimal pallet size should have a relatively good fit in all means of transport. Optimizing a pallet size to fit all the means of transport may seem relatively simple at first glance, but considering that pallets can be shuffled around, the layout of pallets in a truck or container can vary from neat rows to more complex patterns, which makes the optimization very complicated. This issue was handled by testing different hypotheses to find pallet sizes that perform better than the ones currently used. One hypothesis was that pallet sizes optimized for the means of transport that have the highest allocated cost, i.e. truck and 40' container, would have a high total deck-area coverage. Another hypothesis was that optimizing pallet sizes based on the simplest loading pattern possible, would result in pallet sizes with a high total deck-area coverage. The simplest loading pattern possible would be to load all the pallets in rows with the long sides of the pallets parallel to the long sides of the means of transport. Using a simple loading pattern also has the advantage that it is more efficient and safer to load the pallets.

The first step in testing the two hypotheses was to divide the width and depth of the truck and the 40' container into numbers of sections which represents the pallets, see table 14 and 15 in appendix. The widths and lengths in the tables can be combined for the same means of transport which would create a pallet size with a close to 100% deck-area coverage of that means of transport, e.g. a 1230 x 820 pallet would have close to 100% deck-area coverage in a Euro Truck. This would be useful if the means of transport is known when palletizing is done. The next step was to decide which combinations of widths and depths were worth analysing, since it would require too much time to analyse all combinations. It was decided that the new pallet should deviate maximum 100 mm from the width and length measurements of the Euro Pallet, since a lot of AddMat's infrastructure and racks are adapted to this size. From table 14 in appendix, the relevant pallet widths were 820 mm and 770 mm. From table 15, the relevant pallet lengths were 1130 mm, 1200 mm, and 1230 mm. Both the lengths and the widths are similar to the Euro Pallet's length and width. By combining the lengths and widths, six new pallet sizes were conceived. These pallet sizes were called the "optimized pallet sizes" and were analysed along with the pallet sizes currently used.

7.1.2. Deck-area coverage

To compare the utilization efficiency of different pallet sizes, the deck area coverage for all the pallet sizes used by AddMat, as well as the optimized pallet sizes, were analysed. The analysis was done with the help of StackBuilder, a software used to design and optimize packing, palletizing, and shipping of goods. Given the length and width of a pallet and a truck or container, StackBuilder can find the optimal loading pattern to reach the maximum number of pallets that fit in the means of transport. Safety distances were used between pallets and walls, see section 10.3 in appendix for further explanation. Pictures of a StackBuilder analysis of the Euro Pallet is shown in figure 8. Since the goal is to calculate the deck-area coverage, stacking pallets on top of each other was not allowed. All combinations of pallet sizes and means of transport were analysed in StackBuilder. This gave the maximum number of pallets for each pallet sizes in each means of transport, which can be seen in table 16 in appendix. With this data, the deck-area coverage could be calculated by using equation 1. The deck-area coverage for each pallet size in each means of transport can be seen in table 17 in appendix. If the means of transport was known when palletizing is done, this data would be enough to analyse the performance of each pallet size. Table 17 shows that the deck-area coverage of Euro Pallets is high in Euro Trucks but low in containers, which is in line with theory. The third and fourth most used pallets, i.e. the 1200 x 750 pallet and the 1200 x 1100 pallet, have relatively high deck-area coverage of all means of transport. Some of the optimized pallet sizes have high deck-area coverages in both trucks and containers and could potentially perform better than any of the pallet sizes currently used. However, it is difficult to compare pallet sizes based on their total performance, due to the difference in importance between the means of transport. The solution to this issue is presented in the next section.

Equation 1: Deck area coverage

$$\text{Deck area } coverage = \frac{maximum\ number\ of\ pallets\ in\ the\ means\ of\ transport * pallet\ area}{deck\ area\ of\ the\ means\ of\ transport}$$

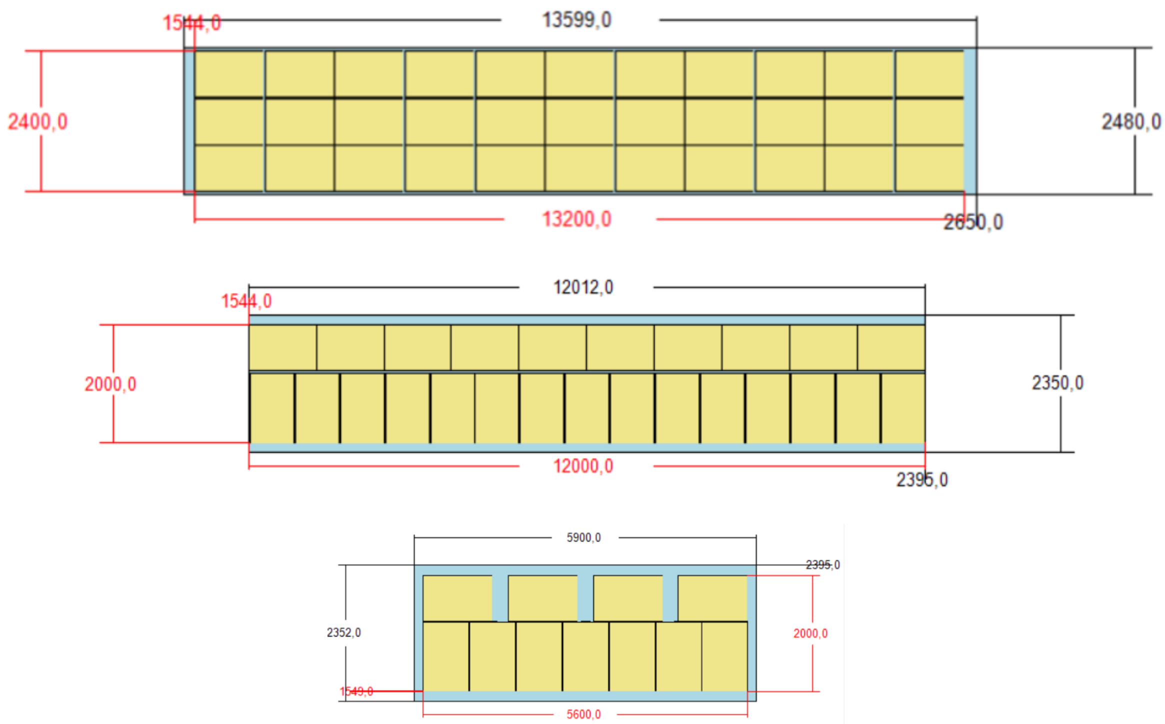

Figure 8: An analysis in StackBuilder that shows the optimal loading patterns for a Euro Pall in the different means of transport, starting with Euro Truck in the top, followed by 40' Standard Container, and lastly, 20' Standard container. The means of transport is seen from above, each beige rectangle represents a pallet and the light blue area represents the unused space.

7.1.3. Assessment of total performance

The next step was to compare the pallet sizes based on their total performance, i.e. their deck-area coverage in all means of transport. A comparison could be made for each means of transport separately, but this would not give enough information on which pallet size performs best, since the means of transport are used to different degrees. To handle this problem, a method was constructed with the idea of weighing the means of transport according to their importance. The importance can be based on the degree to which they are used, the total costs allocated to them, or the CO_2e emissions allocated to them. Of these factors the total allocated cost was chosen, since cost is an important factor according to AddMat and since changes in CO_2e emissions follow changes in cost relatively well. For each pallet size and means of transport, the deck-area coverage (table 17) was multiplied with the percentage of allocated cost (table 5), which gave a score on the performance of the pallet size. For example, the total performance of Euro Pallets for the product area Closures was calculated by taking the deck area coverage of Euro Pallets in the means of transport (93,8% in Euro Truck, 84,9% in 40' container, and 76,2% in 20' container) and multiplying it with the percentage of allocated cost to each means of transport for closures (54,5% for Euro Truck, 36,2% for 40' container, and 9,3 % in 20' container), which gives the total performance 89,1 (all calculated numbers are multiplied with 100 to get the performance score):

$$0{,}938 * 0{,}545 + 0{,}849 * 0{,}362 + 0{,}762 * 0{,}093 = 0{,}891 \rightarrow 89{,}1$$

This calculation was done for all product areas in total and for each product area separately; the result is shown in table 18 in appendix. This data is useful for evaluating whether any of the pallet sizes currently used should be replaced by another size and for assessing the improvement potential from using an optimized pallet size. It is important to remember that Closures stand for 92% of the pallets shipped and is therefore the most important product area to consider.

A part of the result is visualized in figure 9, which includes the three pallet sizes used the most and the two best performing optimized pallet sizes. The Euro Pallet is shown to perform poorly, due to the low deck-area coverage in containers. Out of all pallets used by AddMat, the Strips pallet (1200 x 750 mm) had the second-best total performance (table 18), therefore this size could be a good substitute to the Euro Pallet. The pallet size with the best total performance was the 1200 x 770 pallet. This size will be called OP1 (Optimized Pallet 1). OP1 performed better than any other pallet size analysed for both Closures and Straws, and for Strips it was the third best performing pallet size. It is most likely the best substitute to the Euro Pallet, since it only differs 3 cm in width and since it does not have a longer width or length than the Euro Pallet, which could lead to problems with racking or automation. Therefore, replacing Euro Pallets with OP1 was the case that was analysed further.

Another part of the results is visualized in figure 10, which shows the total performance of all pallet sizes. This information is useful if the goal is to standardize pallet sizes over product areas. The 1200 x 1200 had a much lower performance than any other pallet size. Table 17 shows that the deck-area coverage of the 1200 x 1200 pallet is high in trucks, but very low in containers. The products loaded on this pallet might be excluded from the rule that all products are made to stock, i.e. that the means of transport is unknown when pallet sizing is done. Further research is needed to understand why this pallet size is used and whether it can be replaced with another size that has a better deck-area coverage in trucks, which would also increase pallet size standardization. Increasing standardization may be beneficial, this will be discussed further in section 7.1.4.2.

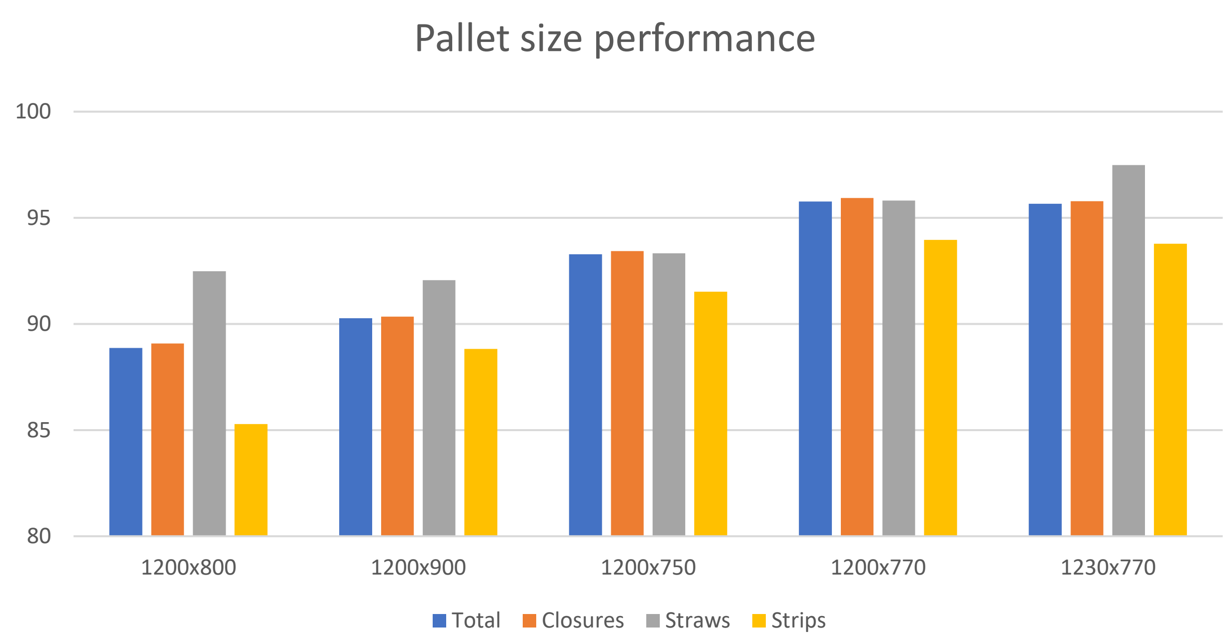

Figure 9: The performance of the three pallet sizes most commonly used by AddMat, followed by the two best performing optimized pallet sizes, for each means of transport.

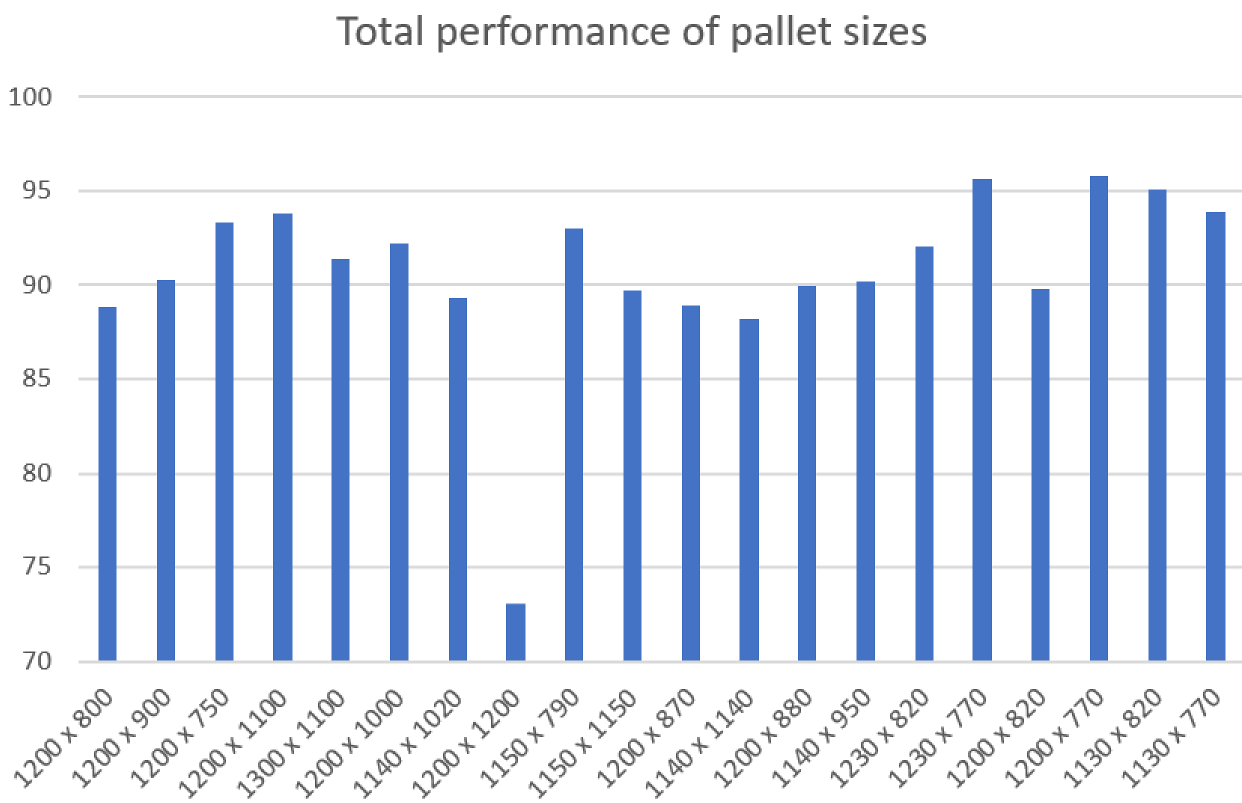

Figure 10: The total performance for all pallet sizes. The last six pallet sizes (furthest to the right) are the optimized sizes.

7.1.4. Additional factors

In this section factors affecting the choice of pallet size are discussed. Especially factors that affect the choice of switching from the Euro Pallet to OP1.

7.1.4.1. Weight restrictions on trucks and containers

Using pallet sizes that have a better fill rate might not lead to that more products are shipped per transport if the number of products shipped are constrained by weight restrictions on trucks or containers. To understand whether this was the case, the payload weight was calculated for a truck full of pallets, for each product. The payload weight of a full truck is always equal to or greater than the maximum weight of the payload of a full container. The lowest max payload for containers and trucks in table 4 is 28600 kg. Most products have a payload weight that is far below this restriction. The highest payload weight is 27000 kg and the products with this weight could potentially reach the weight restriction if an optimized pallet size is used. However, only a few products have a weight that could be affected by the weight restriction, and if they are affected, the products could potentially be shipped with other lighter products to circumvent this issue. Therefore, it was assumed that weight constraints on means of transport is not restricting further loading.

7.1.4.2. Standardization
Currently AddMat use 15 different pallet sizes, some of which are very similar. The reason for using so many different sizes is likely due to historical reasons, for example a pallet size might be adapted to a certain customer or a certain product or box. Another reason is that product areas and factories are not always communicating with each other when choosing pallet sizes, which leads to a lower standardization. AddMat has expressed that they want to increase standardization of pallet sizes, for each product area internally, but also between product areas, since customers and packaging factories handle pallets from different product areas. Increased standardization could potentially lead to increased efficiency throughout the supply chain, e.g. due to more efficient storing, better compatibility with material handling equipment, cheaper and more reliable supply due to larger scale, more possibility to automate, etc. Standardization might seem beneficial in itself, however there might be downsides with increased standardization, for example a lower customizability of pallets to boxes or to customers supply chains. Further research is needed to prove whether increased standardization would lead to any benefits, what the business gain would be of the benefits, and whether the benefits outweigh any potential downsides.

The data on total performance of the pallet sizes (visualized in figure 10) could be used to choose pallet sizes for all product areas. Table 18 could be used to phase out poorly performing pallet sizes which would also increase standardization. If one of the optimized pallet sizes are implemented it could be replaced by one or more of the pallet sizes currently used to not decrease standardization. Additionally, if the goal is to increase standardization, it would be good to analyse whether the number of pallet sizes used can be reduced through changes of the box dimensions, especially for pallet sizes with similar dimensions.

7.1.4.3. Box sizes
An interview was conducted with Diego Garvas, a category manager at AddMat, for discussion on the viability and impacts of changing box sizes. If Euro Pallet are changed to OP1 pallets, the box dimensions would have to be changed as well. Boxes are in general loaded two in width on the Euro Pallet. If the pallet width is reduced 3 cm the box width would be reduced 1,5 cm. A reduction of box width could affect factories and customers in two ways. Firstly, new box dimensions could affect the automation in factories, for AddMat and for AddMat's customers. For example, one factory in Seville requires boxes to have a bottom area that is square shaped. If square boxes are reduced 1,5 cm in width, they would have to be reduced 1,5 cm in depth to remain square shaped, which would result in a reduced pallet fill rate. This is only an issue for the Seville factory and Garvas stated that the factory already has problems with square boxes not being exactly square. Therefore, future automation would likely be able to handle boxes that are not square. According to Garvas the risks of incompatibility with automation is much lower for other factories, since they are not using as advanced automation.

Secondly, a reduced box width could lead to that fewer products fit in the box. The number of products in a box is important, since factories are programmed to produce a certain number of products per box and handle boxes with a specific number of products. A solution to this issue could be to increase the box height slightly, which would keep the number of products per box constant. This could lead to problems with the laden pallet height being too high, but since the height is only increased by a few centimetres it is assumed to be unlikely to cause problems. For some products it is more difficult to change box sizes than for others. The box sizes for Strips are more difficult to change than for Closures and Straws, due to the larger size of a strip rolls, compared to the size of caps or straws. Garvas stated that most boxes can likely be changed and that issues revolving automation could potentially be fixed, given that the savings from changing pallet sizes are high enough to make changing box sizes worthwhile. All in all, the implications of changing box sizes are uncertain and must be researched further before a new pallet size can be implemented.

7.1.4.4. Rack compatibility

Before implementing an optimized pallet size, the compatibility with racks needs to be analysed. If OP1 is to substitute the Euro Pallet, it must fit in the same racks as the Euro Pallet. OP1 fits in the same racks if the pallet is racked along the short side, since the length is the same and the width is lower. If the pallet is racked along the long side it is assumed to fit in the same racks, due to the difference in width only being 3 cm. This must be tested further, since a suboptimal fit could be acceptable or unacceptable, depending on the weight of the loads.

7.1.4.5. Loading patterns

When pallet sizes are analysed by StackBuilder, the maximum number of pallets that can fit in the means of transport is shown through the simplest loading pattern possible. Nonetheless, complicated loading patterns still occur. Therefore, loading patterns of a new pallet size must be checked. Complicated loading patterns can lead to damage of goods, lower safety, and a slower loading. The loading patterns for OP1 are shown in figure 11 in appendix. These patterns are clearly not complicated and would therefore not cause any problems in the loading phase. This figure also visualises the high deck-area coverage of OP1.

7.1.5. Cost savings

Calculating the cost savings from changing pallet sizes can lead to varying results. The optimized pallet sizes could be implemented to different degrees and the pallet sizes currently used could be changed in several ways. To get an understanding of the improvement potential from using an optimized pallet size, the cost reduction was calculated for using OP1 instead of Euro Pallets. For these calculations it was assumed that the pallet fill rate of OP1 is the same as for the Euro Pallet, i.e. the same number of products can be loaded per unit of pallet area. This assumption is fairly reliable for Closures and Straws, since caps and straws do not take up much space and it is therefore easier to scale the number of products per box according to the box size. Strips rolls are much larger and therefore this assumption is not valid for Strips. This does not impact the total savings for replacing Euro Pallets, since Strips do not use the Euro Pallets. The first step was to calculate the improvement in deck-area coverage rate and the reduced number of transports, see equation 2 and 3. The result can be seen in table 11.

Equation 2: Improvement in deck-area coverage

$$Improvement\ in\ deck\ area\ coverage = \frac{fill\ rate\ 2 - \ fill\ rate\ 1}{fill\ rate\ 2}$$

Equation 3: Reduced number of transports.

$$Reduced\ number\ of\ transports\ (\%) = 1 - \frac{1}{Improvement\ in\ area\ fill\ rate - 1}$$

Table 11: The improvement in deck-area coverage from switching from Euro Pallets to OP1, for each means of transport, and the resulting reduction in the number of transports required.

Means of transport	Euro Truck	40' container	20' container
Deck-area coverage of Euro Pallet	93,8 %	84,9 %	76,1 %
Deck-area coverage of OP1	95,7 %	98,0 %	86,6 %
Improvement in deck-area coverage	2,1 %	15,5 %	13,8 %
Reduced number of transports (%)	2,0 %	13,4 %	12,1 %

The cost reduction was calculated for all containers and trucks that were fully loaded with Euro Pallets and were shipped from a European city in 2018. 232 337 Euro pallets were used in shipments that match the previous description. The reduced cost was calculated by multiplying the cost allocated to the transports of the Euro pallets for each means of transport with the reduced number of transports (%) for that means of transport. This resulted in a **7,86 % yearly cost reduction** of the transport cost, given the previous assumption that the pallet fill rate remains the same for OP1 pallets as for Euro Pallets. To make sure that this assumption is true, further research is needed. Additionally, dunnage bags would not be needed between the pallets in containers, which would further reduce costs.

The actual reduced number of transports can be lower than the ones previously calculated due to different factors. For example, it might not be possible to adapt the boxes to OP1 for some products, which was previously discussed. Another reason could be that customers do not have a demand for the extra products shipped. This risk is deemed relatively low, since the trucks and containers are already fully loaded, which indicates that if more space was available it would likely be used. To take these factors into consideration, the cost reduction can be multiplied with a factor that represents the percentage of improvement realized.

A narrower pallet size resulting in narrower boxes could lower the number of products per pallet. If the number of products per pallet decrease, the number of pallets required increase (and vice versa). This would lead to a change in the pallet purchasing cost. However, as stated before, this change could be counteracted with increasing the box height, to keep the number of products per box constant. Even if the pallet purchasing cost increases by a few percent, the total transport cost for the 223 337 Euro

Pallets is 6,98 times larger than the total pallet purchasing cost for the same pallets, so the lower transport cost would heavily outweigh the potential higher purchasing cost.

The Euro Pallet is the most common pallet type in Europe. This has led to lower manufacturing costs due to economy of scale. The purchasing price could therefore be higher for OP1 compared to Euro Pallets. How prices and costs change if OP1 replaces the Euro Pallet depends on which pallet material is used. For example, it is much easier to customize paper pallets than plastic pallets. Diego Garvas, a category manager at AddMat who has visited several pallet suppliers, states that it is relatively simple for wooden pallet manufacturers to change dimensions of their pallets and therefore the difference in cost should not be high. Further research is needed to verify this. IKEA currently use 1200 x 760 mm paper pallets which they buy from Saica Pack. If AddMat were to use this size which is very similar to OP1 and use paper pallets, no new size would have to be invented and IKEAs large demand for pallets could potentially lead to a lower cost from Saica Pack for this size.

7.1.6. CO_2e savings

The total CO_2e emissions from transports of the 223 337 Euro Pallets previously mentioned was 2 655 219 kg. The reduced CO_2e emissions from changing these Euro Pallets to OP1 was calculated by multiplying the CO_2e allocated to the transports of the Euro pallets for each means of transport with the reduced transports in percentage for the means of transport respectively. This resulted in a **191 146 kg** CO_2e reduction of emissions from transports, which is the same as a **7,20 %** reduction. To put this into perspective, this represents the yearly CO_2e emissions of 73,5 average Swedish cars [1]. As for the cost reduction, the CO_2e reduction can be multiplied with a factor that represents the percentage of improvement realized.

7.2. Pallet materials

To understand which pallet material is best suitable for AddMat, information about the performance of the pallet materials on several factors was collected from theory and through the empirical study. In this section the information about pallet materials from theory and from the empirical study is compared to AddMat's situation and requirements. One pallet design from one supplier was chosen for each material for comparison. Lastly, costs and CO_2e emissions are analysed.

7.2.1. Pallet designs chosen for comparison

For a pallet material, the performance of pallets can vary a lot depending on the design. To facilitate the comparison of pallet materials, only one pallet design was chosen for each pallet material for analysis. The chosen design was the one that was deemed to have the best overall performance for AddMat. Since 82 % of AddMat's pallets are Euro Pallets, this size will be used to compare the materials. For

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[1] The average Swedish car drove 12 000 km in 2018 and used 0,076 litres of petrol per km (Länsstyrelserna, 2018) and the average Swedish petrol sold in 2017 had 2,85 kg CO_2e emissions per litre (miljofordon.se, 2019) 191 146 kg CO_2e emissions therefore represents: $191\ 146/(12\ 000 * 0{,}076 * 2{,}85) = 73{,}5$ average swedish cars yearly emissions.

wood, the EPAL Euro Pallet was chosen, since it was the only available design from EPAL that was a Euro Pallet. For plastic, the PolyPool Euro Pallet with top-deck lips was chosen, despite the low maximum temperature without deflection, due to the lower cost of this design. For paper, the Saica Pack pallet was chosen, due to its low cost and weight.

7.2.2. Performance on factors

In this section, the pallet design for each material will be compared on relevant factors. In table 2 in the theory chapter, pros and cons for each material is shown. In table 12, quantitative data for each pallet design is shown. In this section pallet strength will be discussed, along with customers use of pallets and disposal of pallets. The price, height, and weight of the pallets will be discussed in the following sections on cost and CO_2e emissions.

Table 12: Quantitative data on one pallet design for each pallet material.

Pallet material	Wood	Plastic	Paper
Pallet design	EPAL Euro Pallet	PolyPool pallet with Top-deck Lips	Saica Pack
Dimensions (mm)	1200 x 800 x 144	1200 x 800 x160	1200 x 800 x 55
Maximum safe working load (kg)	1500	1250	400
Tare weight (kg)	25	19	2,2
Pallet entry height (mm)	100	100	50
Average price	100	Higher than wood	29,5

7.2.2.1. Strength

The safe working load for each material can be seen in table 12. No pallet load weighs more than 900 kg, but some pallet loads weighs more than 400 kg. These pallets are only Strips pallets and Strips pallets only make up 5 % of the total pallets shipped. Almost all of Strips' pallet loads have a weight above 400 kg and the Saica Pack pallet is therefore not viable for strips, unless the safe working load is improved.

7.2.2.2. Customers use of pallets

AddMat's wooden pallets are most likely used by customers after they are received and depalletized. Changing the pallet material to paper or plastic would prevent this, since paper pallets are single use and plastic pallets from PolyPool would go back into PolyPool's pallet pool. This could lead to a lower perceived value from customers. A new pallet material must also be compatible with customers automation and material handling equipment.

7.2.2.3. Disposal

No information was available on how wooden pallets are currently used and disposed by customers. PolyPool's plastic pallets must be sent back to the pallet pool, which should be simple for AddMat's customers who are customers of PolyPool. Disposal is taken care of by PolyPool, and they are assumed to recycle most of their pallets. Since plastic pallets have a high durability, they can be reused more times than wood or paper pallets which decreases pallet disposal. Saica Pack's paper pallets are assumed to be recyclable, and most countries have functioning recycling systems for corrugated paper, so it is assumed to be relatively easy and cheap for AddMat's customers to dispose of paper pallets.

7.2.3. Cost

7.2.3.1. Purchase cost

PolyPool's plastic pallet cost more to lease than the price of the EPAL pallet. For PolyPool's pallet to be viable for AddMat, other benefits like increased food safety, potentially lower CO_2e emissions, and a lower weight must outweigh the higher cost. Saica Pack's paper pallet has the lowest cost and would reduce the total purchasing cost by **70,5 %** (100-29,5=70,5. 29,5 is the price index for the Saica Pack pallet). Since AddMat purchase a lot of pallets, this would lead to large yearly savings.

7.2.3.2. Initial cost

Implementing paper or plastic pallets for AddMat's supply chain would lead to initial costs. Example of cost drivers are pallets performance testing, potential changes to racks or material handling equipment, and education of staff. It is difficult to assess the total investments required, but it is safe to assume that the costs are significant, and the potential savings must therefore cover this initial cost in a reasonable time frame.

7.2.3.3. Transport cost

The transport cost could be lowered if the pallet weight or height is lower. These costs were not calculated, but clearly Saica Pack's pallet would lead to the the lowest transport cost. PolyPool's pallet has lower weight, but a higher height than the EPAL pallet. Further research is needed to understand the difference in transport cost between the two.

7.2.4. CO_2e emissions

The theory on LCAs for different pallet materials generally show that wooden pallets perform the best. However, theory is limited for alternative materials, especially paper. In addition, contexts and functional units are unique in each paper, and more research is needed to understand whether they are applicable to AddMat. For example, the number of usage cycles for each material is different between the papers. AddMat considers their wooden pallets single use, since they are not returned from customers, but in all the papers, the number of usage cycles for wood is much higher, which leads to that the results might not be applicable to AddMat. The generalizability of the papers is limited due to the varying methods and contexts and therefore no certain conclusion was drawn from the life cycle assessments. This led to that information from the life cycle assessments was not used in this thesis.

An option for Tetra Pak could be to conduct their own LCAs in collaboration with pallet suppliers. These LCAs could have consistent methodologies and be customized to Tetra Pak's supply chain, which would give more accurate results. No quantitative data was gathered from pallet suppliers about CO_2e emissions for different materials. The most important factors and life cycle phases affecting CO_2e emissions will be discussed for each material, but no new conclusions will be drawn, due to limited data. After that, the difference in CO_2e emissions in the use phase will be calculated, from using pallets with different weights.

7.2.4.1. Wood

The emissions for wood pallets in the materials phase depends on how the lumber is sourced. If trees are cut down which would otherwise have remained alive and growing, the short-term net impact on the atmosphere can be large. LCAs which take biogenic carbon into consideration often sees burning wood as CO_2e neutral, since carbon from the atmosphere is absorbed into trees when they grow. For the end-of-life-disposal phase, several scenarios were presented for wood pallets in the theory chapter. As can be seen in the LCAs, the total CO_2e emissions from wooden pallets are highly dependent on which scenario is used. More information needs to be collected about how customers use and dispose pallets, to understand the CO_2e emissions of wood pallets.

7.2.4.2. Plastic

PolyPool's plastic pallets have high emissions in the materials phase, since they are made from virgin plastic, which is a non-renewable material. They are currently looking into using recycled plastic for their pallets. The emission in the use phase are lowered due to that plastic pallets are durable and can be reused many times. PolyPool's plastic pallets are assumed to be recycled.

7.2.4.3. Paper

Cardboard used for paper pallets is originally made from wood. If recycled paper mass is used (e.g. Tetra Pak's used beverage cartons) to manufacture the pallets, the CO_2e emissions are lower, especially in the short-term. Paper pallets are single use, but if this would lead to higher CO_2e emissions for AddMat is unclear, since no information was acquired on whether customers use pallets for other purposes. Paper pallets are assumed to be recycled.

7.2.4.4. CO_2e emissions from the use phase

The three designs have different weights and heights, which affects the CO_2e emissions in the use phase. The differences in CO_2e emissions due to differences in height will not calculated, since that would require volumetric fill rates to be calculated, which is a very complex procedure with high uncertainties.

However, clearly a lower pallet height leads to lower CO_2e emissions, and Saica Pack has the lowest height, followed by EPAL and lastly PolyPool. The CO_2e emissions from transport of the pallet weight was calculated for each pallet design for the 306 605 Euro Pallets used by AddMat in 2018 (for transports originating in Europe). The CO_2e emissions were calculated for each transport with the help of Tetra Pak's emissions factors from table 7 in combination with data on transport distance, transport mode, and weight of the pallet designs. The results can be seen in table 13. Using PolyPool's pallet instead of EPAL's pallet would lower the yearly CO_2e emissions from the use phase with **60 644 kg** and using Saica Pack's paper pallet would lower the CO_2e emissions with **230 447 kg**. To put this into perspective, 60 644 kg CO_2e emissions and 230 447 kg CO_2e emissions is equivalent to the yearly CO_2e emissions of 23,3 and 88,7 average Swedish cars respectively[2].

Table 13: The total CO_2e emissions in the use phase from transports of the pallet weight of the 306 605 Euro Pallets used by AddMat in 2018 (for transports originating in Europe).

Pallet design	**Pallet weight (kg)**	CO_2e **emissions (kg)**
EPAL	25	252 683
PolyPool	19	192 039
Saica Pack	2,2	22 236

7.2.5. Summary of pallet materials

Not changing from wooden pallets would be the choice with the lowest risks in the short term. However, wooden pallets have a low food safety and an inconsistent performance, which is not in line AddMat's Zero Aspiration 2020. The EPAL pallet is heavy and much higher than the Saica Pack pallet, which leads to high transport costs and CO_2e emissions. For PolyPool's plastic pallet, the main benefit is the high food safety and durability, which is in line with AddMat's strategy and goals. The PolyPool pallet is lighter, but also higher than the EPAL pallet, so changes in transport costs and emissions is uncertain. The PolyPool pallet has a low max temperature without deflection and this is a high impact risk which needs to be researched further. PolyPool's pallets are more expensive to lease than the purchase price of wooden pallets, so the benefits must outweigh the increased cost for PolyPool to be viable. The main benefit of using Saica Pack pallets is the low price, weight, and height, which would reduce costs and CO_2e emissions from the transport phase significantly. The risk factors of using Saica Pack's pallets are mainly the durability, the water resistance, and the safe racking load. These areas need to be tested if Saica Pack pallets are to be implemented.

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[2] The average Swedish car drove 12 000 km in 2018 and used 0,076 litres of petrol per km (Länsstyrelserna, 2018). The average Swedish petrol sold in 2017 had 2,85 kg CO_2e emissions per litre (miljofordon.se, 2019). 60 64'4 kg CO_2e emissions therefore represents: $60\ 644/(12\ 000 * 0{,}076 * 2{,}85) = 23{,}3 \text{ average swedish cars' yearly emissions}$. 230 447 kg CO_2e emissions represents $230\ 447/(12\ 000 * 0{,}076 * 2{,}85) = 88{,}7 \text{ average swedish cars' yearly emissions}$

8. Discussion of results

In this chapter, the results are discussed and compared with theory.

In general, the empirical study and results from the analysis was in line with information collected from the literature review. Information on factors affecting the pallet choice was acquired from theory. This information was in line with which factors ended up affecting the material choice in this study. Bilbao et al. (2011) emphasized the trade-off between cost and strength/durability and this ended up being true for the pallet materials analysed. If the pallet material had a higher strength/durability it also had a higher purchasing/leasing cost. One factor which was not mentioned much in theory was the impact throughout the supply chain from changing the pallet. New pallet and box dimensions affect material handling equipment and racks, both of which are expensive to change, and it can also lead to new loading and storing patterns, which requires education of staff. New pallet materials can lead to similar changes and can also lead to new handling of pallets and new pallet management.

The study found that Euro Pallets performed well in Euro Trucks, but poorly in containers. This was in line with information from theory. No additional theory was found on how pallet dimensions affect fill rates. For pallet materials, paper performed the best on several factors and is likely the best material choice for AddMat. Theory states that paper is good for long, complex supply chains, and in open systems where pallets are usually disposed after a few or a single use. AddMat's supply chain fits this description and therefore the results are in line with theory. However, it is important to remember that each material has advantages and disadvantages and that this study only looks at AddMat. Throughout the study it became clear that a lot of factors must be taken into consideration to change any part of the pallet, whether it is changing the material or making the pallet 3 cm narrower. For example, changing the pallet width, lead to changes in the box width, which can affect the number of products per box, which can affect automation and customers. Therefore, the interactions between a pallet and the supply chain must be mapped and analysed before any decisions are made. This is in line with Pålsson's (2018) statement that the physical flow of goods and its related information flow should be viewed as one integrated system.

Using OP1 instead of Euro Pallets was calculated to reduce shipment costs and CO_2e emissions with 7,86 % and 7,2 % respectively. AddMat has a large supply chain which results in millions of euros in shipment costs yearly and therefore a reduction of 7,86 % is significant. A 7,2 % reduction in CO_2e emissions is equivalent to a reduction of 191 tonnes of CO_2e emissions yearly. To put this into perspective it is the equivalent to the average yearly emissions of about 19 Swedish people (Naturvårdsverket, 2019). The absolute values of the yearly reduction of CO_2e emissions was lower than expected. These values are based on emission factors from NTM. If they were based on other emission factors the results could have varied drastically, e.g. the emission factor from the UK Government on trucks is 120 g CO_2e emissions per tonne.km. for 100 % laden trucks (UK-Government, 2019), which is more than double the 58 g CO_2e emission per tonne.km.

Using Saica Pack pallets instead of wooden pallets was calculated to reduce the pallet purchasing cost by 70,5 %. If the pallet height is increased the price would likely go up a bit, but the reduction in purchasing cost would still be significant, which would lead to large yearly savings for AddMat. The CO_2e emissions in the use phase would be reduced by 230 tonnes due to the lower weight and the lower height would reduce the emission even further. This is a significant reduction which is in line with Kočí (2019) who states that a large part of CO_2e emissions from pallets can be attributed to the pallet weight.

9. Conclusion

This chapter initially presents conclusions from the analysis on pallet sizes and pallet materials, as well as recommendations for AddMat. After that, contributions to theory and to AddMat, Tetra Pak, and the industry are discussed. Finally, suggestions are made on future research areas.

9.1. Conclusions and recommendations

9.1.1. Conclusions for pallet sizes

The aim of the first research question was to answer which pallet sizes are best suited for each of AddMat's product areas. The study found that the Euro Pallet, which currently accounts for 82 % of the pallets used, performs poorly due to low deck-area coverage in containers. Therefore, the focus became to find a substitute for this size. The study also found that AddMat is currently using many different pallet sizes, some of which only differ one or two centimetres. It is recommended that AddMat reduce the number of pallet sizes, especially for similar pallet sizes, in order to increase standardization. Out of the sizes currently used, the 1200 x 750 and 1200 x 1100 sizes perform best for Closures and Straws and if no optimized pallet size is used, it is recommended for Closures and Straws to use these sizes.

Out of all pallet sizes, including the optimized ones, OP1 performed the best, met all the requirements from factories, and also lead to simple loading patterns. Therefore, it is recommended for AddMat to substitute the Euro Pallet to OP1, if testing and future research shows that it would be viable. This would change most of the pallets used for Closures and Straws. For Strips, the 1200 x 750 pallet size is used for 89 % of their pallets. Since this size performs well, and Strips boxes are assumed to be relatively difficult to change, it is recommended for Strips to not change their pallet size, at least in the short term. Replacing Euro Pallets with OP1 has several implications. The most important factor to research further is the impact a new pallet size would have on boxes, which could impact the compatibility with automation in AddMat and customer factories. The transport cost reduction of replacing all Euro Pallets in fully loaded containers or trucks shipped from a European city in 2018 with OP1 was calculated to be 7,86 %. The reduced CO_2e emissions from changing to OP1 was calculated to be 191 146 kg CO_2e, which is the same as a 7,20 **%** reduction.

9.1.2. Conclusions for pallet materials

The aim of the second research question was to answer which pallet materials are best suited for each of AddMat's product areas. To compare the materials, the best performing design (with Euro Pallet dimensions) was chosen for each pallet material. Despite the high food safety, PolyPool's plastic pallets are not recommended, mainly due to the higher cost, but also due to risks of deflection in high temperatures, a higher pallet height, and that plastic is a non-renewable material. The recommendation for AddMat is to use Saica Pack's paper pallets for Closures and Straws, while staying with wooden pallets for Strips. Saica Pack pallets are not viable for Strips due to the high weight of loaded Strips pallets and the low safe working load of Saica Pack pallets. For Saica Pack's paper pallet, the main benefit was the low purchasing price, which could lead to a 70,5 % decrease in thse pallet purchasing cost if the price does not change after the height is increased. The pallet is also very lightweight, which would reduce the CO_2e emissions from transports of Euro Pallets in 2018 by 230 447 kg compared to using the EPAL pallet. The low height reduces the transport costs and CO_2e emission further. Paper pallets can easily be customized, which would facilitate a switch to optimized pallet sizes. The risk factors of using Saica Pack's pallets are mainly the durability, the water resistance, and the safe racking load. These areas need to be tested before Saica Pack's pallets can be implemented.

9.2. Contributions

9.2.1. Contributions to theory

This study applied available research to a unique case context. No theory was found on how to optimize pallet sizes or how to analyse the fill rate performance for several means of transport, and therefore two new methodologies were invented. The first methodology was constructed for finding optimized pallet sizes (section 8.1.2). This methodology was based on testing several ideas and dividing the means of transport into sections based on the number of pallets that could be loaded in width and depth. The result was that several optimized pallet sizes were conceived, some of which had much higher deck-area coverages than any of the pallet sizes currently used. Another methodology was constructed for how to analyse pallet sizes when several means of transport needs to be taken into consideration. This methodology is based on using a software (e.g. StackBuilder or Cape Pack) to facilitate calculations on deck-area coverage and then weighing the means of transport according to their allocated cost. This resulted in that transport costs and CO_2e emissions could be lowered substantially. The data on deck-area coverage for the different pallet sizes in the different means of transport covers many of the world's most commonly used pallet sizes and can therefore be used outside of this case, by companies in any industry that ships pallets. Since OP1 has a higher deck-area coverage than the Euro Pallet in both Euro Trucks and standardized containers, this size could potentially be a good substitute to the Euro Pallet for any company who use Euro Pallets in these means of transport.

9.2.2. Contributions to AddMat, Tetra Pak, and the industry

This case study is useful for AddMat's transition to a new pallet solution. All the information gathered through the literature review is useful for any company who wish to analyse their pallets and the information gathered through the empirical study is useful for AddMat, both for this case and for any future analyses of pallets. Following the recommendations from this study could lead to large savings in costs and CO_2e emissions, as well as other benefits like increased food safety. Tetra Pak can use the methodologies conceived in this study for future projects, e.g. for analysing the pallets of other departments. The methodologies can also be used by other companies who wish to do similar analyses or transitions of their pallet systems. The data on deck-area coverage can be used by several departments at Tetra Pak.

9.3. Suggestions for future research

From the literature review, only one LCA on paper pallets was discovered. Further research on paper pallets is recommended in order to apply different methodologies and contexts, which can increase generalizability. For pallet dimensions, no theory was found on how different dimensions affect fill rates and how changing dimensions can impact the supply chain. This thesis showed that there is potential for large improvements in this area and further research is therefore recommended.

There are several areas that AddMat are recommended to research further before changes are implemented. For pallet sizes, AddMat could look at whether boxes are currently optimized for pallets, how box dimensions would change if pallet sizes are changed, and what impact this would have on the supply chain. Secondly, the current loading patterns could be analysed with the help of data acquired from Stack Builder. Pallets might currently not be loaded optimally, which could be improved by following the optimized loading patterns in StackBuilder. Lastly, it could potentially be beneficial for AddMat to research if pallet sizes could be standardized, but only if the benefits of standardization outweigh any potential downsides of standardization.

For pallet materials, Tetra Pak is currently looking into using PolyAl. This is a material consisting of the plastic and aluminium that comes from films used inside beverage cartons. PolyAl pallets would be managed like plastic pallets and therefore PolyPool would be the only viable option. Consequently, researching PolyAl as a pallet material is only recommended if PolyPool is the best option to start with. To assess the environmental impact of pallet materials Tetra Pak could conduct LCAs in collaboration with pallet suppliers. The methodology would then be consistent and customized for Addmat's situation.

In this project several delimitations were used. By removing these delimitations, the scope could be broadened, for example other environmental factors could be researched, as well as more effective material handling and storage.

10. Appendix

10.1. Optimized pallet sizes

Table 14: In this table the means of transport are divided into sections based on the number of pallets in width. This results in optimized pallet widths.

EuroTruck		Container	
No. of pallets in width	Pallet width (mm)	No. of pallets in width	Pallet width (mm)
2	1233	2	1168
3	820	3	777

Table 15: In this table the means of transport are divided into sections based on the number of pallets in depth. This results in optimized pallet depths.

EuroTruck		40' container		20' container	
No. of pallets in depth	Pallet length (mm)	No. of pallets in depth	Pallet length (mm)	No. of pallets in depth	Pallet length (mm)
18	756	16	751	8	713
17	800	15	801	7	817
16	850	14	858	6	957
15	907	13	924	5	1152
14	971	12	1001		
13	1046	11	1092		
12	1133	10	1201		
11	1236				

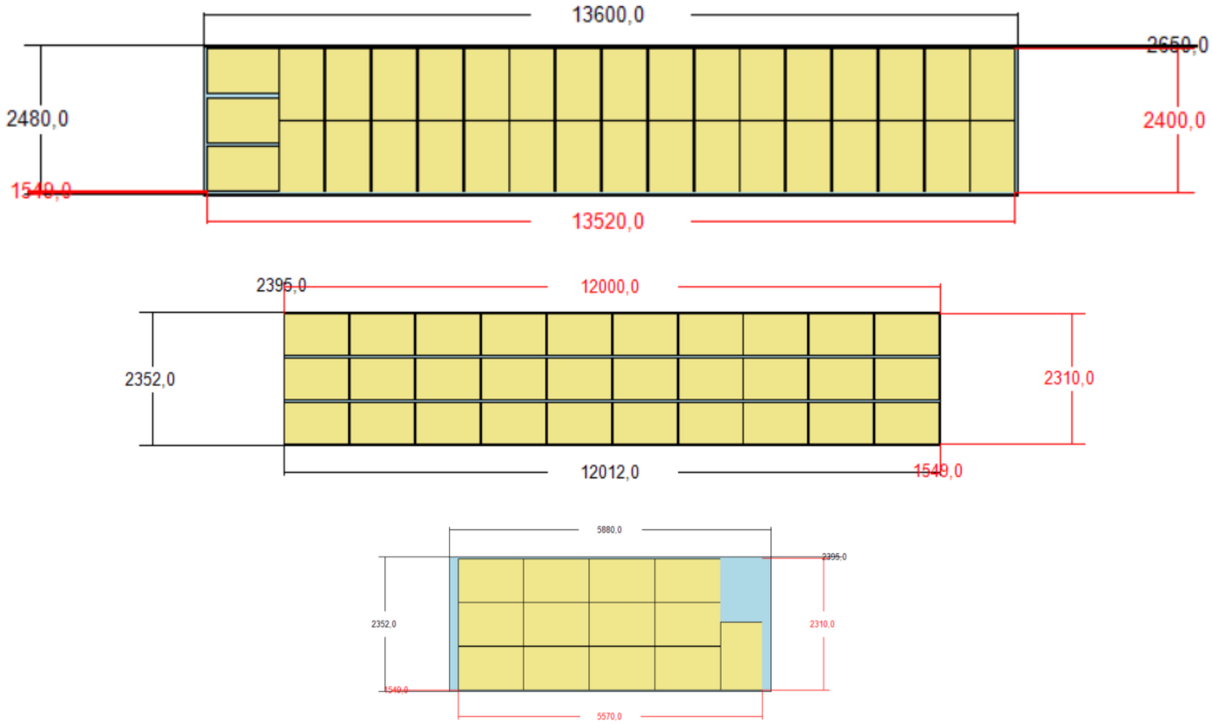

Figure 11: A StackBuilder analysis of the optimal loading patterns for OP1 (1200x770 mm)l in the different means of transport, starting with Euro Truck in the top, followed by 40' Standard Container, and lastly, 20' Standard container. The means of transport is seen from above, each beige rectangle represents a pallet and the light blue area represents the unused space.

10.2. IKEA's experience

Ikea successfully invented and implemented a solution based entirely on paper pallets. The paper pallets are custom made for Ikeas supply chain and they can carry up to 750 kg. They are 5 cm high, only weigh about 2.5 kg, and have custom made dimensions. This leads to increased volumetric and weight-based fill rates, which in term leads to lower costs and CO_2e emissions, as well as lower product damage (IKEA, 2018). From section 6.1 a requirement of 60 mm pallet entry height was stated. Could AddMat use the same solution as Ikea with pallets that are only 5 cm high, which is below the requirement? Unfortunately not, since it would not be possible for AddMat to implement a solution that only takes their own supply chain into consideration. The difference between Tetra Pak and Ikea is that Tetra Pak does not own their entire supply chain. Ikea's pallet solution lead to adaptations to their racks, forklifts, and stores, as well as heavy investments in training personnel to correctly handle the new pallets. Such large changes are not viable for AddMat, since their supply chains are long and complex, and all their customers would have to be included in the change as well. Nonetheless, if the pallet height is higher than 5 cm, material handling equipment would not have to be changed and paper pallets could be used, which could lead to similar benefits.

10.3. Safety distance

Before new pallet sizes were analysed, the requirements on safety distances between pallets and the walls of the means of transport had to be decided. No data on safety distances was found in theory, but according to Jawdat Higab, a supply chain operations manager at AddMat, pallets should be stacked as close to each other as possible to prevent pallet movement during transport. He also stated that a safety distance might be required to the door of the means of transport. To make sure this distance was not overstepped, it was based on the smallest distance that currently exist between pallets and the door of the means of transport, which is 2 cm. The safety distance in width for the means of transport should be as small as possible but still allow for pallets to be placed and removed without damaging each other. An assumption was made that a 5 mm safety distance between the pallets in width and between the pallets and the walls of the means of transport would be enough for picking and putting away pallets in the means of transport without damages.

10.4. Maximum number of pallets per means of transport

Table 16: Maximum number of unstacked pallets for different pallet sizes in different means of transport. The pallet sizes currently used are sorted in descending order according to how much they are used. The optimized pallet sizes are written in bold.

Pallet size	Euro Truck	40' container	20' container
1200 x 800	33	25	11
1200 x 900	29	23	11
1200 x 750	35	30	13
1200 x 1100	24	20	10
1300 x 1100	22	18	8
1200 x 1000	26	22	10
1140 x 1020	26	22	10
1200 x 1200	22	10	4
1150 x 790	35	29	13
1150 x 1150	22	20	10
1200 x 870	30	23	11
1140 x 1140	22	20	10
1200 x 880	30	23	11
1140 x 950	28	24	11
1230 x 820	33	24	11
1230 x 770	35	28	13
1200 x 820	33	24	11
1200 x 770	35	30	13
1130 x 820	36	28	13
1130 x 770	36	31	15

10.5. Deck-area coverage of pallet sizes

Table 16: Deck-area coverage of the pallet sizes currently used and the optimized pallet sizes, in each means of transport. The pallet sizes currently used are sorted in descending order according to how much they are used. The optimized pallet sizes are written in bold.

Pallet size	Euro Truck	40' container	20' container
1200 x 800	93,8%	84,9%	76,2%
1200 x 900	92,7%	87,9%	85,7%
1200 x 750	93,3%	95,5%	84,4%
1200 x 1100	93,8%	93,4%	95,2%
1300 x 1100	93,1%	91,0%	82,5%
1200 x 1000	92,4%	93,4%	86,5%
1140 x 1020	89,5%	90,5%	83,9%
1200 x 1200	93,8%	50,9%	41,5%
1150 x 790	94,1%	93,2%	85,2%
1150 x 1150	86,1%	93,5%	95,4%
1200 x 870	92,7%	84,9%	82,8%
1140 x 1140	84,6%	91,9%	93,7%
1200 x 880	93,8%	85,9%	83,8%
1140 x 950	89,8%	91,9%	85,9%
1230 x 820	98,5%	85,6%	80,0%
1230 x 770	98,1%	93,8%	88,8%
1200 x 820	96,1%	83,5%	78,1%
1200 x 770	95,7%	98,0%	86,6%
1130 x 820	98,8%	91,8%	86,9%
1130 x 770	92,7%	95,4%	94,1%

10.6. Total performance of pallet sizes

Table 17: The performance score of each pallet size in total and for each product area. The performance score was calculated for a pallet size by multiplying the deck-area coverage of the pallet size with the percentage of allocated cost for the means of transport shown in table 5. Pallet sizes currently used are sorted in descending order according to how much they are used. Optimized pallet sizes are written in bold.

Pallet size	Total	Closures	Straws	Strips
1200 x 800	88,9	89,1	92,5	85,3
1200 x 900	90,3	90,3	92,1	88,8
1200 x 750	93,3	93,4	93,3	91,5
1200 x 1100	93,8	93,7	93,8	94,0
1300 x 1100	91,4	91,5	92,7	89,3
1200 x 1000	92,2	92,3	92,4	91,1
1140 x 1020	89,3	89,4	89,5	88,2
1200 x 1200	73,1	73,6	88,1	62,3
1150 x 790	93,0	93,1	93,9	91,2
1150 x 1150	89,7	89,6	87,1	91,6
1200 x 870	88,9	89,0	91,7	86,9
1140 x 1140	88,2	88,1	85,6	90,0
1200 x 880	89,9	90,0	92,7	87,9
1140 x 950	90,2	90,3	89,9	89,5
1230 x 820	92,0	92,2	96,8	88,3
1230 x 770	95,7	95,8	97,5	93,8
1200 x 820	89,8	90,0	94,4	86,1
1200 x 770	95,8	95,9	95,8	94,0
1130 x 820	95,1	95,2	97,8	92,6
1130 x 770	93,9	93,8	93,0	94,2

Table 18 shows that, out of the pallet sizes currently used, the 1200 x 750, 1200 x 1100, and 1150 x 790 sizes perform best for Closures and Straws. For Strips, the 1200 x 1100 size performs the best. Out of all the pallet sizes including the optimized sizes, OP1 performs best for closures, 1130 x 820 for Straws, and 1130 x 770 for Strips. The best performing pallet sizes for Straws and Strips could be chosen to replace

Euro Pallets for Straws and Strips respectively. However, these two sizes differ more to the Euro Pallet than OP1 does. This means that boxes would have to be changed more and there would be a higher risk for incompatibility with automation, racks, and material handling equipment. The lower lengths of the pallet sizes result in a smaller pallet area, which leads to that more pallets and boxes are required to ship the same number of products, which increase the shipping costs. Using these sizes is therefore not recommended. 11 % of the pallets currently used by Straws are 1150 x 1150 pallets, but this size has a relatively low performance for Straws (87,1). Why Straws use this pallet is not known; it could be due to the large area or the square shape. Further research is needed to understand if this pallet size could be replaced with a pallet size that performs better for Straws.

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