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Improving Supply Chain and logistics and reducing costs by design and improvement of packaging with the help of Lean and DFL

Project-based case study

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Abstract:
Logistics is critical part of supply chain, due to enabling efficient and reliable value-creating operations, with the potential to increase sales and profits. Main goals of the case study are to improve product transport packaging, packaging process, packaging and transportation costs and all related material flows throughout the supply chain in the case company. This is done by analyzing current state and employing rarely used Design for Logistics (DFL) theory framework, combined with Lean, to form a ground up approach for optimizing the supply chain.

Empirical study is carried out as case study research utilizing inductive case study framework, action research cycles and mixed methods. Both deductive and inductive reasoning are used. Theories have been employed and tested in practice, but new case related theory has also been made from ground-up based on data, experimentation, observation, and analyses. 3D-modeling is utilized extensively.

Case results include various findings regarding current state of logistics processes, costs and their relationship between packaging and packaging processes in the case company. Results also include creating a modular, interchangeable transport packaging for upcoming new product families, creating new material flow processes throughout supply chain, overhauling packaging process and creating a semi-automated packaging cell. Other resulting outcomes include e.g., significantly lower production costs, process variance and time, and transportation costs, together with increased economies of scale as well as flexibility and availability regarding transportation options. Results also point theory-wise the potential and significance of packaging for the whole supply chain entity as a creator of increased value and efficiencies, especially by facilitating and enabling creation of new capabilities regarding various internal and external processes and related production technologies.

Results of the study are both valid and reliable due to the methodology used, where de facto continuous validity and reliability evaluation was built-in because of periodical group reviews and other events partaken by cross-functional team of professionals. Results have been realized by utilizing various, both alternative and supplementary research methods. Findings and results have been further verified by prototyping, various in-practice testing, 3D-modeling as well as by ongoing implementation and commissioning to the case company's operations.

Further research could include how to systemically introduce and implement DFL into use as integral part of product and production development alongside other DFX tools.

KEYWORDS: Supply Chain optimization, logistical process, logistics costs, innovation, transportation, packaging, packaging process, design for logistics, Lean

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1 Introduction

Logistics is a vital part of companies' operations. Logistics include inbound, production and outbound logistics which can employ various differing means of transportation, warehousing, and intralogistics during the process of making and delivering a product to a customer. Therefore, as logistics is present all the way from receiving goods required to make a product, to delivering a product for the end-customer, it poses a constant challenge but also opportunities for companies (Farahani et al., 2011). By improving the logistics companies can improve efficiency and save money. In doing this, delivery packaging is one part, and arguably a challenging one, because of many variables and interdependencies.

1.1 Research questions and limitations

The aim of this research is to find out the answer to the following research questions:

1. Could current package design be improved in some way for the new upcoming products from NPD project?
2. How to minimize transportation and other packaging related costs by package design?
3. How could current packaging process be improved for the new upcoming products from NPD project?
4. How to reduce worktime and worker need in packaging process for the new upcoming products from NPD project?

Main goal is to try to improve current product transport packaging, packaging process and all related material flows throughout the supply chain in a new product development project by finding out how current transportation processes, logistics costs, packaging processes and packaging costs can be improved. Focus will be in drive products, which need to be packed and delivered on pallets due to their size and/or weight. Transportation contracts, delivery terms and transportation documentation are excluded from this research.

1.2 Structure of the thesis

This thesis consists of 8 main chapters. Theoretical part consists of three chapters. First chapter is introduction. Theoretical framework for supply chain, logistics and packaging related theories are in second and third chapters. Theory is followed by empirical case study in four chapters. In fourth chapter methodology and case are presented, fifth chapter comprises of current state analyses and strategical framework creation, in sixth chapter results are presented, followed with conclusions in seventh chapter and lastly further research suggestions are in eight chapter.

2 Supply chain management, logistics and Lean

2.1 Lean

Modern Lean has been established mainly based on Toyota Production System's principles, which was created for Toyota by Taiichi Ohno, Shigeo Shingo and Eiji Toyoda. Earlier version of Lean manufacturing philosophy was developed in the beginning of 20th century by W.F Taylor and Henry Ford for Ford Motor Company's automotive factory in 1913.

Lean is a management and production philosophy, which is one of the most researched and used strategies together with Agile in modern business environment. Lean places focus on minimizing waste to maximize customer value, especially by continuous improvement and standardization (Ritvanen et al., 2011, pp. 60-61). Lean can be used both for production and services, even though popular misconception has been that lean is suited only for manufacturing (Ritvanen et al., 2011, pp. 60-61).

Lean is related to total quality management and places focus on big picture, instead of partial optimization. Ultimately Lean could be summarized as maximizing customer satisfaction (value stream) and producer satisfaction (resource efficiency). Organization which is Lean, understands customer value and places focus on key processes to continuously increase customer value (Lean enterprise institute, 2021a).

Therefore, focus is on optimizing flow of products and services through complete value streams, which are flowing horizontally across technologies, assets, and departments – instead of optimizing separate technologies, assets, and vertical departments. Lean enterprise institute (2021b) states, that that way wastes along entire value streams are eliminated and efficient processes created with less human effort, space, capital, and time required to make products or services, with smaller costs and much fewer defects. These create better capability to respond to changing customer needs with high variety, high quality, low cost, and fast throughput times. While simultaneously making management and information management simpler and more accurate.

There are five principles in Lean management (Womack & Jones, 2003):

1. Value - defining value based on customer's point of view.
2. The value stream - mapping the value stream for each product and removing all non-value-added steps.
3. Flow – creating continuous flow through value-added steps.
4. Pull – introducing pull between all steps where continuous flow is possible.
5. Perfection – managing towards perfection so that steps, amount of time and information required to serve a customer can be reduced continuously.

Value-adding steps are activities which customers are ready to pay for (usually e.g., manufacturing processes which create products for a customer), while non-value-adding steps are activities which do not create added value or can be removed without making product or service worse (e.g., extra reporting, extra movement, and setup times) (Voehl et al., 2014, p. 110). Business value-adding steps are in some sense non-value-adding but necessary for creating and delivering products or services to customers (e.g., security, bookkeeping and marketing), nevertheless, these should be optimized also (Voehl et al., 2014, p. 110).

2.2 8 wastes of Lean

Waste is any activity that consumes resources but creates no value for the customer. Most activities are waste: either non-value-added activities, or non-value added, but necessary and unavoidable activities (Voehl et al., 2014, pp. 67-68). Original seven wastes (Muda) were developed as part of the TPS, with eight added later in the 1990s when TPS was adopted in the Western world. Resulting 8 wastes can easily be memorized with "TIMWOODS" acronym (Lean enterprise institute, 2021b). The eight types of waste include transport, inventory, motion, waiting, overproduction, overprocessing, defects and skills/unused human talent (Voehl et al., 2014, pp. 67-68).

Overproduction happens when more products are made than necessary from customer's or next processes point of view. Overproduction usually causes other wastes also, namely extra production storage, which in turn lead to increased movement of personnel and materials. Overproduction is caused e.g., by uneven scheduling, unbalanced work, and long setup times (Voehl et al., 2014, pp. 67–68).

Inventory (extra, unnecessary storage) comprises e.g., of raw materials, work in process (WIP) or ready products being stored which therefore are not creating added value. Of all the wastes extra storage has been discovered to have biggest effect for optimizing production. Extra storage is caused e.g., by bad forecasts, complex products, uneven scheduling, and unbalanced work (Voehl et al., 2014, pp. 72, 7-8.).

Transportation is the movement of materials (resources) from point A to point B. This does not add value to products or for customers. Waste of transport can increase costs a lot, as equipment such as trucks, forklifts and carts are required together with personnel resources. Transportation is caused e.g., by bad buying practices, big production lots and storage areas, bad factory layout and bad understanding of process flow (Voehl et al., 2014, pp. 89-90).

Defects are caused by quality errors and they result to extra costs caused by disqualified products, rework, repair, changing of production plans and image costs (to name a few). Quality costs are caused e.g., by bad buying practices, bad product design and weak process control (Voehl et al., 2014, p. 76).

Overprocessing is use of inappropriate techniques, oversized equipment, too tight tolerances and performing extra processes which are not required by customer. Overprocessing is caused e.g., by "just in case" thinking, unclear or undefined customer requirements, extra quality control, bad communication and "filling of idle time" (Voehl et al., 2014, p. 80).

Waiting comprises of waiting time of personnel, machinery and waiting for material processing. Waiting is caused e.g., by stockout of materials, uneven scheduling and unbalanced worktimes between process phases, bad layout, long setup times, quality problems and automation misuse (Voehl et al., 2014, pp. 83-84).

Motion waste comprises of movements of employees, machinery or equipment which are unnecessary. Extra movement causes extended production time, damage risks and extra resource use. This is opposite of when materials, machinery, personnel, and methods are combined successfully, resulting to continuous flow. Unnecessary motion is caused e.g. by bad efficiency of personnel, materials or machinery, variance in working methods, bad layout, bad organizing and uncleanliness (Voehl et al, 2014, p. 87).

Skills/unused human talent is the underutilization of personnel talent, knowledge, and skills. This happens to some extent and form in every company even though it is not often admitted. Waste of unused talent is caused e.g. by old-fashioned management thinking and company culture, bad work introduction practices, low investment into training, poor incentives or compensation (Voehl et al., 2014, pp. 93-94).

2.3 Logistics and logistics costs

Efficient logistics play a critical role in modern supply chains, where inventories are being minimized while requirements such as delivery time and accuracy are rising all the time. Being able to run a company according to Lean-philosophy principles and to be Agile in the operations, logistics must be well-planned and executed in a stream-lined fashion. As logistics are involved at every point of supply chain, those who master logistics, will gain competitive advantage.

Logistics costs as a percentage of sales revenue varies between 6-26 %, depending on the industry and study in question (Skerlic, 2018). Optimized logistics can bring great competitive advantage, as reduction in logistics costs has greater impact to profits than increased sales volume (e.g., one euro saved in logistics costs vs. one euro additional sales with 4 % profit margin) (Stock et. Al, 2001).

Ritvanen et al. (2011, p. 19) highlights that Finland has especially high requirements and demands towards logistics, as most of export markets are situated far away. Average logistics costs for Finnish industries are 14,1 % of sales according to a 2018 Finland state of logistics research (Solakivi et al., 2018). It should be noted that costs vary strongly depending on the branch of industry. Market conditions and price of fuels greatly affect logistics costs. Structure of industries have a clear effect on the size of logistics costs, relative to turnover and GDP. Industries with higher added value have relatively lower logistics costs than industries with lower added value (Solakivi et al., 2014).

According to World bank (2017) logistics costs in industrialized and developing countries make up 13 % of GDP on average, though the amount varies greatly country by country. As of 2017 total logistics costs were around 9% in the two most efficient countries (USA and Netherlands), while in the least efficient countries logistical costs were up to 25% of GDP.

Indicator/year	1990	1995	2000	2005	2008	2009	2011	2013
Logistics costs (billion €), manufacturing and trade (incl. functions abroad)	20,9*	18,1*	22,7 *	34,6	43,8	37,9	34,5	37,8
Logistics costs, share of turnover	11,0 %	10,3 %	10,2 %	13,1 %	14,2 %	11,9 %	12,1 %	13,4 %
Transportation costs, share of turnover	4,8 %	4,7 %	4,5 %	5,0 %	6,3 %	4,4 %	4,6 %	4,4 %

* Old calculation method

Table 1. Logistics and transport costs for manufacturing and trade firms operating in Finland as a time series from 1990 to 2013 (Solakivi et al., 2014).

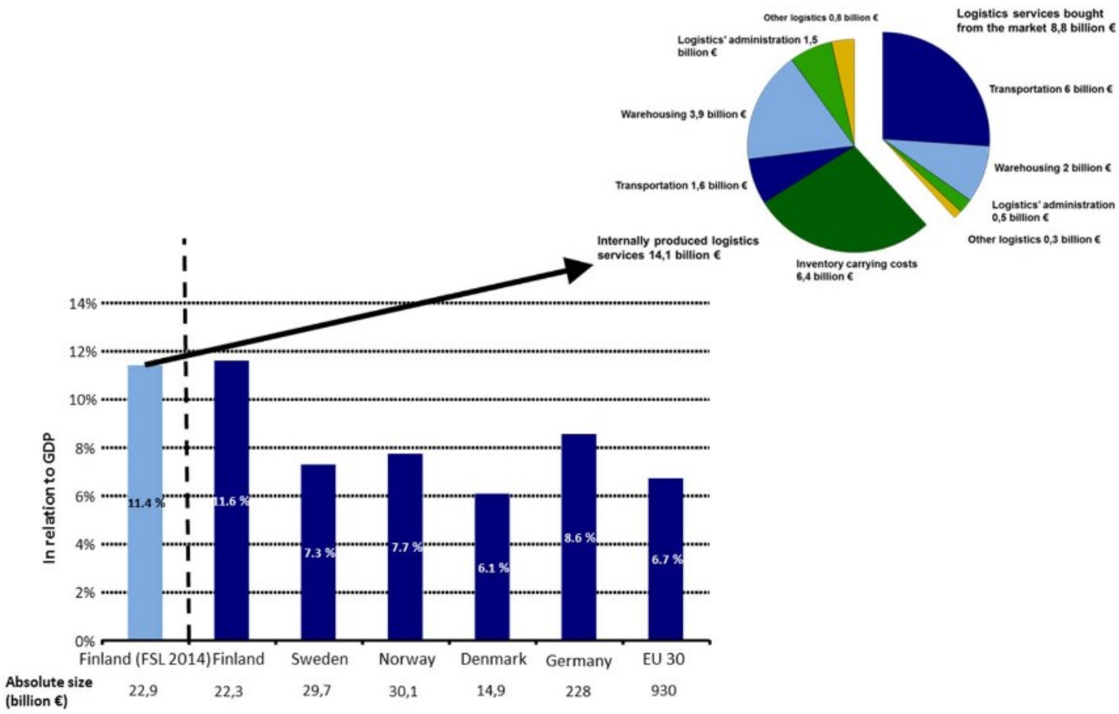


Figure 1. Estimated size of the logistics market and breakdown by logistic costs in Finland and other countries. Finland based on Solakivi et al. (2014) and other countries' logistics market sizes based on Kille and Schwemmer (2014).

Both Ritvanen et al. (2011, pp. 19-20) and Karrus (1998, pp. 12-15) emphasize that logistics need to be understood as a comprehensive, holistic entity. One must create a comprehensive understanding and vision of the business environment to be successful in managing supply chain logistics. Karrus (1998, pp. 12-14) also emphasizes need for creative and innovative thinking, knowledge of technologies and understanding of economics.

Nowadays especially in business-to-business delivering in time is challenging due to tight schedules. As transportation costs on average can form 5-10% of the total sales price, there is also high pressure of delivering at the right price (Rodrigue et al., 2012, p. 232; Van Goor et al., 2003, pp. 114-115). High transportation costs reduce sales margins which could be very problematic especially in highly competed markets.

Duty of the supply chain management is to define how fast, from where and at what price customers can get a product (Gattorna & Walters, 1996, p. 6). Supply chain management also needs study, evaluate, and decide what are the “added value” factors being offered for customers (Gattorna & Walters 1996: 6; Simchi-Levi et al. 2012, p. 368). Therefore, it is important to find out and understand what things are valued the most by customers. It could be fast delivery, ease of delivery, low price or maybe even something else.

2.4 Logistics and supply chain

Logistics can be summarily defined as controlled planning, storage, movement, and transportation of various material-, information- and capital flows (Karrus, 2005, p. 13; 2001, pp. 12-13). Development, management and control of warehousing, movement and transportation can be considered most important core tasks of logistics (Reimi & Saarela 2010, pp. 11-12). Synchronizing storage, movement, and transportation to work together in an optimal way is important for the correct functioning of a supply chain and ensuring that users get the right product and quantity, at the right time, -place, -customer and -price; just in time (JIT) (Ritvanen et al., 2011, p. 19).

Logistics need to account for all parties involved in the supply chain and improve functioning of the whole supply chain through optimization (Karrus, 2005, p. 25). Supply Chain and logistics both provide direction, guidance and carry out activities regarding how assets must be situated and positioned. Supply Chain considers all activities taking place and being necessary from taking an order, all the way to customer receiving the ordered product. Supply Chain focuses more on finished products and customers, while logistics is a subset of supply chain and orientated towards planning, coordinating, and executing all the necessary transportation, movement and storage of goods and products throughout the supply chain (Karrus ,2005, p. 25).

Due to logistics being present in some form on most activities throughout the supply chain, many logistical tasks are often handled by different persons across multiple functions. This kind of fragmentation presents a clear challenge for the improvement and control of factors affecting efficiency of logistics and therefore the whole supply chain (Karrus, 2005, p. 25). The most optimal logistics in the supply chain can be achieved by encouraging cross-functional cooperation and information flows, as differing views and interfaces towards logistics naturally lead to differences in what is seen to be important, what are the priorities and what should be done to enhance operations (Ritvanen et al., 2011). Ritvanen et al. state, that due to natural fragmentation of activities related to logistics, there is a risk present that some areas can be left neglected, unidentified, or only partial optimization is done. Logistics chains have gotten longer together with globalization: suppliers and customers can be situated around the world. This in turn means controlling logistics chain has become more challenging and requirements for packaging are higher (Ritvanen et al., 2011, p. 187).

2.5 Logistical process

Efficient and well-functioning logistics is vital for being able to run successful business. According to Ritvanen et al (2011, p. 19) in the case of Finland due to long distances, high portion of exports and small inner markets, logistics is especially important.

When all the phases related to delivering goods or services around the company are merged as a one comprehensive entity from start to beginning, they form the logistical process. Logistics is not a single function moving items forward in the value stream, but tasks and responsible persons related to it are scattered and fragmented across organizations. Logistics is a comprehensive process forming up from all mentioned little pieces, which as a whole support the core activities of businesses (Sakki, 1999, p. 25).

There are four different types of flows which form up the logistical process (equivalent with supply chain management) (Sakki, 1999, pp. 24-26).:

- Material flow
- Information and data flow
- Money flow

- Reverse flow - Von Bagh et al. (2000) and Hokkanen et al. (2002) include reverse flow as a fourth, separate flow.

Material flow usually goes from suppliers to customers and is thought as the most crucial logistical flow because the whole real process of a company is depending on it (Hokkanen et al., 2002, p. 15). Material flow can also be called physical material flow. In practice it consists of physical handling, storage and transporting of goods, which form the biggest expenses in material flow and thus design and planning of procurement and distribution are important (Sakki, 2009, p. 23).

Information/data flow is necessary communication and information exchange required to start material flows and money flows. Information flows both from suppliers to customers and from customers to suppliers. Information flow has strategic implications as management requires enough good quality information for making right decisions. Accurate and real-time information is required for guiding operational activities. As networks are increasingly vast, information flows are vital for success. (Sakki, 2009, p. 22.)

Money flow into company and out from company dictates profitability with respect to invested capital (Sakki, 2009, p. 23). Money flows from customers to suppliers. The faster money flows between different parties, the better. Quicker turnover rate requires good information flow to facilitate it. With quicker turnover goods can be delivered faster, billing is faster, and payments are received faster also (Reinikainen et al., 1997, p. 12; Sakki, 2009, p. 23).

Reverse flow is material flow, which goes to opposite direction than other material flows, i.e., returning materials from customers to suppliers (Von Bagh et al., 2000, p. 154; Hokkanen et al., 2002, p. 15). It can be e.g., customer returns, recycling or companies own waste. Challenges from logistical point of view surface from how to recognize, control and efficiently utilize these flows, as faster reverse flows free tied-up capital faster (Karrus, 2001, p. 29).

2.6 Inbound logistics

Inbound logistics forms a set of company’s operative activities, which concentrates on obtaining, moving, and organizing of materials, components, other unfinished goods as well as tools and other necessary goods required in operations of various production facilities, warehouses, or stores (Reimi & Saarela, 2008, p. 11).

Inbound logistics incorporates all functions, work phases and controlling measures which are required to get required goods in the possession of a company (von Bagh et al., 2000, p. 158). Inbound logistics’ material flow starts from suppliers, possibly goes through subcontractors, and ends when goods are unloaded to the receiving company.

Inbound logistics can also be called procurement logistics, as Inbound material flows, such as components, usually come from multiple different sources via different channels (Pouri, 1997, pp. 1-2.). Sources can be located on different geological areas and rely on different modes of transportation with different delivery times, which can present a challenge for operations.

2.7 Inhouse/ production logistics

Inhouse logistics describes internal logistic processes taking place in a value-adding facility such as a factory. Inhouse logistics comprises of material handling, storage activities and related management (Von Bagh et. al., 2000, pp. 159-160). Inhouse logistics has interfaces with inbound and outbound logistics at the loading platforms. Inhouse logistics starts with unloading of goods at inbound loading platforms and ends with preparing shipments ready for loading to outbound platforms. Generalized, inhouse logistics comprises of process phases which do not refine the products and are taking place in a facility (Von Bagh et. al., 2000, pp. 159-160).

Inhouse logistics processes include three main phases according to von Bagh et al. (2000, pp. 159-160): goods receiving, non-refining phases in production (storage, internal transports, and packing) and preparing shipments.

2.7.1 Goods receiving

Receiving goods is the first activity of storage and inhouse logistics. Its task is to receive, inspect, identify, and allocate incoming goods so that they can be found and used appropriately and effectively (Karhunen et al., 2004, p. 374; Von Bagh et al., 2000, p. 191). Receiving process starts with unloading the delivery and inspecting goods (quality and quantity against purchase order), next goods are marked as received and then goods are usually allocated to production or storage in the organization (Lambert et al., 1998). Inspection does not need to be necessarily done immediately after unloading but can be done also later (Karhunen et al., 2004, pp. 374-375).

Goods receival acts as a critical point for the operations following it, as inventory levels need to be up to date to prevent stockouts or need for excessive storage (Von Bagh et al., 2000, p. 191). After goods have been received, responsibility changes from deliverer to the receiving party. Supply chain works in close relationship with purchasers and goods receival as the information about deliveries and of their quantity and quality comes from them (Karhunen et al., 2004, p. 374).

A separate quality inspection can be performed for inbound goods after receiving goods. Function is to ensure that goods fulfil quality criterion set to them according to various specifications, which are related to the properties of the material, component, tool, or corresponding goods itself and not the delivery shipment as opposed to the standard inspection on goods receiving process (Lambert et al., 1998).

2.7.2 Storage

Storage is commonly required to secure the continuous functioning of business and related business operations for various reasons (Lambert et al., 1998). Nevertheless, storage is seen as a waste according to various aspects of Lean philosophy and the goal to minimize storage is widely accepted across industries using Lean. In practice, however, complete removal of storage or even very high rate of storage turnover ratio is not realistic or possible in many cases (Karrus, 2001). Some materials might be required to order in bigger quantities due to e.g., delivery costs or delivery time or some products need to be manufactured due to fluctuating demand and delivery time requirements (Karrus, 2001).

Generally, need for storages can be argued for with the following according to Waters (2009); Karhunen et al. (2004, p. 302) and Hokkanen et al. (2002, pp. 143-144):

- Acting as a buffer between different parts of supply chain
- Acting as a buffer between customers (demand fluctuation)
- To enable optimal filling of transports to lower costs
- To benefit from economies of scale (e.g., economic order quantity)
- To utilize price discounts related to big orders
- To be able to benefit from material price fluctuations (e.g. cheap copper bought to storage)
- Acting as a buffer for seasonal fluctuations
- To ensure availability of ramping down or hard to get products
- To prevent stockouts
- During high inflation environment to “make profit”

When considering a warehouse, it can be considered that they have clear goals to maximize their own efficiency through maximizing utilization rate of personnel, storage space and turnover rate (Tostar & Karlsson, 2013). Lean principles can be utilized with storage, to gain those benefits (Bartholomew, 2008).

Storages costs can be divided to equity and operating costs. Equity costs comprise of capital tied-up to e.g. infrastructure, material and WIP, while operating costs comprise of operations required to operate storages. **Operating costs can be further broken down as storage, replenishment and stockout costs**. (Sakki, 1994; Haverila et al., 2009.)

According to Waters (2009, p. 341) **replenishment costs form up of ordering and purchasing costs** for storage refilling. Amount of replenishment cost greatly depends on how often replenishment orders need to be made. Higher ordering frequency leads to higher replenishment costs but reducing the frequency leads to increased storage.

Purchasing cost is to be understood as material buying price where transportation costs are added (Karrus, 2003, pp. 234-235).

Ordering costs are costs which are generated while making the order. Ordering costs usually vary based on what is being ordered and order quantity. According to Stock and Lambert (2001, p. 236); Waters (2009) and Russel et al. (2009) Ordering costs comprise of placing the order, following the status of delivery, receiving, and inspecting materials, shelving, other handling costs and costs related to processing.

Stockout cost is a cost which results from the company not being able to fulfil demand or orders from customers. Stockouts can lead to paying late delivery sanctions, reduced customer satisfaction levels and lastly to loss of sales. Loss of sales and loss of profit should be counted (estimated) as part of stockout costs. Challenge comes from estimating how much sales have been or could be lost due to stockouts. (Russel et al., 2009.)

According to Stock and Lambert (2001; 1999); Karhunen et al. (2004, p. 305); Russell and Taylor (2009) **Total carrying cost of inventory** are comprised of all costs associated with carrying the available storage (storage goods).:

- **Costs of storage upkeep (physical storage)** originate from costs of money tied to the inventory and costs related to the space. Space costs include e.g., loan costs, rents, electricity, heating, maintenance, security services and cleaning). (Russell & Taylor, 2009.)
- **Reduced value or loss of value** for stored goods are a result of the risk from goods losing their value or need for the goods ceases to exist (Stock & Lambert, 2001, 1998).
- **Loss of stored goods** is a result of losing the goods and therefore new substitutive goods need to be bought to replace lost goods (Stock & Lambert, 2001; 1998).
- **Legal obligations** are required necessary actions such as insurances, taxes, and bookkeeping (Russell & Taylor, 2009).
- **Handling costs** comprise of personnel costs (salaries), machine costs and tools costs (Karhunen, 2004, p. 305).

2.7.3 Internal transportation

Internal transportations are material flows inside a production facility, warehouse, or shop (Hokkanen et al., 2002, p. 163). Internal transportation is connected to receiving goods, production, and shipment (packaging) activities. Internal transportation is also connected to processes taking place in a facility, by moving goods between different production processes (e.g., moving goods to storage or from storage to a manufacturing station) (Hokkanen et al., 2002, p. 163).

Internal transportation can be further specified into processes of shelving, picking and transports.

- **Shelving** includes handling of already received goods, verifying, and locating correct placement location and placing goods to the location to wait for consumption (Frazelle, 2001, p. 230).
- **Picking** is where required quantity of correct materials or products are gathered either for another process or for distributing (Karrus, 2001, p. 122). This includes

walking to picking place and searching, picking, and preparing goods for the next step (Tompkins et al., 2003).

- **Transport** is moving materials, production lots or products between storage and point of production inside the same organization (Karrus, 2001, p. 122).

According to de Koster et al. (2007), approximately half of total storage costs are personnel costs and that most of personnel costs go to picking.

2.7.4 Packing and preparing for shipping

Packing of products is usually done in the production. Packaging plays an important and critical part throughout a supply chain; packaging is ensuring that products can get to target destination efficiently (Hokkanen et al., 2002, p. 178). Packaging protects from damage and can also enhance marketing; information sharing and reduce transportation costs (Järvi-Kääriäinen et al., 2007, p. 9).

Dispatch department is responsible for preparing loads for shipping, dispatch department can be considered as the function fulfilling the tasks listed later, as smaller companies might not have dedicated dispatch departments. Dispatch department should have enough space so that customer deliveries could be allocated (separated or combined) and grouped appropriately. If this is not possible, functioning of dispatch department will not be efficient. (Karhunen et al., 2004, pp. 382-383.)

According to Karhunen et al. (2003, pp. 382-383) tasks of dispatch department include e.g. the following:

- Preparing dispatch notes and check that they add up with the physical goods
- Allocating customer deliveries
- Sending information of dispatches for transportation ordering
- Indicating deliveries, loading, and monitoring loading of outbound transports

2.7.5 Outbound logistics and reverse logistics

Outbound logistics or distribution logistics is the process where goods are transported to customers or to local distribution centers together with related management and supervision. Therefore, outbound logistics should be evaluated as the whole network required to successfully deliver goods to target destinations. Outbound material flow starts with loading the goods to transport on a loading bay and ends with unloading the goods at destination (according to interfaces with inhouse logistics) (Von Bagh et al., 2000, p. 161).

Reverse logistics is the material flow from customers to suppliers and thus the direction of material flow is reversed compared to usual material flow (Von Bagh et al., 2000, p. 154). It can comprise of customer returns (returning parts, products), returning packages and packaging materials, industrial waste, recycling, and re-use goods (Hokkanen et al., 2002, p. 15). During 2000's reverse logistics has been getting increased attention and its importance has risen together with the increase of recycling across businesses.

Well-organized and well-functioning reverse logistics is said to improve profits and customer satisfaction. On average it is estimated that 3-6% of profits are tied up for the use of reverse logistics (Logistiikan maailma, 2020a). In USA it is estimated that up to 10% of logistics costs can be attributed to reverse logistics. In Finland reverse logistics is one of the most outsourced logistics activities as the amount of work and control required with reverse flow is estimated to be much more burdensome than handling other logistical flows (Logistiikan maailma, 2020a). Means of transportation and routes are usually different from the ones used in supplier's outbound logistics.

2.8 Modes of transport and transport choices

When choosing the way of transportation, there are many factors influencing the choice of transportation type, such as e.g., service quality, transportation costs, delivery time, destination of delivery, way of transports, transportation company, delivery terms and risks associated with the transportation (Gattorna, 1997, p. 317). Chosen transportation method can greatly affect the success of the delivery and costs. Legislation, customs procedures, currencies, and taxation as well as quality of infrastructure and technological level can have an effect for a company doing international business (Gattorma, 1997, p. 317).

Optimal transportation method depends on top of above-mentioned factors, also on size, weight and value of the products being transported and how long the transportation distance is (Mangan et al., 2012, p. 126). Countries involved can also affect or limit mix of transportation methods. Also, availability of transportation services due to e.g., demand or technological level can vary and have an effect on the transportation method mix (Mangan et al., 2012, p. 126).

Delivery time can either give a lot of freedom in choosing the method, to select cheapest option possible, or delivery time can force to pick from more limited options of transportation methods, such as air transport, to get goods to customer in time. Generally, it can be observed that longer distances together with shorter delivery time greatly restricts the options to choose from and increases transportation costs.

Ways of transportation can consist of five different modes, which are in order from fastest to slowest the following: air transport, road transport, railway transport, sea transport and pipe transport. Each transportation method has unique advantages, downsides, limitations and differing cost structure and cost formation mechanisms.

2.8.1 Road transport

Road transport is the most common and widely used means of transportation. Availability, reliability, and ease of use are good, as in practice these can provide e.g., vast competitive tendering possibilities between transport service providers due to high competition, accurate tracking of goods during transportation and the possibility to deliver goods directly from manufacturer to the customer (Mangan et al., 2012, p. 126).

Cost structure for road transports consists mostly of variable costs, such as equipment investments and maintenance, fuel, and personnel costs. Equipment used in road transport are highly standardized and storage space sizes can be found out from transportation companies' websites or from truck and trailer manufacturers. Commonly outer and inner dimensions of trucks and trailers between different manufacturers are very close to be the same, and therefore biggest differences come from to what type of truck and/or trailer type category the equipment in question falls to. Load capacity depends mainly on the number of axles on the equipment used.

This kind of standardization benefits both the transportation service provider and their customers: as transportation companies want to drive as full loads as possible to maximize profits and customers want to deliver goods as much as possible with lowest price possible, they both have interest to use storage space to the fullest. Customers have better possibilities to design their packaging so that maximum amount can be fitted to trailers, with minimized space usage, translating to reduced transportation costs per unit. Transportation company in turn benefits from equipment's higher utilization (filling) rates, as costs (fuel, equipment maintenance, etc.) become smaller relative to the billing.

According to Waters (2007), in practice it is challenging to fill truck/trailer storage so that it is completely full, due to differing packages between customers (e.g., cannot stack with each other), destinations (e.g., only customer delivering to destination x) and returning trips from destinations (e.g., partial or nothing to load on the way back). Even up to 20-40% of total travel is done with empty transports. Therefore, in practice costs from "empty space" being transported on various forms are added into prices paid by customers (Waters, 2007, pp. 273-275).

Therefore, it can be argued that the principles of road transport can offer big cost-savings potential for customers if they are able to increase the standardization and productivity of their packages so that economies of scale could be better employed, in order to create new kind of synergies enabling more lean and cost-efficient operations. To enhance higher capacity utilization rates and to be able to ensure adequate quality (e.g., protection and speed level) in transportation, two different transportation loading options are usually offered for customers by transportation companies: full truckload (FTL) and less than truckload (LTL).

With full truckload (FTL), goods from a certain company are usually delivered directly from loading point to the target destination without extra drops on distribution/transportation terminals. With less than truckload (LTL), goods from multiple companies are loaded to and transported with same trucks or trailers. Typically, FTLs have faster delivery times, smaller risk of product damage, higher costs due to smaller space utilization and potentially faster availability (no need to wait for other companies or certain date) (Rodrigue et al., 2012, p. 91).

FTL is paid for the whole space. LTL pricing is usually based on dimensional weight or loading meters (Waters, 2007). With dimensional weight pricing, the price is formed based either on package weight or package dimensions, according to a certain formula. Method with highest resulting price is used by default, for the benefit of transportation service provider. Usually, it is required that packages need to be stackable to be eligible for this kind of price formulation (Waters, 2007). Usually when packages cannot be stacked, loading meters are used for price formulation. Usually, truckloads could take more goods according to one or more before mentioned criterion even when they are “full”. E.g., light objects can take all the space but only use small portion of weight capacity. Heavy objects might use little space, but they cannot be stacked and therefore are billed according to loading meters. Optimizing before mentioned parameters as close to each other as possible, offers significant cost saving potential and other benefits (Waters, 2007, pp. 277, 281-282, 284).

2.8.2 Rail transport

Rail transport is usually cheaper, but nevertheless slower than road transport with long distances. Rail transport is also more economical and ecological, according to Rodrigue (2012, p. 269) using up to three times less energy than road transport and according to Mäkelä (2009a, b) electric rail transport has also multiple times smaller CO2 emissions than road transport. Though it needs to be considered, that road transport needs to be used to get to railway station at both ends of the transportation process, which creates the need to use road transportation anyway (Sadler, 2007, p. 84).

When loading goods to train, they need to be loosened from the truck, placed, and tightened to train and then at train's end-destination the same needs to be repeated in reverse. This means, depending e.g., on the type and size of transported goods, that lots of extra work is required compared to road transport. Also there arises extra challenges with right timing, as goods need to be available for handling, loading, fastening, unloading etc. at certain time for the rail transport. All these factors combined can lead to rail transport being more expensive than road transport (Sadler, 2007, p. 84). Railway carriages used to transport trucks and containers would take some of the extra work away and in some cases could be an option. In some special cases this method is required when railway transport must be used, and the same truck/machine needs to be used before and after rails (e.g., heavy machinery and military transportation).

2.8.3 Sea transport

Common reason to use sea freight to transport goods are natural limitations due to geography and/or infrastructure available (Rodrigue, 2013, p. 96; Gilbert & Perl, 2010, p. 97). Sea freight is carried on oceans, through shores, along rivers and canals.

Sea freight is the most economical means of transport to deliver large amount of goods over long distances as the capacity is very big (Albaum, 2011, p. 876) and economies of scale bring the costs down with e.g., variable costs being divided between all containers.

Sea freight pricing is not sensitive, unlike air freight, towards fuel price changes as the utilization and operating efficiency are high (Freightos Group, 2020).

Sea freight is the most used way of transport globally and approximately two thirds from all freight is transported via sea (approx. 90 % of international freight). Compared to air freight sea freight has less restrictions, e.g. flammable items such as phones or corrosive items such as batteries are allowed in sea freight. (Freightos Group, 2020.)

Some downsides with sea freight include the slow delivery time and relative inflexibility, as goods need to be provided to and from certain points at a certain time and the delivery cannot be hurried once it is on the way (Rodrigue, 2012, p. 269). Even though sea freight is not very sensitive to changes in fuel prices, big changes can still affect goods deliveries negatively. Freighter companies can reduce the speed of freighters, leading to higher delivery times as well as reduce amount of visited harbors on their path (Rodrigue, 2012, p. 269).

Cargo ships used in sea freights can be divided to two categories based on what kind of routes they perform. First ones are cargo liners, which travel on a pre-scheduled and fixed route with charged tariffs (Marine Insight, 2019a). As cargo liners travel along specified routes, they operate in a way such as trains which helps to ensure full utilization rates. Second ones are tramp ships are vessels which do not follow any kind of pre-determined schedule or route and are instead chartered case by case by various users to transport goods for an agreed fixed contractual price (Marine Insight, 2019a). Generally smaller shipping companies are operating tramp ships as they do not have enough fleet to operate voyager lines.

There are four different main types of cargo ships which can be used either as cargo liners or tramp ships to transport goods. Classification of the cargo ship types are based on the cargo being carried. Four types consist of general cargo vessels, multi-purpose vessels (Ro-Ro), bulk carriers and tankers (Marine Insight, 2019a, 2019b):

- General cargo vessels carry usually various packaged goods such as food, miscellaneous items, machinery, vehicles etc.
- Multi-purpose vessels or Ro-Ro (roll-on/roll off) ships carry wheeled cargo such as trucks, trailers and cars which are loaded and unloaded to the vessel by using vessel's built-in ramps. Ro-ro vessels can further be divided into sub-categories of ferries, cruise ferries, cargo ships and barges. Ro-ro vessels have two distinctive features in general compared to other ship types: cargo does not need to be loaded with a crane, and the cargo (billing) is measured based on lanes in meters (LIMs) units. LIM is calculated based on cargo's length (space usage) by multiplying it with number of decks and lane widths used.
- bulk carriers are designed for carrying loose bulk cargo in dry forms like grain, coal etc. and therefore offers the least flexibility together with tankers.
- Tanker vessels are designed for carrying liquid cargo such as petroleum.

2.8.4 Air transport

Air transport is commonly used in global import and export when goods are needed rapidly and reliably. Air transport is faster, safer, and more reliable way of transporting goods internationally than other modes of transport, but air transport is usually more expensive than any of the other transportation methods. Usually, delivery time is guaranteed. Approximately 10% of international freight is transported via air. Air freight has also the biggest number of restrictions and limitations to account for, compared to other methods. (Karhunen et al., 2004, pp. 115, 290-292.)

Restrictions and safety measures have been tightened all the time since 11.9.2001. There are national and international regulations what need to be accounted for and IATAs Dangerous Goods Regulations (DGR), which is the only standard recognized in the industry (IATA, 2020). E.g., flammable, or corrosive items such as lithium and acid batteries are forbidden in most air freight.

Air freight types can be divided into three main types and further by the equipment used:

- Freight in passenger airplanes
    - Narrow and wide body aircraft
- Freight in dedicated freight planes
    - Narrow and wide body aircraft
- Freight in express &courier freight services
    - Passenger airplanes or freight planes are employed commonly, but also light aircraft or helicopters are employed on some instances.

Most of the air cargo are transported in common passenger airplanes, which have dedicated cargo decks and compartments with space reservations for commercial cargo not related to the passengers travelling on-board. These planes usually have strict limitations for cargo dimensions and weights as passenger airplanes have less space for cargo than dedicated freight planes. Dedicated freight planes are better suited for big cargo deliveries or higher volume deliveries due to bigger capacity.

Cargo is usually pre-packaged into “igloos” which are freight plane type specific pallet net combinations, usually packaged into a shape of cube to maximize space efficiency. Special low-profile pallets are used to minimize total height, and to be able to secure the loads firmly to aircraft’s deck. In some cases, cargo can be placed into containers, which are easier to handle and provide better protection against damage but are more expensive and have more restrictions for what can be placed inside. (Nimsai, 2017.)

Importance of good packaging and how it can be handled and loaded becomes very important with air freight. Non-optimized packages are relatively common practice and main source of profits for cargo for airline companies (More than shipping, 2019).

As an example, plastic pallets can be generalized to weigh about 30-40% less than same sized wooden pallets and have nesting features (Nelson Company, 2018). As a downside, plastic pallets can vary in price from about the same up to three times more expensive than wooden counterparts and weight capacity can be up to two times less. E.g., wooden

Euro pallet weighs around 25 kgs dry, while plastic pallet can weigh only 15 kgs, which can mean air freight difference of 40$ per one pallet. Average air cargo rates typically exceeded 4$/ chargeable kg according to a 2009 World Bank study (World Bank, 2009).

Selection of the packaging material and package construction can have a big effect in costs on most cases, no matter what transportation method. This is especially true with air transport expenses, exporting and customs procedures and also on company’s own internal logistics during manufacturing operations. Suitability of the goods for air freight should be estimated thorough. Also, the necessity and reasonability of air freight in the larger scale should be analyzed, if air freight is being used frequently. As supply chains are streamlined and equity is tried to be freed from factory walls and inventory, air freight offers possibilities to achieve those goals, as air freight offers supporting capabilities (speed, dependability, regularity etc.) (Karhunen et al., 2004, p. 290).

According to Karhunen et al. (2004, p. 290) market size, location, product value and sales volume are factors which determine whether e.g., localized storage, factory or air freight deliveries are more economical option for a company. Further, logistics between company’s own locations, such as factories, require high speed and dependability as JIT (just in time) production raises requirements posed for logistical chains. For example, factories can be focused on producing certain components or spare parts which are required in another factory and storing these parts could be very costly with high-added value items. Or items can be required rarely but when required, they are needed fast. Air freight services can provide efficiency and unique capabilities for example on this kind of challenges.

Products delivered to customers as air cargo are usually urgent, relatively small, and high value goods, which are delivered either with passenger airplanes or cargo airplanes (Karhunen et al., 2004, pp.290-292). For example spare parts, warranty items, electronics, or even perishable groceries. Products with big dimensions and weights can also be delivered as air cargo, if schedule is a critical factor (Karhunen et al., 2004, pp.290-292). For example, different kind of project deliveries could have such critical schedules that fast air freight becomes mandatory.

So called express and courier services have become more and more popular together with higher requirements for delivery speed, time, traceability, and efficiency. Air express (sometimes spoken as courier) refers to courier companies shipping goods “door to door”, from picking up goods from a requested point (e.g. factory in Finland) and taking them to a designated address (e.g. construction site in Brazil). The courier company handles all the associated transportations and supporting tasks such as customs clearance, restricted dangerous foods transport related handling etc. Minimum of two separate road transportations are required together with air freight, usually even more. Therefore, express services bring convenience and reduced organizing burden for a company ordering the service, together with increased speed.

Recently there has also been a lot of initiatives and developments regarding development of drones and UAVs (unmanned aerial vehicles) for cargo transportation. Now regulatory and legal limitations present their own challenges on top of technical challenges for implementing these technologies on wider scale outside intralogistics. Drones are already used e.g. in automobile industry in intralogistics, but there is a strong drive to take the capabilities farther. According to a Morgan Stanley (2019) research, there is potential for 1.5 $ trillion market by 2040 for autonomous aircraft.

Nevertheless, there are multiple startup companies and established actors such as Boeing developing UAVs and drones solely for use in cargo transportation, taking the scope farther from intralogistics. According to some estimates, if successful, UAVs and drones could even halve the costs compared to conventional air freight due to smaller fuel requirements and no flight crew. In urban settings they would be competing against wheeled vehicles with the cost-levels. Weight capacities, range and speed of technical demonstrators are rising fast with the increasing amount of interest in the sector. This would be a disruptive development in the transportation industry and open new level of capabilities for companies and individuals using various transportation services. Especially for companies operating in the B2C market or with time-critical delivery times, smaller drones could turn out to be remarkable due to their delivery speed and accessibility especially on urban areas. Drones wouldn't need to suffer e.g. from traffic jams. E.g., Boeing conducted first outdoor tests in May 2019 successfully with their experimental electric VTOL (vertical takeoff and landing) UAV, which had a load capacity of 227 kgs and estimated range of 80 km (Boeing, 2019). The UAV measured 5,33 m in length, 6,1 m in width and 1,52 meters in height.

2.9 Transportation costs and pricing principles

Total logistical costs of the supply chain form from many parts, e.g. such as transportation costs, handling costs in operations (physical and organizational) and storage costs (Van Goor, 2003, pp. 114-116.). Transportation costs are generated when goods are transported from one place to another. Transportation costs' relative amount of total costs vary greatly depending on the goods or product type being transferred, and the product's own value as well as the physical properties of the product. In general, the bigger and heavier the product, the bigger the transportation costs, but the product itself can have very high value and therefore the proportion of transportation cost can be small. On the other hand, some small and light products can have small sales price but take a lot of space, resulting to transportation costs of up to tens of percents (e.g. furniture and groceries). Volume and recurrence of transportations also affect the costs, the bigger the volume and recurrence, the smaller transportation prices are billed (Van Goor, 2003, pp. 114-116).

Other costs related to transportation can be quality related costs. E.g., a product is damaged in transportation and customer makes a reclamation of the product, demanding discount, repairment or a new product. In the worst-case damaged product is shipped back to manufacturer, scrapped and new replacing product made for free, together with sanctions/or penalties depending on the contract made and a dissatisfied customer. Therefore, it is paramount to assess and consider secondary costs.

Nevertheless, general estimations of transportation cost’s proportion of sales prices are given in academical literature. According to Gattorna (1997, p. 315) transportation costs alone are on average 5-6% of a product’s sales price. On the other hand, Rodrigue (2012, p. 232) places this value even at 5-10% of sales price. According to Van Goor (2003, pp. 114-115) many external factors can influence greatly the amount of transportation costs, such as e.g. inflation and cost of fuels.

3 Packaging and design for logistics (DFL)

3.1 Design for logistics (DFL) and packaging in general

Various design tools exist and are widely used for e.g., manufacturing (DFM), assembly (DFA, DFAA), maintenance (DFS) and quality (DFMEA, PFMEA) to name a few. None of these tools especially address transportation and other functions associated to it, such as packages, packaging, product design's impacts for logistics and storage to name a few.

The concept of DFL (design for logistics) was first created by Stanford University professor Hau Lee in 1993 in a research paper "Design for Supply Chain Management: Concepts and Examples". Lee argued that three main components are economic packaging and transportation, concurrent and parallel processing, and standardization. Packaging plays vital part in throughout a supply chain, all the way from raw materials and components to ready end products (Lee, 1993). Nonetheless, there is no clear established guidelines or instructions for how to implement and use DFL.

Optimized packaging design can lead to more efficient usage of transportation model's loading space (e.g. truck, trailer or aircraft's cargo deck) so that they take less space, they can be stacked and/or weight less (Albaum, 2011, p. 888.). These lead to reduced unit costs and potentially to other benefits such as streamlined and easier to control operations, resulting to increased competitive advantage.

Companies have only recently started to understand the considerable effects packaging can have for logistical costs throughout the supply chain and especially efficiency of freight transportation (Dongmin et al., 2013). In the study it is also pointed out that most companies still nevertheless neglect the importance of packaging, not paying special attention to packaging (especially package design), regardless of their significant impacts to logistical costs and operations. Packages are valuable parts of the entire supply chain and by optimizing them, it is possible to get both direct and indirect benefits throughout supply chain.

Those research findings further strengthen my thesis's original hypothesis and starting point, that with good quality optimized packaging design one can achieve higher effectiveness and cost reductions throughout the whole supply chain, thus resulting to increased competitive advantage compared to competitors, due to the relatively unique manner of an approach. For reference, according to Ritvanen et al. (2011, p. 67) approximately three million tons of packaging are used every year as of 2011 in Finland alone.

3.2 Functions and requirements of packaging

Packaging has many functions, but main purpose is to preserve, protect and enable distribution of the product to target destination. Good packaging is also informative, practical, and optimized from economical point of view. Good packaging enables economical handling, transportation, and storage of goods. (Ritvanen et al., 2011, p. 67.) Good packaging considers vast number of requirements originating from external factors such as laws and regulations, environment and climate, transportation, production, and consumers (Järvi-Kääriäinen & Leppänen-Turkula, 2002, p. 15). Good packaging can lead to enhanced customer experience.

Priority between different functions of packaging vary depending on which part of the supply chain is in question and priorities also vary based on product type, product cost, environment, customer, and modes of transportation. E.g., in B2B marketing via packaging is not as important as with various consumer goods in B2C. Sheet metal parts and electronical components require different levels of protection during transportation.

3.2.1 Protection and preservation

According to Ritvanen et al. (2011, pp. 67-68) package needs to protect the goods from physical, chemical, climatic, and biological stresses, though it is important to note that overpackaging is not good for a company or its customers and causes waste. Protection and preservation features of packaging can also affect safety of the product. Ideally packaging should indicate if it has been opened or handled unauthorized and if goods inside are contaminated or damaged (Järvi-Kääriäinen et al., 2007, p. 11).

Physical stresses include e.g. vibration, compression, impacts, drops and other external stresses having potential to cause damage during transportation, storage or even usage of the goods (Ritvanen et al., 2011, pp. 68-70).

Chemical stresses include e.g. oxygen and sunlight. Chemical stresses mostly impact groceries and other spoiling goods, but also goods which properties may change or degrade due to exposure to chemical stresses over time (e.g. plastics) (Ritvanen et al., 2011, pp. 68-70).

Climatic stresses include e.g. humidity, temperature, air pressure, UV-radiation and corrosion (Ritvanen et al., 2011, pp. 68-70). E.g., sophisticated electronics can be vulnerable to humidity during transportation and storage.

Biological stresses include e.g. bacteria, bugs, smells and mold (Ritvanen et al., 2011, pp. 68-70).

3.2.2 Easy and cost-efficient logistics

Packaging must ensure that goods being carried can be transported throughout the supply chain as required, e.g. from supplier to manufacturer or from manufacturer to end users. Packaging should be cost-efficient to procure and enable optimized, cost-efficient transportation (Ritvanen et al., 2011, pp. 67-68). These can be achieved by e.g. employing different packaging or packaging combinations depending on the products and mode of transportation. Trying to take advantage of a so-called module dimensioning system when possible, can usually enable significant cost savings compared to other custom packaging sizes (Järvi-Kääriäinen et al., 2007, p. 11; Ritvanen et al., 2011, pp.67-68).

Package design and construction should consider the packaging process used for packing the goods into packages. Other related processes need to be considered also, such as e.g. is manual or robotic packing used, because manual or automated storage requires different features (Järvi-Kääriäinen et al., 2007, p. 11). Nevertheless, packaging should provide necessary information required for identification, tracing, and handling throughout its supply chain to enable efficient logistics (Ritvanen et al., 2011, pp. 67-68, 72-73).

Packaging should be portable, easy to open and handle. Taking the goods inside should be easy and practical. Depending on the type of goods, packaging should be resealable and provide enough information about the contents and disposal of the packaging (Järvi-Kääriäinen et al., 2007, p. 11).

3.2.3 Providing information and communication about product

Packages need to have necessary information and markings on them so that supply chain can function correctly and efficiently. Package markings include e.g. markings required by legislation and standards as well as markings required for handling, transporting and recycling of the packaging, while shipment labels include e.g. information about sender, receiver and the goods (Järvi-Kääriäinen et al., 2007, pp. 233-237).

Package markings can include e.g. (Järvi-Kääriäinen et al., 2007, p. 237):

- Handling marks (e.g. orientation, fragile, keep dry, stacking limit, center of gravity)
- Marks required by legislation
- Warning marks
- Weight marks
- Environment and certification marks
- Manufacturer ID, lot etc. information

Shipment label must include according to (Järvi-Kääriäinen et al., 2007, p. 233).:

- Sender's name and address
- Receiver's name and address
- Transportation instructions
- Description of content
- ID/tracking number
- Barcode for handling in logistics

Packages can support marketing by being recognizable and good looking for end users. Packaging can play vital part in enhancing brand image and ensuring originality of the product, as well as give main information about the product and its characteristics and have storage, usage, or maintenance instructions (Järvi-Kääriäinen et al., 2007, p. 11).

3.2.4 Safety and security

Packaging can ensure product safety so that, it is possible for the end user to see already from packaging if goods inside can be damaged. Packaging must also be safe to handle, transport and open. Therefore, it is important to have adequate handling and warning marks so that handling can done with appropriate caution throughout logistics. Packaging and its quality also need to be consistent so that they wouldn't create unexpected dangers from e.g. breaking up or coming loose. (Ritvanen et al., 2011.)

3.2.5 Environment and sustainability

Packaging should minimize number of materials used in the packaging, waste and minimize energy required to make the packaging (Verghese et al., 2012, p. 70). Packaging should aim to enable packaging's reuse, recycling, or utilization as energy after use (Järvi-Kääriäinen et al., 2007, p. 12; Ritvanen et al, 2011, pp. 67-68).

Under- or overpackaging has an effect both on sustainability and cost-efficiency of the packaging. Overpackaging creates unnecessary waste, especially if done with non-green packaging such as PE plastics or Styrofoam and energy used is from fossil fuel sources (Ritvanen et al., 2011, pp. 74-75).

On the other hand, according to Hellström and Olsson (2016, pp. 23-24) underpackaging causes even more waste and negative environmental impacts if it results to product damage during transportation, requiring new replacement products to be sent together with new packaging. According to them, as products create more environmental waste than their packaging when whole lifecycle is considered, negative effects from underpackaging can be, and usually are, multiple times more severe than effects from overpackaging. It is important yet challenging to find good balance between these.

Generally, when designing packaging, attention should be given to the following environmental points (Ritvanen et al., 2011, p. 75).:

- Packaging is made and tested according to standards
- Alternative materials have been evaluated
- Resulting waste has been minimized
- Reuse possibilities of the packaging

3.3 Packaging materials

Packaging materials used in packaging differ based on usage. Most common packaging materials are fiber-based papers, carton, corrugated cardboards and molded pulp, wood, plastic, metal, and glass.

Fiber-based materials form essential and increasingly popular material in packaging. Fibers can be further divided into wood-based and non-wood types (Järvi-Kääriäinen et al., 2007, pp. 128-129). Main characteristics are renewability and recyclability.

Paper is commonly used in packaging to enable e.g. prints and other markings. It has also strong cutting length compared to plastic and it can also be easily formed, paper can usually withstand surprisingly well common sharp edges encountered during transportation processes (Järvi-Kääriäinen et al., 2007, p. 138). Usually, paper is used as protective wrapping or combined with other materials in wrappings, bags, and labels.

Carton is manufactured from multiple fiber layers which distinguishes it from paper together with higher area (m2) density (Järvi-Kääriäinen et al., 2007, pp. 142-143). One of the most common packaging made from carton are various carton boxes and containers used in consumer packaging and folding cartons. By using different carton types and combinations it is possible to achieve different qualities for the packaging as required, such as. improved stiffness, resilience, moisture resistance, or automation readiness (Järvi-Kääriäinen et al., 2007, pp. 142-144).

Corrugated cardboard can have one or more fluted corrugated inner mediums (flutes) and two or more sheets of paper (liners). By altering the type, height, amount and combination of flutes, liners, and types of walls together, customized properties and features can be achieved (The European Federation of Corrugated Board Manufacturers FEFCO, 2021). According to FEFCO, possibilities are further expanded by altering the material, its treatment and surface treatments used.

Corrugated cardboard is the most common packaging material in the world and is used the most in distribution packaging in the form of sheets, sleeves, lids, trays, containers, and boxes (Järvi-Kääriäinen et al., 2007, pp. 150-151). Cardboard is also used as further customized consumer packaging, product display and presentation stands etc.

Molded pulp or molded fiber is a comprehensive term describing the process used to make strong and environmentally friendly material from recycled fiber materials. Usually, molded pulp is made from recycled paper, newspaper, carton or cardboard and molded pulp is renewable and biodegradable material (International Molded Fiber Association IMFA, 2020). Common applications include customized protective packaging, dampeners and trays e.g. for eggs, vehicle parts and electronics.

Molded pulp can act as an alternative option especially for widely used polystyrene (EPS), as it is biodegradable and therefore disposing costs are smaller and packaging is exempt from polystyrene packaging penalties used in some countries. As pulp is biodegradable, highly customizable and materials used are cheap, it offers innovative possibilities for packaging and presentation of goods in a cost-effective way (International Molded Fiber Association, 2020). Compared to corrugated cardboard packaging it can offer benefits by e.g. reducing amount of work and by offering better dampening.

Wood is durable and firm material and therefore commonly used to make e.g. boxes, cages, pallets and supporting structures. Wood is easy to modify. Wooden pallets can easily achieve over 1000 kg load capacities and therefore packaging structures made from wood enable making flexible and customizable packaging for especially heavy and more demanding goods (Järvi-Kääriäinen et al., 2007, pp. 69-70).

When exporting it is important to note that International Standards for Phytosanitary Measures No. 15 (ISPM 15) requires all wooden materials with over 6 mm thickness to be specially treated to prevent spreading of harmful insects and diseases, which can be present in wood (Transport Information Service, 2020). ISPM 15 standard's requirements do not apply to packaging material used only inside EU, except when exporting to Portugal. Exempted from ISPM 15 are pallets made from alternative materials such as e.g. plywood, press wood, plastic and metals (Fedex, 2020). Non-compliance to ISPM15 when exporting can lead to quarantine of the cargo and extra work or in extreme cases disposal of the cargo (Fedex, 2020).

Plastic enables usage of varying combination structures in package design. By using varying plastic qualities and quantities, numerous different properties can be given and combined for a package. Likewise structures as made with plastic are unachievable with any other material, as it is not technically possible (Järvi-Kääriäinen et al., 2007, pp. 85-95). Therefore, using plastics in various package designs have and continue to offer unique benefits and options for package designs. It should be noted that as environmental concerns and related expenses rise, pressure to find and adopt alternative greener packaging solutions are constantly on the rise. Price of oil has the biggest effect on cost of fossil-based plastics and therefore can either speed up or slow down emergence of competing renewable solutions for plastic packaging (Järvi-Kääriäinen et al., 2007, pp. 85-95).

Less harmful plastics made from renewable materials such as e.g. corn or potato have started to emerge in the industry and are called biodegradable plastics. Nevertheless, biodegradable plastic market share is only under 1% of total plastics productions as of 2018 and production of fossil-based plastics are still growing much faster in tons (Bioplastics MAGAZINE, 2020). Production of biodegradable plastics have only started to accelerate in recent years as of 2020.

Narancic et al. (2018) consider biodegradable plastics to include plastic qualities such as Polylactic acid PLA, thermoplastic starch TPS and Polycaprolactone PCL to name a few, though these plastics have limited properties of being biodegradable. They note, that in industrial facility with well-regulated conditions these plastics can be composted according to European standard EN13432 requirements if kept in industrial conditions (e.g. 50C heat), but in practice packaging do not often end to such specialized facilities. In a study commissioned by European Union an 80/20 mix of PLA-PCL blend was the only exception and evaluated to be as degradable as plant fibers after 12 months in normal "home conditions" (Narancic et al., 2018).

Metal materials used to make packaging include e.g. coated and non-coated steel and aluminum plates. Metal packages are mostly used in cans, canisters, and barrels in paint-, chemicals and food industry to preserve and transport goods. Benefits of using metal packages are superior defensive properties against e.g., light, moisture, gasses, and ability to prevent foreign substances getting in or out of packaging (Järvi-Kääriäinen et al., 2007, p. 78). They note that metal can be recycled without losing its quality properties.

3.4 The three levels of packaging

Packaging units can be divided hierarchically to three levels based on their roles (Järvi-Kääriäinen et al., 2007, p. 10):

- **Primary packaging (closest to product)**
  - Consumption unit
  - Sales unit
- **Secondary packaging (combines primary packages together)**
  - Delivery unit/multi-pack
  - Order preparation units
- **Tertiary packaging (combines secondary packages into a easy to move unit)**
  - unit loads
  - transport packages

It should be noted that not all products and shipments use all three levels of packaging and therefore in many cases one packaging level provides also functions of other levels.

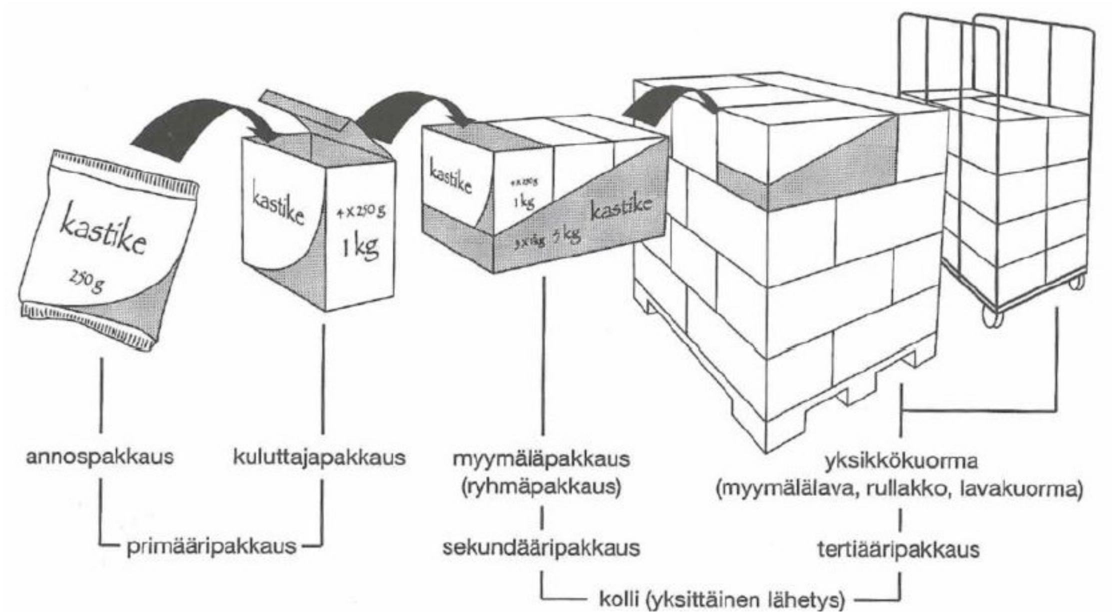


Figure 2. Packaging types and order in grocery packaging according to Järvi-Kääriäinen et al. (2007, p. 10). Note the module dimensioning system.

All three levels of packaging can most often and easiest be found and recognized with consumer and grocery products.

- **Primary units comprise of sales units and consumption units**, which are tasked with containing, protecting, and marketing or informing about the individual product until consumption. Sometimes also just called product packaging in the case of small packages (e.g. a candy bag with paper-wrapped candies inside).
- **Secondary packages comprise of delivery units**, which bundle primary packages together making moving and storing easier as well as assists in marketing and information (e.g. 10 candy bags in a tray on a shop shelf).
- **Tertiary packages are various unit loads** which main task is to protect and help transport the goods efficiently and intact to target destination with good handling characteristics. Unit load is a basic transport and storage unit which is formed as a modular support construct or in packaging such as e.g. pallets, containers, crates or dollies.

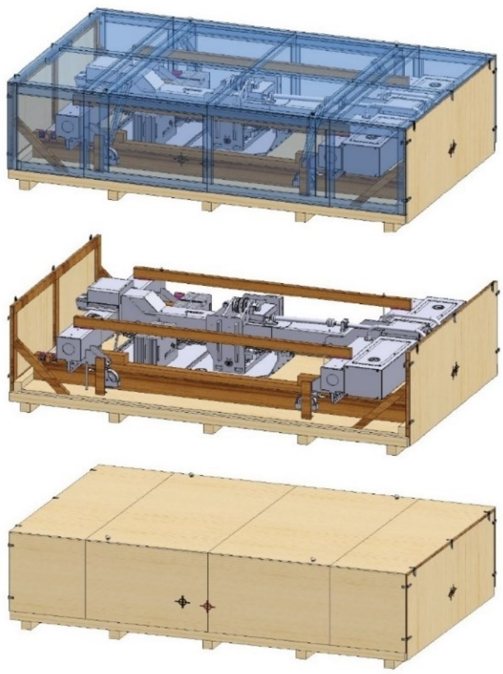
Transport packages are used for shipping, storage, and handling of product units. Transport packages are tertiary packages, but in practice they can also be the only packaging used, also serving the function of secondary and primary packaging (Järvi-Kääriäinen et al., 2007, p. 69).

Unit load is a goods lot placed and tied together, so that handling is efficient (Karhunen et al., 2004, p. 308). They can be fastened together e.g., by bundling, tying, or strapping with plastic film or plastic wraps. Basic principle behind the unit load concept is that it is quicker and more economical to move as much items as possible at the same instead of having to move them individually (Järvi-Kääriäinen et al., 2007, p. 69).

3.5 Crates, boxes, and pallet boxes containers

Crates are usually large protective containers which have a self-supporting frame structure, and they are used as transport packaging. Crates are commonly assembled from separate pieces “on site”. Crate can be open or completely enclosed. Crates are often used for transporting larger, heavy, or sensitive items which need high level of protection. Crates are usually made of wood or plywood and may have corrugated cardboard components.

- Advantages of crates are high durability and protection, simple and easy manufacturing process, which make potential supplier base big and even enables local or on-site manufacturing. Wood and plywood have good weather resistances.
- Disadvantages are that a lot of wooden material is required, purchasing price can be high. Packaging also takes relatively long, requires tools and other assistance.



Picture 1. Custom crate used as transport packaging in export business (Modpack, 2021).

Boxes are usually enclosed containers, but they can also be open containers. Usually, containers smaller than crate are referred as boxes and boxes are preassembled at least partially. Boxes are usually made from corrugated cardboard, plywood, wood, or plastic.

- Advantages of cardboard boxes are small purchasing price, fast assembly, wide selection and availability of packaging and inserts, small weight, versatility and possibility of different constructs and good printability.

- Disadvantages of cardboard boxes are low weather resistance, unsuitability for very heavy items, continuing need/one time usage.

Pallet boxes or bulk boxes are usually large, corrugated boxes attached to wooden or corrugated pallets. Wooden, plywood and plastic versions are also common. Usually, pallet boxes are used to ship bulk quantities of loose goods and they have four separate parts: pallet, tray, sleeve forming the walls and a lid. Parts are strapped together to keep them in place.

- Advantages compared to wooden boxes and crates can include lower cost of materials, lower storage costs as cardboards can be folded when not used, lower transport costs with smaller packaging, lighter packaging, and easy handling.
- Disadvantages compared to wooden boxes and crates include e.g. usually lower durability from transportation stresses and lower preservation features.

Picture 2. Pallet box construction manufactured by DS Smith (DS Smith, 2020).

3.6 Pallets

Most common transport platforms used in transport packaging are various wooden pallets, which enable machine-assisted handling of goods on every logistics step (Järvi-Kääriäinen et al., 2007, p. 69). Pallets can be combined with various attachments and accessories such as collars, walls, lids, and other constructs to form final transport packaging. Pallets also vary by handling characteristics into two-way or four-way pallets. Two-way pallets can be handled from two sides and four-way pallets from all four sides (Järvi-Kääriäinen et al., 2007, p. 69).

There are two main types of pallets:

- **Standard pallets**, which are returnable, reusable and usually kept in circulation for a long time between different companies. Standardized pallets are sturdy and compatible with various means of transport and other equipment throughout the logistical chains. Standard pallets are widely available and can be bought, rented or there can be a pallet exchange system.
- **Single use or customized pallets** are non-standard and are often custom-tailored for customer's needs. Even though they are not standard they can and often are compliant with international regulations. Usually they are used once, one way. This type of pallets is used widely especially in export business.

Standardized pallets are of constant quality, safe, verified and their dimensions are according to specified standard used with the pallet in question (Logistiikan maailma, 2020b). Manufacturing and repairing standard pallets require an official certification from companies doing it. As a result of standardized pallets and their dimensions, transportation and storage equipment dimensioning is also based on them, to ensure optimal functioning and compatibility in logistics.

Cost-effectiveness of standardized pallets is based on pallet exchange systems ensuring long lifecycle, resulting to low costs per use compared to single use pallets which are usually disposed after use. Usually, customer returns same number of pallets to supplier as they have gotten from the supplier. Standardized pallets are compatible with all common transportation equipment. Other benefits of using standardized pallets include ready and widely available selection of accessories such as e.g. pallet collars, collars with hatches, stacking corners, dividers, pallet distance spacers, lids, frames and document holders to name a few.

Picture 3. Two standard Euro pallets with collar, divider, distancer, document holder and stacking corner accessories (Billington Group, 2020).

There are a lot of different pallet sizes and standards used and pallet type used in practice varies greatly based on the geographical area: e.g. North America, EU, Asia or Australia. The International Organization for Standardization (ISO, 2020) defines six pallet area dimensions in "ISO Standard 6780:2003: Flat pallets for intercontinental materials handling — Principal dimensions and tolerances", which was published in 2003 and has been reviewed and confirmed lately in 2020. Pallets are sorted by floor space usage in standard containers (ISO intermodal container) in ascending order.

Six pallet sizes belonging to ISO Standard 6780:2003		
Dimensions (width x length) mm	**Wasted floorspace in ISO intermodal container (full container)**	**Region most used in**
1016x1219	3,70 %	North America
1000x1200	6,70 %	Europe and Asia
1165x1165	8,10 %	Australia
1067x1067	11,50 %	North America, Europe, and Asia
1100x1100	14 %	Asia
800x1200	15,20 %	Europe

Table 2. ISO pallet dimensions with floorspace usage in ISO containers and region where mostly used.

Most pallets used in Europe are based on European pallet associations EPAL pallet dimensioning, of which EPAL 1 and EPAL 2 also belong to ISO 6780 pallets standard. In Finland Euro pallets (EPAL 1), Half Euro (EPAL 6) and FIN-pallets are most common pallet types used. Euro pallets are optimized for logistics in Europe and to fit from normal doorways, therefore they are not the best option for standard ISO intermodal containers.

Many companies need to use single use pallets instead of standardized ones due to e.g. product dimensions which do not fit well together with standard pallets, too high costs for pallet exchange and return arrangements (e.g. from abroad) or lack of such systems. Single use pallets are often used in export packaging.

Picture 4. Example of custom plywood pallet (Eglet EU, 2020).

From terminology point of view all non-standard pallets are called single use pallets which could lead to misleading conceptions. Single use pallets usually are customized pallets with differing outside dimensions and features from standard pallets and tailored according to specific customer requirements. Often singe use pallets are of higher quality and have better features compared to standard pallets but are also more expensive. Therefore, it would be possible to use them multiple times from quality and construction point of view.

In some cases, single use pallets can have corresponding outer dimensions with standard pallets, but have e.g. less sturdy structure with lower load ratings or non-compliance to

ISPM15 with the aim to make pallet price smaller and/or reduce weight, while still keeping other benefits from standard dimensions.

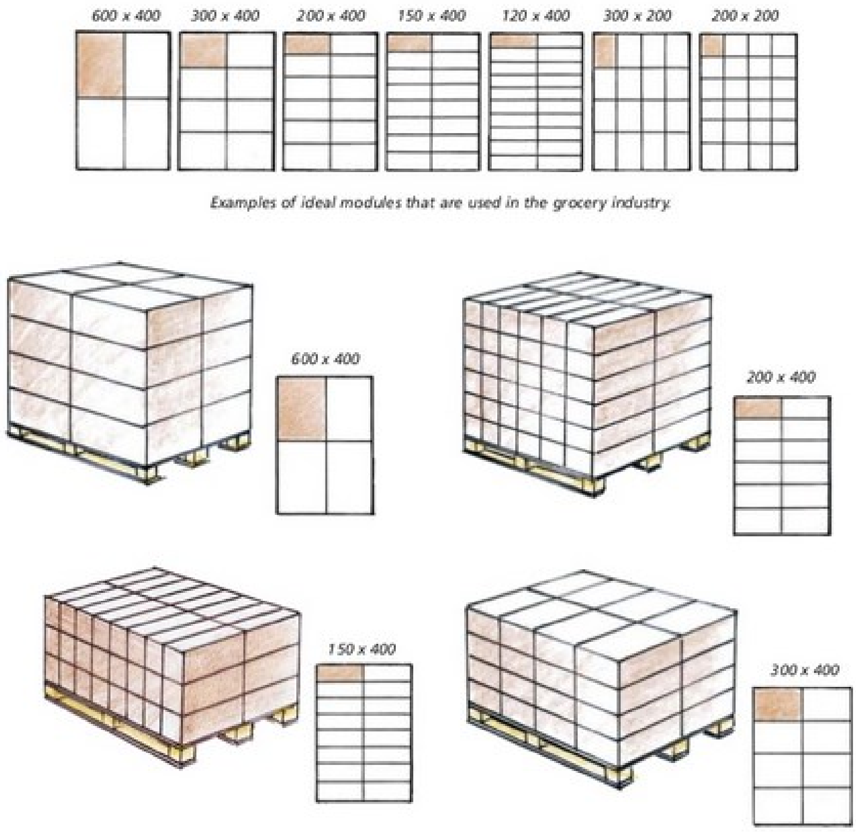
3.7 Modular dimensioning system for efficient and economical logistics

Modular system for package sizes was originally designed based on the needs of grocery industry to enable efficient flow of goods through whole logistics chain by effective utilization of production, warehouse and transportation equipment and resources (ECR Europe, 2012).

The modular system is based on the principle of standardized, compatible area modules where main area module is 600x400 mm. Standardization's main goal is to substantially enhance and optimize logistics by minimizing waste space during transportation and to also enable efficient warehouse and production logistics and creating better opportunities for adding automation to related systems (ECR Europe, 2008; Järvi-Kääriäinen et al., 2007). Reduced number of variations (i.e. package sizes used) together with higher volumes increase efficiency and create new opportunities (Järvi-Kääriäinen et al., 2007, pp. 20-22, 26; Ritvanen et al., 2011).

The system has been standardized by INSTA (a group of certification bodies with common Nordics wide standards) and SFS (The Finnish Standards Association). 600x400 mm module is also used at least in Germany as a standard. Module sizes and other related instructions are mentioned e.g. in SFS 5352 standard (SFS, 2000). Standards are recommendations and non-binding (Järvi-Kääriäinen et al., 2007).

System's basic area module with external dimensions of 600x400 mm, forms the ideal area module with various standardized Euro/EPAL pallets, trolleys, roll cages, dollies, and shelves. Other ideal area modules can be formed by multiplication or division of the basic area module, which acts as a baseline. Package sizes are recommended to be slightly smaller than the ideal area module so that they can fit into transport package (e.g. four boxes on a pallet) (ECR Finland, 2008). Modules can be fitted onto standardized pallets, roll cages etc. to form stable loads with minimal waste. It is also possible to combine different sized area modules on same pallets with relative ease at the same time (Järvi-Kääriäinen et al. 2007, Ritvanen et al., 2011).



Picture 5. Example of standard area module sizes with modules placed on standard 1200x800 Euro pallets (ECR Europe, 2008, p. 18).

It is important to understand that these principles and dimensions offer only a general guideline for optimization, as unit load dimensions and standards can vary between geographical areas and how widely other adjacent companies are using them, truck inner dimensions can slightly vary based on company and industry etc. Some products will simply not fit into module dimensions. Nevertheless, these principles can and should be used and adapted whenever possible. One can also try to adapt the principle with differing dimensions but keeping the philosophy to aim for corresponding benefits.

3.8 Costs of packaging

According to According to Dongmin et al. (2013) companies should use standard boxes, crates etc. which are loaded to standard transportation pallets so that the pallets are filled as full as possible. It is also said that using pallets in transportation brings the biggest efficiencies in transportation. However, in many cases it is not possibly to use standard boxes or pallets, and on some cases even if they could be used, they would not be the best choices. Nevertheless, findings from before mentioned research can be considered as a good general guidance and starting point. Consolidation and standardization of packaging types used inside one's company should always be aimed to be standardized, even if they are not universally standard. Packaging affects all main logistics cost types (e.g., transport, warehousing, and administration), and therefore it is a clear, but somewhat hidden, cost driver. It affects also various processes throughout supply chain.

4 Methodology and case

4.1 Case Danfoss Drives

Danfoss Drives is part of Danfoss, a global company with nearly 28 000 employees worldwide (Danfoss, 2020). Danfoss Group has four different business segments: Power Solutions, Cooling, Drives and Heating. Danfoss Drives was formed in 1968 and in 2019 Danfoss Drives had a turnover of 1.45 Billion euros or 23% of Danfoss Group's net sales (Danfoss, 2020; Danfoss, 2021a). Danfoss Drives is one of the largest companies in the industry and has 11 factories in 7 countries with nearly 5000 employees.

Danfoss Drives is 100% focused on developing, manufacturing, and supplying AC drives and related services with the focus on creating innovative technologies which tackle climate change, helps cope with rapid urbanization and bridges the gaps between energy creation and consumption (Danfoss, 2021b). AC Drives made by Danfoss Drives maximize process performance, save energy, and minimize emissions. Company has estimated that in 2025 approximately 50% (5 billion) of estimated world population will directly or indirectly benefit in their daily lives from benefits brought by Danfoss Drives products.

Company places very heavy focus on R&D, innovation, and continuous improvement both with its products and operations in order to be the Drives market leader. Company provides Life Cycle Services, low voltage drives, decentral drives, system modules, enclosed drives, harmonic mitigation filters, motion control and servo drives, medium voltage drives, gear motors and soft starters (Danfoss, 2021c).

Picture 6. Examples of Danfoss low voltage drive products (Danfoss, 2021c).

In 2014 Danfoss Drives bought Finnish competitor Vacon Plc and the two companies were merged. Nowadays in Finland there are around 800 employees and three sites: factory and headquarters in Vaasa, with offices in Tampere and Vantaa. Vaasa site produces various Vacon branded drives.

This thesis and related research are done related to ongoing new product development and implementation projects of new-generation AC drives, which are related to Danfoss Vaasa factory. Projects comprise of different product families with tens of products and product variants. Projects are largest in company’s history but cannot be discussed more in detail due to confidentiality and as they are considered as trade secrets.

Thesis is especially related to improving logistics and supply chain performance by improving product packaging, production logistics, production packaging process and technologies as well as inbound and outbound transportation of all related material flows. Therefore, there is significant relation for existing production processes and most likely outputs which can be utilized on a wider scale, even though research is now done as part of the NPD & NPI project.

4.2 Research methodology

Empirical study is carried out as case study research utilizing inductive case study framework, action research and mixed methods. Both deductive and inductive reasoning are used. Theories have been employed and tested in practice, but also new case related theory has been made from ground up based on data, experimentation, observation, and analyses. 3D-modeling is also utilized extensively. Case study was carried out according to inductive case study framework described in Kathleen M. Eisenhardt's (1989) research paper "Building Theories from Case Study Research". According to Eisenhardt (1989) case study research method was used when phenomenon and context do not have exact boundaries and is especially suitable when focus is on contemporary phenomenon with real-life context.

Action research is a process aiming for a transformative change through active involvement and intervention. In action research there are four steps of (re)planning, action, observation, and reflection following each other in a cyclic process, which can and often is repeated several times, forming up the overall action research spiral (Coghlan & Brannick, 2007). It is important to note that the research process is not necessarily linear. Most often action research is done in the organizations to improve performance and/or quality of the organization in question (Coghlan & Brannick, 2007, Routio, 2007).

It is typical that in the beginning of action research problems and questions might not be clear. Often during the development processes, new side problems or side questions appear, generating new separate research cycle "spirals" and possibly a change of direction for the research (Routio, 2007). Action research method can be considered as continuous improvement and systematic learning process, where researcher is actively participating in change processes by solving practical problems, collecting data, and working in the case organization during the research (Coghlan & Brannick, 2007). Often there is a group of participants or teams taking part and relevance is guaranteed because the focus of research is determined by researchers, who are also primary consumers of the findings (Coghlan & Brannick, 2007).

3D-modeling is also used in the research, which is maybe not so traditional method in scientific research, but it's widely utilized in various industrial companies (e.g. in machine and equipment design). Benefits and possibilities of 3D-modeling include among others: easy creation and testing of alternative design choices (e.g. concepting and experimentation), partial verification of designs (e.g. technical feasibility and dimensioning), reducing amount of prototypes, supporting and visualizing of ideation, and getting better understanding of phenomenon in general. 3D-modeling can also reduce development time and costs due to smaller need of physical prototyping and testing, though they are still needed. In general 3D-modeling enables rapid creation and innovation of new designs.

Data and analysis of the data used in this study are seen in the appendix 1. Almost all the data is confidential and unpublished material consisting of different kind of notes, documentation, manufacturing drawings and 3D-models concerning development process, workshops, meetings, results as well as financial numerical data.

General goal in the case study research is to create new practical applications improving overall supply chain functioning via enhanced logistics and production processes as well as reduced cost levels. New capabilities will be created for upcoming products from new product development and implementation projects.

Into the overall design process of new package and packaging concept took part in some form all the personnel listed in references section. Bi-weekly/monthly, design- and internal design approval meetings have been held in 2018-2020 with usual participants being me, one or two external packaging consultants, Logistics Engineer, SC Project Manager and in a changing fashion R&D lead designers, Mechanical Engineers, Product

Managers, and personnel from other professional fields as required. Meetings have been occasional throughout 2020 and 2021 among other things due to Covid-19 pandemics.

During prototyping rounds, where most of workshops, practical and in-house laboratory testing took place, participants differed a lot based on the needs. In total all the personnel listed in the references took part at some point and in some form. Nevertheless, basically in every bigger event present was at least me, some SC project manager and external packaging specialist. Usually, present were also logistics engineer and at least one person from R&D. In workshops there were usually significantly more participants as required and depending on the projects in question, e.g.: R&D Project Manager, lead designer, few mechanical engineers, product manager and serviceability manager.

Packaging design and overall packaging area with related processes and technologies were developed simultaneously and in parallel with each other due to various synergies and interdependencies between each other. New process times were evaluated by replicating designed equipment and movements in real-life and recording those times (e.g. moving and handling package materials). Feasibility and process times was also evaluated based on equipment supplier materials, corresponding videos in open sources (e.g. YouTube videos with likewise applications) as well as discussions with prospective equipment manufacturers/integrators.

5 Current state analysis of outbound packages and packaging process

To get a benchmark for improvements, analysis needs to be made for current benchmark product families packaging related issues. Current state analysis is made regarding package constructions, packaging area layout and storage, packaging processes, inbound and outbound logistical processes taking place in and out of the factory. Also, projects' products, general requirements and future goals will be evaluated. Production related current state results are mainly gathered by making practical tests and observations as well as making logical deductions based on the findings and comparing to theory. Package construction, external logistics and product information related current state analyses are made by employing wide range of research methods explained in detail in the research methodology chapter and table appendix.

Current state analysis is done especially bearing in mind the 8 wastes of lean (motion, inventory, waiting, defects, overproduction, transportation, over quality) and evaluating against the context of primary and secondary packaging functions (presented and discussed in detail in theory sections 3-3.8). Evaluation will also be done regards to packaging related three main components according to Hau Lee's (1993) original DFL principles and the "ground level" critical features which I estimated to be critical drivers for achieving main components. Optimally, we should be able to find wastes, bottlenecks and interdependence relationships which can be altered with package design, in order to facilitate implementation of new supply chain processes and production technologies.

5.1 Strategical and tactical framework: identifying critical success factors for achieving targets

A high-level framework and critical drivers need to be established to provide clear high-level vision and requirements for the new designs to be made, and therefore context for the current state analysis. Creation of new package and packaging process designs will be based on these features and current state findings. In short, general vision is to develop an overall packaging concept, which will provide superior total cost, delivery time, streamlined processes throughout supply chain from material suppliers all the way to end-customers, while facilitating creation of less labor-intensive packaging processes inside Danfoss factory, with increased ergonomics.

In practice work towards the mentioned vision starts with the DFL acting as framework for our new packaging development. DFL philosophy's three main components are:

1. economic packaging and transportation
2. concurrent and parallel processing
3. standardization

These must be translated and transformed into real-life features, which will be the actual "ground-level" drivers for the DFL main level components, Lean will also be used to further enhance the drivers. Therefore, practical level features crucial for fulfilling main components and Lean principles must be identified and defined. By combining higher level main goals first mentioned, DFL framework, understanding of logistical process and general cost structure, we can descend to grassroots level and identify main cost and/or waste drivers in each process phase of overall logistical process. This is critical in delivering the wanted outcomes in each phase of the supply chain. To help getting more clear view about those critical features and the current "bottlenecks", a current state analysis needs to be done.

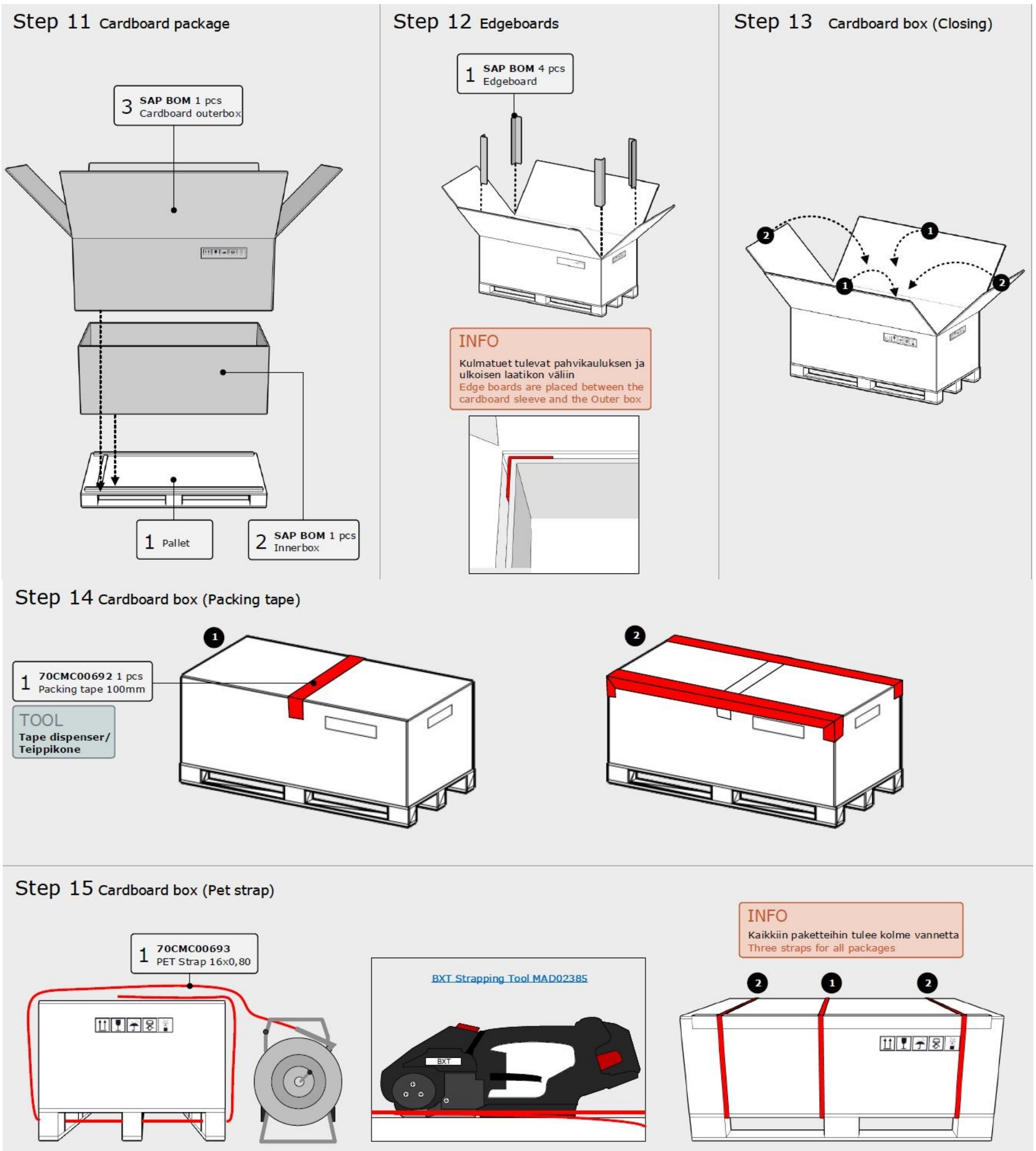
Based on the breakdown of DFL and Lean theories and adapting them to Danfoss production strategy, we can identify packaging related critical features, which are relevant in our case projects and should greatly contribute towards the three main DFL components. Therefore, those features present critical success factors for the overall concept. I argue that critical features driving main DFL components are at least the following:

1. Package construction which enables and facilitates concurrent and parallel processing (e.g. possible to handle and transfer many units at the same time)
2. Removal of package variations (complexity and space need removal)
3. Standardization of ways of handling, packaging process and package sizes (increased possibility for automatization or other technology assisted improvements due to reduced complexity and variables)
4. Stacking of packaging (improved space utilization and space density)
5. Aim to use module dimensioning system (standardizing – higher chance of benefiting via using dimensions/dimensional coefficients which are optimized in bulk industry such as food industry).
6. Form factor/space usage of the packaging both when unassembled in storage and when used in transportation as a transport package (minimized costs per individual unit)
7. Empty space inside packaging (minimized costs per individual unit)
8. Fastening of products inside/into packaging (Transportation safety, minimized transportation damage, affects packaging process)
9. Fastening of packaging materials to each other (Transportation safety, minimized transportation damage, affects packaging process)
10. Minimization of total weight (Minimized costs)
11. So far mentioned features driving standardization, economical packaging and concurrent parallel processing also facilitate better chances for achieving relative economies of scale, due to more concentrated logistical streams

5.2 Current package construction

There are five sizes of pallets and cardboard set for the benchmark box pallet packages, but they all use the same basic construction which is clarified below:

- Pallet and corrugated cardboard construction with three separate pieces: inner sleeve, outer sleeve with flaps, and corner boards (picture 7, steps 11-13).
- Ready box is taped, then pallet and cardboards are strapped together (picture 7, steps 14-15).



Picture 7. Current package construction in work instructions (MAD0107; MAD01459).

5.2.1 Package construction improvement potential based on packaging basic functions

Identified improvements related to packaging basic functions are additional, supplementary improvement points compared to the heavily production oriented current state analysis, where Lean theory is employed. Here the identified improvement needs address more external supply chain viewpoint and improvement potential due to different emphasis (DFL vs. Lean). Nevertheless, packaging basic functions improve supply chain operations throughout, with partial overlap of internal Lean-based analysis points. Main identified improvement points are:

- Simplified, improved assembly process of transport packaging (reducing complexity of process and worktime and facilitating new technology introduction)
- Facilitating improved ergonomics during packaging process (assembly times)
- Increased package construction durability (transportation damages)
- Providing information more clearly for correct and efficient handling throughout supply chain (mainly handling and loading related)
- Improved communication about products for end-users (before opening)
- ease of opening and reclosing the packaging
- Increased environmental friendliness (material types and amounts used)

5.3 Waste in inbound transportation and production/packaging process

Waste in inbound materials delivery (vertical orientation and setting of materials): inbound transportation pipeline cardboard unit loads cannot be stacked (picture 8) and therefore roughly only half of a truck’s height-wise space is utilized, meaning that the extra space is waste and billed anyway by the transportation company, significantly increasing transportation cost.

Picture 8. Inbound transport package of inbound packaging materials.

5.3.1 Waste in production storage

Waste exists on the production storage as physical dimensions and construction of the transportation packages for packaging materials restrict the ways how they can be fitted into production areas, shelves, and how they can be used from packaging process point of view (picture 9). This leads to higher area space need on the shopfloor and therefore significantly restricts the possibility to introduce variations in package heights (reducing transportation costs), as there would not be space to store materials. Also, number of materials available for operators to use for packaging is limited, as only materials placed onto floor level can be used due to ergonomics. Materials are big and heavy, therefore only one set of stored cardboards can be conveniently used from a shelf, therefore storage spaces above can be used only for storage space and cannot be utilized during packing as material usage places, resulting to worse storage density (picture 9).

Picture 9. Packaging materials in current delivery form in production and storage.

5.3.2 Waste in packaging area

Packaging area is not very compact, as products need to be transferred and put temporarily “waiting” on the area on top of transfer carts, waiting to be packed. Transfer carts are required to transfer products from assembly line. Packaging cell cannot be in-line with assembly line, due to layout space needs and long cycle times, resulting to long transport distances (figure 3). There needs to be free area to roam in the packaging cell due to mentioned limitations, big sizes of packaging materials, and many packaging variants, further adding storage space needs and access areas required to materials (picture 9; figure 3). Total walking distance for a product's packing phase is 668 meters.

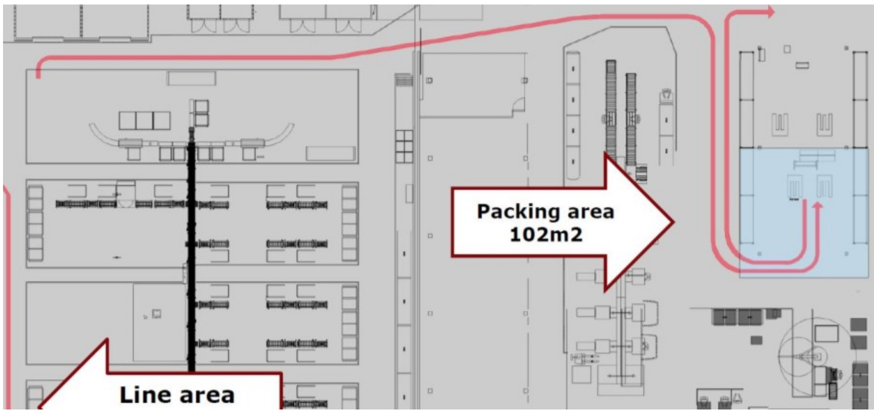


Figure 3. Benchmark packaging cell in blue and packaging related product material flows in red. Snapshot from Danfoss productivity improvement program (2017).

5.3.3 Waste in packaging process

Packaging process has waste and inefficiencies in many forms, below are some of the main observations:

1. Lifts, different lifting aids and changing of lifting aids are required to handle different product variations. Products are lifted from transfer carts to pallets. These are changeover wastes (consider single-minute exchange of die, SMED).
2. Packaging materials are in general big and heavy (especially pallets), and require two persons, forklifts, and other assisting equipment to handle (extra-processing).
3. Unergonomic and slow handling of outer sleeves due to big size and weight, which leads to a situation where two persons are required to handle sleeves together, to make handling fast and convenient enough.
4. Many different pallets and cardboard sizes need to be handled but all of them cannot be kept in usage places due to storage space limitations. This leads to increased movement and handling (waiting, motion and transportation waste).
5. Packaging materials are big and require a lot of space, therefore increasing size of packaging area in general. Storage space required by materials and area required by handling and packing is one of the reasons why packaging needs to

be done in separate packaging cells and cannot be placed at the end of product assembly lines as “in-line”, there is no space for it. This leads to increased waiting and transportation times for products between assembly lines and packaging cell.

6. Some packaging materials are used in more than one packaging cell, but products still cannot be packed in the same area due to too long takt times/not efficient enough packaging process so that throughput would be big enough.
7. Possibilities for introducing semi-automation or automation are very limited (if not impossible) due to high amount of product, process and packaging material variations combined with a lot of process steps. Complexity, cost, and space usage of the system would very likely end up being too high to be feasible. Overall technology risk would be high, adding further risks for successful implementation.
8. As products are packed onto different pallets, to differing locations, with different orientations it can be said that there is significant variation involved in the packaging process (picture 10). This leads to the number 1 issue: need of additional lifting aids, placement jigs, work instructions and worktime as operators need to change equipment, tools and their positions while working.
9. Different additional transportation supports and fasteners need to be used due to packaging orientations.
10. Due to varying processes and equipment, big sizes of materials and packaging ergonomics etc. workers need to move and work around the packaging “under assembly”. Unrestricted access to packaging from all sides is required. This creates extra movement, processing and restricts potential placement of machinery or other technology to packaging area.
11. Box outer sleeve flaps need to be taped. Process could potentially be left out with other construction. Taping takes time and increases bill of materials (BOM) cost.

Packaging process also seems to have potential waste in the form of over-quality in some cases: workers need to drill holes to pallets, then attach bolts through the pallet bottom facing upwards (effectively forming a threaded stud) into where then a drive is placed and fastened with nuts and in some cases with further additional screws. This is partly due to every now and then appearing product damages during outbound transportation pipeline, caused by products coming loose from the pallets and becoming damaged or dented. Such issues have been partly improved by using "bolting through" fastening method instead of using top-down wood screws only.

To lesser extent the same "extra processing" issues encountered by internal production will also be faced by the customer or integrator receiving the drives in the packaging: extra bolts to loosen, extra tools, need to watch out hitting the products with tools, extra time is spent (field technicians and fitters are not cheap) and there are extra items which needs to be removed (extra supports, fastening bars, bolts). In the very least recycling becomes more complicated, if wooden pallets have fixed metal bolts attached and there are few separate, loose metal support bars.

5.4 Waste in outbound transportation/distribution logistics

On the outbound transportation pipeline/distribution logistics waste results in my opinion from the basic issue, that packaging cannot be varied or modified closely enough to "conform" with individual product's outer dimensions. This limitation is caused by many factors, but especially due to packaging construction and process. E.g. by:

1. Variating package sizes more would result into a significant increase in packaging material variants, which could not ne fitted into production lines and packaging areas (e.g. one new height introduces three new components, one new pallet size introduces four-six new components). These would lead to relatively massive increase in storage space (not available) and less efficient packaging process.
2. Amount of work required by personnel increase as the number of materials increase, due to increased "administrative" work: mainly for sourcing managers, purchasers, material coordinators and production logistics related personnel.

There are a lot of unutilized area and volume left inside current packages, even though there are already many different pallet and cardboard construction variants introduced, with the aim to reduce extra waste and costs. Especially pallet area is lowly utilized with small items, which only utilize small portion of the pallet area. Therefore, if pallet area is unused inefficiently, it also means all the empty space on top of that area is unused (effectively waste). It is billed and creating extra costs in transportation.

As some of the smaller and bigger products need to be packed into and transported with same transportation packaging, e.g. sharing same pallets and cardboard construction, it results to unnecessary waste space inside the packaging for the smaller products also height wise. E.g., if box pallet has 500mm high cardboards and the construction is shared between 300 mm and 500 mm high products, smaller product has a lot of unnecessary costs.

Bigger than necessary cardboards for smaller products also mean that packaging has extra weight, which causes higher costs especially in air transport deliveries, where main pricing factor is total weight of the packaging. Same extra space inside the packaging also mean that availability of transport options are more limited than they could be because more unreserved space is required onboard of transport.

As distribution logistics chains are often quite long, even a single product delivery from Vaasa factory to customer can include e.g. many different:

1. modes of transport
2. distribution centers with related unloading, storage, and loading
3. transportation companies
4. sizes and types of vehicles/aircraft/marine vessels used
5. countries and aerial regulations

Sometimes extra transports need to be arranged (e.g. road and air transports) due to possibly limited availability of trucks or air transport. Especially in air transports this happens, when recurring quotas are used already, or all the products cannot be fitted into the reserved cargo slot in the airplane due to shape, dimensions etc. Products which are left out, either need to wait for next scheduled standard contract flights or new additional air transport needs to be booked to ensure a timely and fast delivery. Additional bookings with tight schedules significantly increase costs, whereas waiting for next scheduled flights can lead to unacceptable delays and deliveries will be reserving limited storage space while waiting.

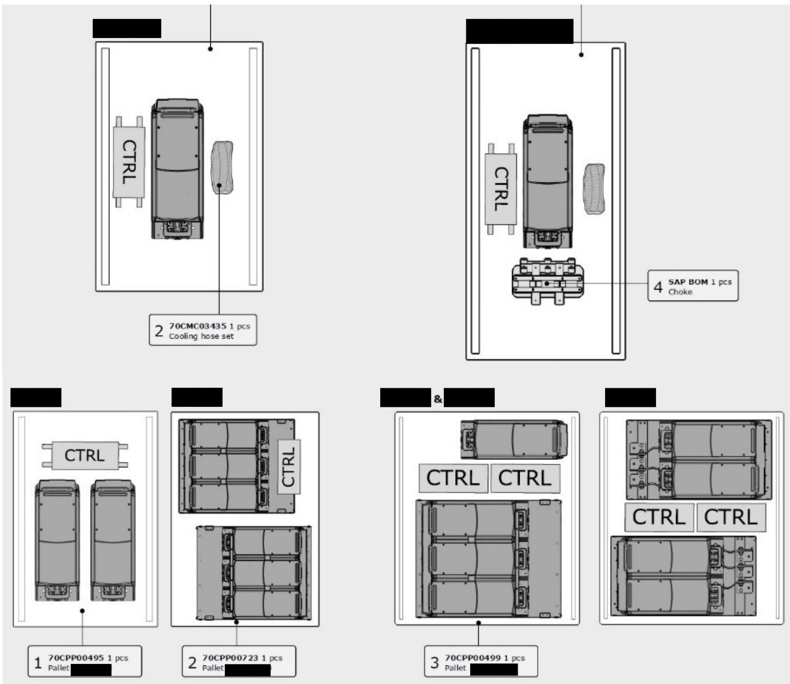
On top of recurring quotas, air transport has some other specific features also. Such as specific dimensional, weight, and especially height limitations. These are especially aircraft type specific: what are the sizes of loading and unloading doorways, what is the shape and size of cargo area and can the delivery be placed into bulk cargo or not.

Even though usually in road and sea transport less optimized packaging and delivery form factors do not lead to as substantial cost and/or delivery time increases as in air transport, there are still various downsides presented in these modes of transport also. Downsides can be estimated to stay more hidden, as they are less extreme in nature and therefore does not cause such immediate and obvious disturbances to functioning of the logistical chain. Also, there is not likewise “direct control” over the long delivery chains with many parties involved along the way.

Therefore, it is reasonable to assume problems originating from waste space inside packaging (picture 10) and waste from overall bigger packaging outer dimensions (total volume) are handled in logistic so that they stay “hidden”. Issues are handled along the normal processes of transportation companies, but end result is inefficiencies and increased costs. Inefficient packaging space usage and form factor causes e.g.:

1. More restrictions and limitations for placement area means less options to choose from during the delivery chain.
2. Choosing next available truck with more space left unused (LCL), possibly leading to higher costs and delivery time. LCLs are usually slower than FCLs.
3. Having to choose either a dedicated FCL truck instead of LCL, or having to book an additional FCL, therefore both scenarios will lead to higher costs.

4. Nevertheless, whether FCL or LCL is used, billing and costs will always be higher than what they could be with better optimized packaging.
5. Additional organizing, scheduling, booking, confirmation, documentation, monitoring etc. work needs to be done in various phases of the supply chain, leading to higher resource usage and costs. It is logical to assume that probability for errors also increase as amount of work and people involved increases.
6. Bigger space usage in distribution centers and increased amount of handling required both in storage and when unloading or loading transports.
7. Arranging additional or higher capacity transports in “last mile” deliveries: choosing bigger van instead of smaller one, three trips instead of two etc.



Picture 10. Different product variants on four different pallets, each pallet requires new set of cardboard materials, note waste space with smaller variants (MAD0107).

5.5 Mechanical transportation stresses and transportation damage related issues encountered with current package designs

Main problems which will be listed and evaluated in this chapter are all related to damage events which have led to broken or damaged products in such manner, that usually new substitutive products have been required to be made. Damage events are mapped according to transportation and other reclamations received. In many cases clear root causes and how to prevent such events have not been established.

All the damage events happen yearly, some multiple times during the year. So therefore, if these issues could be solved even partially, the cost savings would be substantial. The issue is finding balance between extra costs of better protecting packaging and damage costs. it is not cost-effective to make too much “over quality” into the packaging because of rising overall packaging costs offsetting other benefits. With current construction options to limit damages have been estimated to be quite limited.

Below is presented the estimated events leading to damaged or broken products, according to the estimation of logistics personnel and external consultants. Presented are also our collective estimates for the likely root causes after evaluating various features.:

1. **Stacking capability of packages “disappearing” (Only Danfoss packages stacked**). Estimated root cause: bottom package’s cardboard pallet sleeves losing their supporting capability due to slipping off from one of the longer pallet sides during transport vibrations and shocks. Current construction has long tolerance chains, which improve chances of a such damage event.
2. **Pallets falling from top of each other (Only Danfoss packages stacked).** Estimated root cause: pallet slipping on sideways direction from top of each other. Top surface of box pallets is very smooth (slippery) and in many cases top surface is also “bulging” upwards from the middle, making falling off easier.
3. **Top part of packaging tearing or breaking (only Danfoss packages stacked).** Estimated root cause: Pallet on top about to slip off, but instead of falling off, pallet legs partially come through the top “roof” of package underneath.
4. **Top part of packaging tearing or breaking (non-Danfoss packages stacked).** Estimated root cause: Too high point load, e.g. much smaller pallet placed on top of Danfoss package at some point of the delivery chain and the package falls through.

5. **Cardboard sleeve tears or breaks down from a certain spot.** Estimated root cause: Incorrect handling or forklift's spikes driven through.
6. **Pallet breaks, legs come off on one side.** Estimated root cause: Incorrect handling at distribution centers/storage: package "pushed" on ground without lifting it.
7. **Products have become loose inside packaging and products are damaged, but packaging is intact from outside.** Estimated root causes: screws or bolts have become loose from pallet due to shock forces are not "transferred" into a wide enough area (X & Y axis). Alternatively screws or bolts have been "lifted" off the pallet with a forklift underneath the pallet. Bolts/screws prolong from pallet bottom and forklift's spikes "lift" them off, breaking the threads to wood.
8. **Products are not loose inside the packaging but are dented. Packaging is intact from outside.** Estimated root cause: packaging does not dampen external impact forces; forces have been transferred to the product.

5.6 Identified challenges for achieving targets set for overall concept, based on analysis of current state and case projects

Generalized, projects' product family related specifics require significant capabilities to cope with high demand fluctuation with regards to product, variant, options, and accessories mix. Quite significant challenges must be faced and solved in practice, to achieve aspired and successful results from the research.:

1. All of company's pallet-based packages were analyzed, improved, developed, and introduced just few years ago in collaboration with production.
2. Project's products are still under development and products are very modular already on product architecture level, therefore amount of product and variant combinations are very high. Same applies to additional product options, which are very freely selectable by customers: there are a lot of different options, usually with multiple sub-variants to choose from. On top of these will be added "product/packaging accessories", which are usually various product installation

related items. Some of the accessory variants and types are interdependent with the product, product variant, options, or all three.

3. End-product sizes differ greatly, a ready product can differ between 1-16 pieces of various units and/or unit combinations. Out of each before mentioned, there are various power, current and voltage rating variants. Therefore, varying sizes, weights, physical forms, and materials need to be handled. Same applies for related options and accessories of such units.
4. Customer orders' product mix and order sizes can vary greatly but requested delivery times are getting shorter all the time. Requested delivery times for an order placed is in many cases estimated to be substantially short. Therefore, visibility can sometimes be short with limited possibilities to anticipate or "start work early". Company has very high ambition and priority for making fast deliveries.
5. Volumes per individual variant are relatively low, due to the modularity etc. Various products and their variants might be ordered and processed in random sequence among each other (especially in packaging area).
6. Estimated main mode of transport mix for the products, based on historical data and sales area data evaluated by product managers, was estimated to be approximately the following (due to confidentiality, exact numbers cannot be presented):
    a. Transport mix for sub-project A products: more than three fourths by road, and less than one fourth delivered quite equally either by sea, or air.
    b. Transport mix for sub-project B products: Less than two thirds by road, with bigger part of the remaining transport being delivered by air than by sea.
    c. It can be concluded that transport mix is diverse. Air freight's portion is significant on the whole platform level, as on average air freight's portion is internationally only around 10 % (Worldbank, 2009) and in intra-Europe logistics air transport is only 0,05% (Solakivi et al., 2018). Therefore, special attention needs to be paid into air aspect.

6 Results: improvements of new packaging and processes throughout supply chain & comparison to benchmarks

New overall concepts developed offer superior delivery times and cost efficiencies with less part variants, while enabling higher package customization and cross-usage between multiple product families. Introduction of semi-automated packaging was also made possible, due to smaller materials amount, weight, and easier packaging process with less process variation.

Results turned out to be excellent and well in line with original target settings and conforming to DFL main components, supporting the notion that by going to such a grass roots level you can make significant impact on logistical costs and processes, production processes and customer service level even on a supply chain wide level. You can make much more efficient supply chain design as originally proposed by Stanford University's Hau Lee (1993).

In practice by making overhaul on package level, it is possible to potentially overhaul even the whole related supply chain model, which is quite big finding. One good example of likewise realization is Ikea and their significant focus on packaging, as I found out during this development project by coincidence. Ikea even designs their products from the beginning with transportation costs and packaging as one main criteria, as packaging is thought to be integral part of the product design itself and vice versa (DFL ideas used in some form). Packaging is not only added over a product as a "necessary part" which enables functioning of supply chain and logistics – it is integral part of creating extra value for many actors on the course of early product lifecycle, until reaching the customer.

Results and findings in my research are very likewise: on top of significant cost improvements, also logistical process improvements through the whole supply chain are substantial: arguably reduced delivery times, packaging times, layout space usage and need for controlling and administration of processes. Also new production technologies can now be implemented, and economies of scale benefits can be taken advantage of substantially better in many phases of supply chain.

6.1 Cost drivers and cost formation

General cost information usage and evaluation viewpoint has the aim to evaluate and make the correct conclusions from findings of current state analyses of existing products, production, and NPD projects, it is also important to understand relevant cost drivers and cost formation principles. Such information is vital for developing and deploying further results, e.g. developing new processes, technologies and constructions. Results are vital e.g., to following questions of: what causes the costs, how, and what are the cost drivers during different phases and processes of the supply chain? Main viewpoint has been evaluating physical processes taking place during different phases of supply chain, acting as main drivers for costs.

Packaging material supplier cost structure and cost formation are evaluated based on main production phases and drivers contributing to Danfoss costs, and which therefore are possible to modify with new Danfoss packaging concept designs. Evaluation is based on manufacturing processes taking place during pallet and cardboard manufacturing.

1. Material cost (wood, plywood and cardboard type, form, size, thickness, treatment)
2. Manufacturing cost (cutting, forming, shaping, treatment etc.)
3. Assembly (nailing of pallets, stapling and/or gluing of cardboards to right form etc.)
4. Packing (placing cardboard sleeves, lids etc. to delivery pallets and packaging)
5. Storage (Bigger production lots than Danfoss order quantities)

Transportation and distribution storage cost structure and cost formation related pricing principles and transport information relevant to case study, are gathered based mainly on theory, data, and discussions with logistics engineer and external packaging consultants.

Pricing is based mainly on chargeable weight and it is the main cost driver in transportation. Chargeable weight is converted either from actual weight, volumetric weight, or load meters. Pricing method which brings greatest chargeable weight out of the three methods, will be used. Usually volumetric and actual weight can only be considered if packages can be stacked either on top of each other, on top of other packaging or other “third-party” packaging can be placed on top. From handleability point of view four-way handling generally reduces cost due to increased handling and storing flexibility, especially during long transportation chains with many distribution centers and transports involved.

One cubic meter of (1 m3) space usage usually corresponds to following chargeable weights, which will be compared against actual net weight:

- Road transport 333 kg
- Sea transport 1000 kg
- Air transport 167 kg (can vary depending on airplane model and operator)

Chargeable weight pricing for outbound deliveries varies greatly based on modes of transport, distance travelled, countries involved, and pricing methods used, which is well in line with theory. Generally speaking, number of charges studied conform to what could be expected, compared to relevant theories and industry statistics. Yearly changes in costs can be high due to fuel costs, availability of capacity etc.

Various other charges can also be billed, such as special handling related unloading and loading fees, long goods, air preparation, export, loading and unloading etc. related charges. Generally, the feeling is that such costs have increased over-time. I think that this could be a bad development in the long term because such cost structure development might limit possibilities for a company to lower logistics costs by e.g.

improving own packaging designs. Change of focus from variable rates based mostly on net weight or dimensions, to various smaller fixed rate “fees”, can effectively act towards “hiding” the real underlying product or packaging design-level waste. Therefore, potentially keeping cost structure higher for longer, with limited possibilities to try lowering it. It can become harder to identify the grassroots level cost drivers and reduce incentives to try to lower delivery packaging related cost metrics.

Air transport has also many special features, mainly due to limited cargo space and a large plethora of different airplane types, models and sizes being operated. Package dimensioning becomes very critical in air freight maybe more because of schedules vs. delivery times and airplane availability, even though costs are very important factor also. In general, if air transport packaging cannot be placed to “bulk” cargo area of an airliner, it will mean higher costs and possibly changing airplane type to another, potentially leading up to days of delays when next suitable airplane needs to be available and there must be remaining empty space in cargo space. Specialized cargo space needs to be used. Here also comes another problem: usually air transport is used because of the need for a speedy delivery and few days extra time is not acceptable. This means that an extra air freight booking needs to be made as “urgent”, which can lead to “rocketing” air transport cost compared to usual.

Danfoss production logistics cost structure and cost formation Information is gathered based on discussions with a Danfoss material coordinator and on my own observations working as manufacturing engineer in the company.

1. Materials stock following, order placements, transport bookings and confirmations
2. Goods receiving, delivery to right production hall and production line.
3. Production storage, dismantling delivery packaging when taking materials into use, all production and packaging process related movements and actions.
4. Delivery packaging disposal after packaging materials have been used for packing.

On-site and reverse logistics cost structure and cost formation related information is mainly based on discussions with company's logistical engineer and external consultants, supported by theory materials.

1. Packaging disposal and/or recycling costs to Danfoss
2. Damaged products due to transportation damage and/or protective delivery packaging removed too early on-site considering the environment (e.g. stored incorrectly on open and therefore debris, water or particles get into product)
3. Reclamations together with related repackaging of returning products, transport costs back to Vaasa factory, analyzing faulty products in Danfoss, making new substitutive products, packaging of products and new delivery to site etc.
4. Potential reputation and image losses, possible challenges in customer relationship.

6.2 New package construction overview and comparison to benchmark: significant improvements

Required environmental and other surrounding elements protection is mostly incorporated by design to box pallet construction, its material choices, and coatings, combined with primary and secondary boxes. Therefore, identical packages can always be made and sent all around from at least minus 40 degrees to +50 degrees. Exception is long sea transports between continents where increased corrosion protection is required, and therefore VCI-film and in some cases VCI-capsules under the film are used.

Modularity and interchangeability of new packaging concept is one of the main features, which enables new processes, optimizations, and capabilities on other areas. Constructions are designed to be highly modular, with minimal amount of "area" variants (pallets), while enabling easy and efficient introduction of "height" variants (cardboards/box constructions). This way logistics costs can be further optimized with more efficient space usage on storage and loading areas, while reducing waste space inside packaging and offering increased economies of scale for procurement. Also, internal processes can be simplified, and process steps can be removed, therefore leading to higher efficiencies throughout supply chain and enabling new ways of doing things for the operations.

Pallets are biggest drivers of overall number of additional variants and variations, by introducing more e.g.: cardboard components, handling processes, process variation, storage space, and packaging documentations to name a few. Meanwhile, cardboard variants (boxes) do not have such a big impact on other items and logistics processes, due to smaller interdependencies, if only the height is changing.

Less packages, package components and variations are required and used to pack all possible product variants, in different scenarios. This leads to smaller amount of process steps, which are usually also much faster, as well as reducing variations and variance in the process by removing some operations, tooling, restrictions etc. required earlier. These greatly facilitate introduction of new packaging processes and technologies, further improving benefits related to economies of scale from modular design.

Smaller size and weight of new packages and individual package components when comparing to old benchmark constructions reduce transportation costs, material usage and makes handling easier. If new and old constructions with same outer dimensions would be compared, new cardboard “box” construction on average weigh approximately 60-70 % of benchmark and new pallets 70-100% of benchmark depending on pallet type compared. However, in practice there are bigger differences for the advantage of new construction due to a fundamental difference in the overall conceptual approach and modularity of the design. Though, in some cases weight difference of individual cardboard package components can be even up to 200 % when compared to benchmark, using an actual product packaging scenario employing actual new or benchmark concepts.

Package dimensions of smaller product variants can now be made much smaller and better conforming to product shape compared to benchmark constructions, therefore leading to less waste space inside package and substantially reduced amount of packaging materials used in pallet box construction: pallets, cardboards, strapping, metal fastening brackets etc. Smaller weights also mean increased ergonomics and easier, faster handling of materials. Smaller individual package sizes enable stacking more packages together, further improving product and package density on transport equipment and storage.

Smaller size and weight of packaging components (especially components made from cardboard) enable introduction of new delivery packaging, better handling and production processes, and better storage utilization all the way from suppliers to Danfoss production’s packaging area. Smaller form factor per component makes handling of individual package components significantly more ergonomical, easier, faster, and physically less demanding when assembling a delivery package. All before mentioned together enable new options for material placement (e.g. materials can be placed higher on shelves and still be used during packing), which helps create more efficient packaging area layout and processes, as well as reducing worker and handling aid needs.

Production storage space usage is now multiple times smaller, even while increased amount of overall package (height) variants can be made at the same time, which reduce transportation costs and time. For example, with benchmark construction, packaging materials already would take up all the floor space which is now going to be used for new packaging area and related processes in its entirety.

Increased transport loading area utilization in different modes of transport brings significant cost savings and flexibility of placement regarding packaging. Optimized transportation processes and costs are the result of many different factors. There is less waste space inside individual packages, more packages can be stacked with each other (also in same space as before), package or package stack footprint conforms better with loading areas of different modes of transport.

Higher durability and "smarter" dimensioning enable stacking of higher amount of delivery packages, leading to reduced costs and space usage. Higher durability offers better package compression protection, and reduced risk of package stacks or package parts slipping, leading to reduced damages for products and other items being transported.

Because of outer dimensions chosen, better loading area fill rate in some instances (e.g. containers) can be achieved and risk of product damages reduced, due to making incorrect stacking of third party packages or other interactions harder (e.g. visual indicators and harder placement of oversized loads or point-loads on top of new constructions).

Less tooling, lifting aids, jigs and other supporting equipment are required in packaging area and packaging process. This enables more streamlined production process with smaller layout space need, less motion, waiting, overprocessing and defects.

Less process steps and process variations are required to pack a product and other associated items, and introduction of additional products or product variants do not increase the process steps and process variations. For example, unified placement locations on the modular constructions and new fastening concepts mean that there is no need to e.g., place product variants to different orientations and locations, to pre-drill holes, or to use various jigs, lifting aids and tooling to be able to perform the before mentioned.

Smaller amount of process steps and variations remove technological limitations and costs for introduction of increased automation into the packing areas and processes, therefore greatly increasing viability and business cases for making production more efficient with increased automation.

Facilitation of internal and external logistics functions, including packing through improvements listed. Improvements as a whole improve and optimize various characteristics which can be altered with packaging design or enable creation of new processes and capabilities altogether by e.g. removing restrictions and limitations originating from existing designs.

Improvements in packaging basic functions are also made. For example, in basic functions of providing information (improved handling instructions and standard contents placement) and ease of use (easy opening and reclosing, smaller parts to handle when dismantling packaging).

Sustainability and environmental friendliness of new construction and concept are good, as components use less materials, are more lightweight and require less handling.

6.3 Packaging material supplier, improvements

Supplier benefits from various features of the new packaging concept, including new package construction itself and reformation of related processes. As there are fewer component variations to be made, it is easier to organize and manage production of the orders. As the volumes are higher per remaining components, there are also increased economies of scale for the supplier, e.g. in the form of reduced productions runs, machine setups, storage and other processing. Less materials are required to make the components and for their delivery units. Packaging process for the components into delivery units is significantly streamlined, with complete process steps removed and the packaging process is made much easier. See Table 3 below for all improvements.

	Supplier	New packaging design	Old packaging design
Upstream	Administration & organizing	1. Less administrative work due to reduced variants and similar delivery forms: 2. Bigger, more often reoccurring volume for less parts with less process steps and machines required	"Small" volume streams from separate package constructs with more parts and multiple machinery required.
	Material usage & cost	Less material used per package construct, but slightly more expensive material required	More material used per package construct, but slightly cheaper material required
	Process steps required	1. Lid simpler to make vs. substituted cardboard sleeve with flaps: just cutting and forming of cardbaord, without gluing and assembly 2. No need to set cardboards together anymore	
Supply chain	Machines required	Existing machinery can make new thicker sleeves without changes. Lids require less machinery than sleeve with flaps.	
	Worktime mfg. & packaging	1. manufacturing takes slightly less time due to lid's ease of manufacturing 2. Significantly shorter packaging time for new materials: sleeves and pallets are run in the production process on top of Euro pallets horizontally straight from the manufacturing machines by design. Only straps and filmwrapping need to be placed.	1. Old construction need to be assembled into "sets" of inner+outer sleeve and be placed to vertical orientation to delivery pallets. 2. Cardboards come from machines in horizontal orientation. Need to make two separate production runs horizontally into separate Euro pallets, then set the parts one by one into third delivery euro pallet into vertical position. Planks need to be manually added to delivery pallet to offer support. Delivery pallets are strapped and filmwrapped.
Downstream	Lead time	Shorter: 1. separate machines used for sleeve and lid manufacturing, can be run in parallel 2. Packaging process stesp removed - significantly shorter time.	Longer
	Delivery packaging	No empty space left between sleeves or lids in delivery packaging	Empty space left on top of inner sleeves and between inner+outer sleeve, due to loose fit caused by vertical orientation
	Waste disposal	Less material waste	More material waste
	Environment	Less materials, energy and work used	More materials, energy and work used

Table 3. Improvements at supplier.

6.4 Inbound transport improvements

Benefits in inbound transport originate especially from higher density of package components per delivery unit, making delivery units stackable and then stacking delivery units on top of each other in transport. These together lead to substantially smaller costs (up to 8x smaller), because of 8x higher loading space utilization. Both floor area and height wise space are utilized with higher density. See table 4 for all improvements.

	Inbound transport (road)	New packaging design	Old packaging design
Upstream	Administration & organizing	Easier to allocate resources and trucks due to smaller space usage per unit and radically smaller space usage per delivery lot.	Harder to allocate
	loading area utiliziation	1. Sleeve and lid deliveries can be stacked amongst each other 2. Material flow volumes created high enough to utilize heightwise space completely.	1. Delivery can't be stacked 2. Approximately half of heightwise space (1,1-1,4m out of 2,4m) left un-utilized due to non-stackability and odd shape.
	Chargeable weight	Due to stackability up to 8x less	Up to 8x more
	Stackability	Yes, up to 8 unit loads (8 delivery lots) will be stacked with euro pallets. With circulating plastic pallets or fibermold pallets even more possible.	No
Supply chain	Shape	Slightly better access for cargo securing on transport	Slightly worse access for cargo securing
	Handleability	1. Can move up to 8x amount of units with same time 2. 8x less touches, movements and handling compared to one old unit 3. 3-5 pcs unit loads restrict visibility less than one old one with forklift or pallet jack	1. Can move only one unit a time 2. Need to make up to 8x more touches and movements, movements also longer due to higher m2 space need 3. More obstructed visibility with forklifts or pallet jacks
	Handling instructions	No significant difference	No significant difference
Downstream	(Mechanical stresses)	1. Loading/unloading is one of riskiest phases during transportation: risks are reduced with up to 8x less touches and handling involved. 2. Slightly higher risk during transport due to stacking (cardboard compression risk), but if problem presented it can be solved by placing bulk spacers on Euro pallet corners.	1. Loading/unloading is one of riskiest phases during transportation: need 8x more touches and movements. 2. No spacers needed during transport, but no stacking either.
	Environment	components use less materials, no waste space in truck, less handling required	

Table 4. Logistics improvements in inbound road transport logistics.

6.5 Danfoss Vaasa factory/production improvements

There are numerous improvements brought by the new packaging construction, as well as by the related new processes and technologies enabled by synchronized development (semi-automated packaging cell benefits are excluded). Improvements include e.g., approximately 2-3 times smaller work- and takt-times for packing, significantly enhanced ergonomics, some process steps require only one worker instead of two, less tools and other assisting equipment required during packing, smaller material and component costs (BOM), possibility to move up to 8 times more package component delivery units at the same time, interchangeability of package constructions between different products and production lines, approximately 37-74 m3 less storage space used on shelves for packaging materials in production lines, multiple times smaller layout space need on packaging area for storage. See tables 5 and 6 for more detailed information.

	Danfoss Vaasa production	New packaging design	Old packaging design
Upstream	Administration & organizing	1. Easier, leaner storage level following and material orders. 2. Less buy components, which are also interchangeable between product lines. In case of stock-out, can momentarily take packaging parts from other product line. 3. Due to enabling overhauled packaging process with higher standardization and better materials, only one person required in packing instead of two persons. 4. Up to 2x less workhours required with smaller takt and lead times. Makes production planning and resource allocation easier. 5. Significant further improvements on top of number 4 improvements are made with introduction of semi-automation packaging cell: layout, throughput capacity, work and takt times. Provides even further easing of production planning and resource allocation.	1. More components which need to be followed: storage level tracking, ordering, etc. 2. Can't interchange parts between lines in stock-out situations 3. Limited or no possibilities to improve packaging process, due to non-scalability and too high layout space usage of materials. Materials also hard and slow to handle by one person. A lot of variation in the packaging process. 4. Up to 2-3x more worktime required compared to new manual packaging process and materials. Two persons required instead of one, longer takt times and smaller throughput capacity makes production planning and resource allocation harder.
	Package BOM costs	1. When comparing all new concept's packaging materials and the product platform covered to the old materials and the product platforms covered with them, new concept is significantly cheaper on a platform level from BOM point of view due to removal of unique items and parts. This also facilitates creating better economies of scale advantages in the future. 2. Due to modularity and scalability of new packaging concept it's easy to copy into use to other product lines. This would further significantly increase material volumes per item, adding further economies of scale (especially due to supplier's streamliend manufacturing process). 3. When comparing few individual separate packages (without taking into account the platform idea), packages made with same measurements from new or old constructions have practically same BOM costs in the beginning. Though usually prices are dropped during time so it's logical to assume that in this case BOM cost would also drop for new packages	
	Goods receiving	1. Can move up to 8x amount of units with same time 2. 8x less touches, movements and handling compared to one old unit 3. 3-5 pcs unit loads restrict visibility less than one old one with forklift or pallet jack	1. Can move only one unit a time 2. Need to make up to 8x more touches and movements, movements also longer due to higher m2 space need 3. More obstructed visibility with forklifts or pallet jacks

Table 5. Improvements in Danfoss Vaasa factory 1/3

Supply chain	Delivery to production	1. Production delivery routes (milkruns) can be driven at once with up to 8x units to be placed to production storage. 2. Same units can be placed to more areas (modularity, interchangeability). 3. Direct placement to production storage shelves more likely possible due to less overfilling of shelves happening with materials better form factor)	1. Production delivery routes driven with delivering one or two units at a time. 2. Most units can be placed only to a specific line (as they are not cross-usable) 3. Direct placement to production storage shelves often not possible due to quite regular overfilling or lack of shelve storage space. Operators need to arrange materials at some point.
	Production storage utilization	New substitutive packaging materials compared to old concept's materials can be stored: 1. in 2-3 times smaller floor space. 2. on top of each other on shelves and still be used for packing. 3. space saving in the case of Viking lines is approx two to three times 37m3 or 8,4m2 of shelf space saved. Corresponds to approximately 4-6 pcs of L2800*W1500*H4400 shelves (space not including required loading areas behind and usage areas in front.)	
	Unpacking delivery unit load into ready to use form	1. Less plastic film material used and less work removing 2. During time plastic film can be subtituted with returnable hoods. Much less materials and worktime used (hood placed on top of multiple packages at supplier, e.g. 8 pcs unit loads, and removed at once before delivering to production from goods receiving).	1. More plastic film material to remove 2. Can't reduce plastics due to non-scalability of concept
	Packaging of products/packaging process	Significant benefits: 1. Now one person can pack ergonomically 2. Over two times smaller work time (not taking into account transfer benefits) 3. Significantly smaller lead- and takt times 4. Packaging line incorporated into assembly line (in-line): no need for transfers or carts. No work time from transfers. 5.Small variation in the packaging process 6. Small layout space usage with over two times higher material storage density and "one side access" to packaging possible.	Existing process (see current state analysis) downsides: 1. Two persons required to pack, unergonomic 2. Over two times higher work time (+ additional work time from transfers) 3. Significantly higher lead- and takt times 4. Separate packaging areas: long transfer distances and carts required for transfers. Long additional work times from transfers. 5. A lot of variation in the packaging process 6. Big layout space usage with over two times lower packaging material storage density, need to access packaging from all sides etc.

Table 6. Improvements in Danfoss Vaasa factory 2/3

One of the most significant outcomes from the new overall package construction and packaging process concepts are the removal of various limitations and variances of the original benchmark packaging processes, together with significant reduction of package components to be handled (table 7). These enabled and facilitated the introduction of new machinery and automation, ultimately resulting to a complete packaging area solution of semi-automated packaging cell.

Downstream	Enabling new packaging process concept and semi-automatization	A semi-automated one piece flow packaging cell design, in-line with production line, was created. 1. Cell reduces worktime and lead-time needs to less than 25% of the amount required in other packaging cells. 2. Other packaging cells are not incorporated in-line with their production lines and take 50-100% more layout space. 3. Huge additional benefits also from not requiring to move products between different production halls from production line to packaging as with old products and packaging concept. 4. Standardized packaging process with minimal amount of process and parts variations reduces automation complexity 5. Minimal amount of standardized, modular packaging materials: 5.1 multiple times less different pallet sizes and pallet variants used. 5.2 Pallet widths don't variate and always stay narrow, whereas old concept has many variations in pallet widths also. 6. Substantially increased ergonomics and handling properties from separate lid+sleeve constructions with lighter weights and smaller sizes reduce need for operators to walk and access all around the pallet. This creates possibility to add pallet and product handling machinery into the layout, even though they restrict access with cardboard materials.	Not possible to implement semi-automation or automation due to too high complexity, technology risk together with limited cost and efficiency benefits.
	Disposal of delivery packaging	1. Immediate benefits: 1.1 Less plastic and wood materials to dispose of 1.2 No need to remove 6 nailed planks from every cardboard delivery pallet, approximately 5-10 minutes worktime saved per pallet 2. Future added benefits: no plastic waste at all	Hard or not possible to optimize existing delivery packaging more anymore.

Table 7. Improvements in Danfoss Vaasa factory 3/3

6.6 Semi-automated packaging cell

Huge improvements in production were enabled by development of new overall packaging concept, which improved packaging process, and is compatible with automatization of certain process steps. Therefore, a new packaging cell concept was developed in tandem with packaging design. One concept presentation sheet composed by researcher for decision making can be seen below (figure 4), with general information about the improved characteristics, such as number of operators, lead time, work time, work price per package, layout space usage, annual savings, and some other features.

Some of the main process and equipment features can be seen in another presentation sheet (figure 5). Some improvements are not included in the presentation sheets, e.g.: removed need for transport carts and product transfers from production lines, and other one-piece flow benefits related to placing packing function in-line with production line.

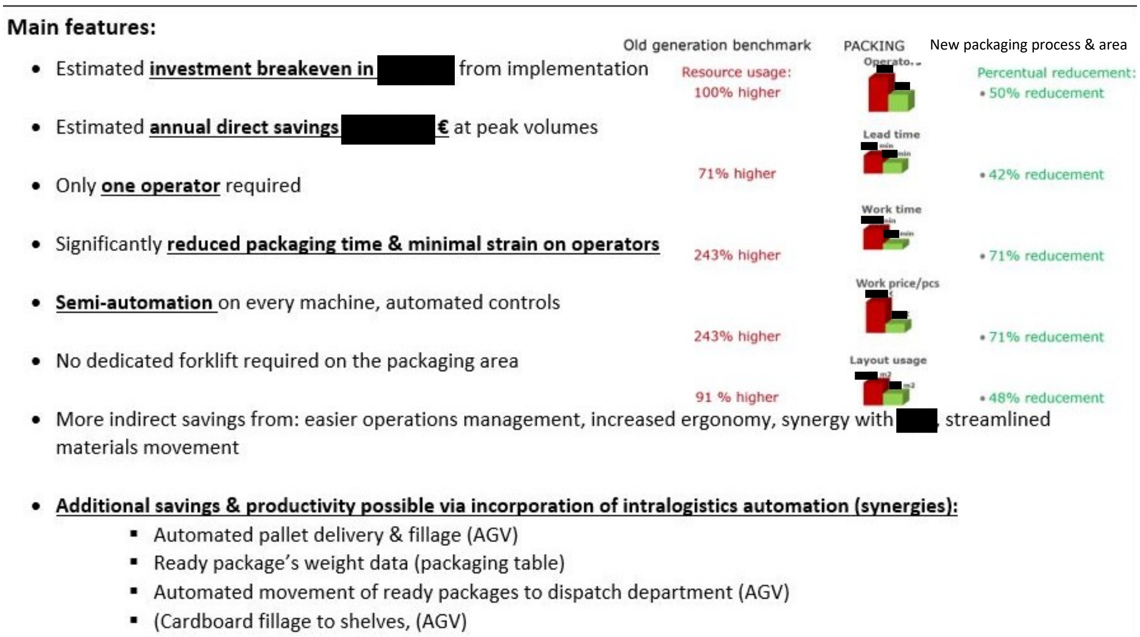
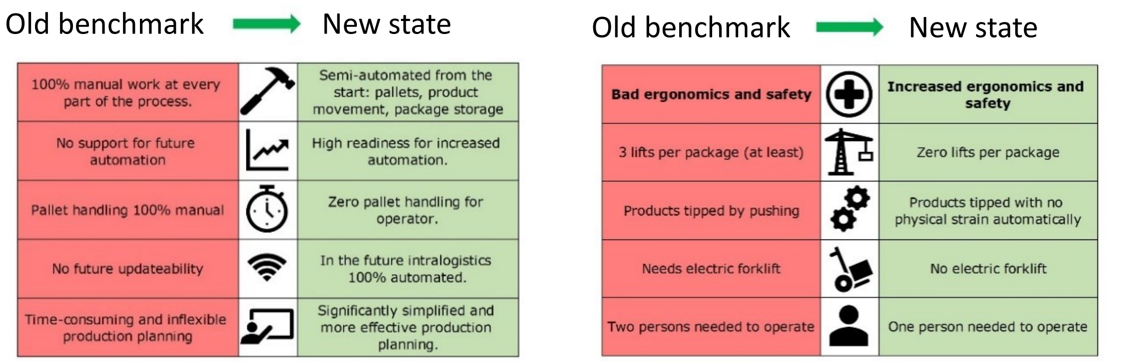


Figure 4. Summarized fact pack presentation of semi-automated packaging cell.



Old benchmark → New state

100% manual work at every part of the process.	Semi-automated from the start: pallets, product movement, package storage
No support for future automation	High readiness for increased automation.
Pallet handling 100% manual	Zero pallet handling for operator.
No future updateability	In the future intralogistics 100% automated.
Time-consuming and inflexible production planning	Significantly simplified and more effective production planning.

Old benchmark → New state

Bad ergonomics and safety	**Increased ergonomics and safety**
3 lifts per package (at least)	Zero lifts per package
Products tipped by pushing	Products tipped with no physical strain automatically
Needs electric forklift	No electric forklift
Two persons needed to operate	One person needed to operate

Figure 5. General features of benchmark and semi-automated packaging cell compared.

New packaging processes and packaging areas are already partially implemented as of 2021. First phase of semi-automated packaging cell is already implemented on one area, with the second phase to be implemented in near future, resulting to the final state of semi-automated packaging cell. Also, a less automated version of the cell has already been introduced to another packaging area. In both packaging cells products use the new package constructions.

6.7 Outbound transport / road, improvements

Benefits from modular packaging design and improved technical characteristics of the package construction are centered especially on less waste space inside individual packages, smaller sizes and gross weights of the individual packaging and increased stacking of packaging (up to two times more packages can be stacked). Overall packaging dimensioning corresponds better to the shape and size of loading spaces inside different transports (trucks, vans, containers, air cargo spaces etc.). Therefore, transport costs are brought down as waste space is reduced overall, product density is higher, shipments in general fit to smaller spaces and improve transport availability. Risk of transportation damages are reduced by various packaging design features. See table 8 for detailed information about improvements.

	Transport 1 / road	New packaging design	Old packaging design
Upstream	Administration & organizing	1. Facilitating faster delivery due to deliveries fitting into more trucks/vans/air cargo slots etc. available than before, effect is bigger in later phase of delivery chain where deliveries are often done with smaller trucks, lorries or even vans. Less limitations and restrictions	
	Loading area utilization	1. Smaller space usage per package (product) 2. Package stacks have more packages within 3. Less unused space left heightwise on top of stacks, on some cases none 4. Packaging materials weigh less and accessories box placements reduce weights of some packages further. Packages where real net weight acts as the chargeable weight pricing factor, costs are reduced.	
Supply chain	Flexibility of placement	1. Higher flexibility with a big amount of products or very small amount of products. E.g. 6 pcs smallest products fit in one stack, whereas before e.g. 2x3 pcs stacks (double area) was needed. Scaling effect along total size of the shipment. 2. Small shipments (e.g. 1-2 pcs) can fit into smaller "leftover" spaces left by other packaging being delivered.	
	Handleability	Four-way handling reduces coss, as it allows unloading and loading from all sides.	Four-way handling included
	Handleability instruction	Visual marking on top of every lid prohibiting point loading on top packages - aim is to reduce handling errors during logistics chain and damage costs.	No visual marking of any kind on top packages.
Downstream	Mechanical stresses/product damage	1. Package construction has slightly higher weight capacity (durability) 2. Package can't be assembled wrong way, so package durability stays always the same. 3. Packages are less prone to slipping off each other. 4. Cardboard sleeves can't fall off the pallets (likely leading to destruction of packaging and products within, potentially a whole stack of products) 5. Point loading durability is smaller, but point loading prohibition area is marked visually. Point loading is an handling error and prohibited already in current contracts. Estimation is that due to better visual indications, frequency of pointloads should be so much less that it negates effects of worse point load durability.	1. Smaller weight capacity (durability) 2. Package can be assembled wrong way, leading to reduced durability. 3. Packages slipp off each other more easily due to more slippery, upwards bulging surface 4. Cardboard sleeves can slip off the pallets, likely leading to destruction of whole stack of packages and products within. Point loading durability better but no visual indicators of any kind prohibiting point loading, therefore increasing likelihood of point loading

Table 8. Outbound logistics improvements in road transport.

6.8 Outbound transport / air, improvements

Improvements mentioned in road transport apply also to air transport, with some additional air transport specific additions. Significantly increased placement options due to smaller individual package sizes increase flexibility and availability of timely air transport options, while reducing costs due to some of the products and their packaging fitting into more confined airliner cargo hold spaces than before or just by being able to place more to same area than before due to better stacking and package sizes. As weight plays significant part in air transport, smaller weights of new designs clearly reduce costs. Having option to place deliveries to bulk cargo more often than before, could offer additional cost savings potential. When smaller, special aircraft is required, the smaller package sizes are crucial so that they can even be used, instead of having to change to e.g. road or sea transport with greatly increased delivery time. There are some new countries (at least 12) where such air transport capability is now enabled. See table 9 for detailed information about improvements.

	Transport 2 / air	New packaging design	Old packaging design
Upstream	Administration & organizing	Facilitating faster delivery due to: 1. more products fitting per air cargo freight slot 2. Packages are able to be placed into more different air cargo slots than before. 3. Better access to bulk cargo reduces need for specialized air cargo capacity. 4. Better package space,form and weight factors open up wider options to choose from when booking air cargo capacity. 5. [redacted]	
Supply chain	Loading area utilization	Same as in transport 1 + air cargo specifics: 1. More products and packages fit into standard [redacted] slots or [redacted], less need for extra additional airplane bookings with [redacted]. 2. Air transports have limited bulk cargo space, so dimensionally smaller individual packages and small stacks enable placement of such small batches now to bulk cargo, which couldn't be fitted before. This reduces costs and need for additional air transport bookings. 3. With all products and package deliveries costs are reduced also due to real weight and dimensional weights being reduced, in some cases significantly.	By standard [redacted] in air transport on [redacted] basis and if deliveries can't fit into those then delivery will likely be delayed. Nevertheless either extra booking for another air transport need to be made and pay highers costs or [redacted]
	Flexibility of placement	1. Bulk cargo placement in airliners possible more often 2. Smaller product variants fit into smaller "aerial"/"local" aircraft than before	Many of the products can't be fitted to the smallest aerial/local aircraft (and in some cases to airliners bulk cargo)
Downstream	Handleability	Same as in transport 1 + 1. Less need for handling with smaller quantity shipments due to fitting into bulk 2. Easy open and closing due to cardboard sleeve+lid makes possible customs inspections easier and faster, therefore cheaper also	Same as in transport 1 + 1. More handling and touches required 2. Possible customs inspections can leave packaging partly "damaged" and inspections take more time, costing more.
	Handleability instruction	Same as in transport 1	Same as in transport 1
	Mechanical stresses	Same as in transport 1	Same as in transport 1

Table 9. Outbound logistics improvements in air transport.

6.9 Outbound transport / sea, improvements

Sea transport related improvements are mostly the same as with road transport (table 8), but there are some sea transport specific improvements, which are related to better conformity of packaging dimensions with containers' inner dimensions: up to 50 % more package stacks can be placed next to each other inside containers.

6.10 Customer and site improvements

All improvements listed so far add up when reaching the customer and/or destination site by e.g. getting there faster (in some cases significantly faster) and more often intact without any damages (table 10). Delivery units are easier and more convenient to handle and store on-site before taken into use (due to smaller form factor of packaging).

	Customer / site	New packaging design	Old packaging design
Upstream	Administration & organizing	1. Faster deliveries (see below), with smaller change of broken or damaged goods on-delivery create better reliability for operations on-site 2. Decreased risk of damaging goods on-site lead to easier handling of operations on-site	
	Fast & in-time delivery of products	**"Early-mid-end" transportation phases with trucks:** less need for dedicated FCL trucks, as some can be switched to STL or LCL instead. in STL and LCL shipments deliveries fit in smaller spaces, enabling wider access to deliveries. Positive effect hard to estimate, [redacted] if destination is one of [redacted] **"mid" transportation phase with air:** less need for [redacted] waiting for [redacted] flight available in some cases. This due to smaller package sizes and higher density of stacking and packaging. Nevertheless, both scenarios would have added to delivery time. Positive effect [redacted] **"Last mile" transportation phase:** usually the least efficient transportation phase, where are often changing local operators and from many countries there are experiences that e.g. small vans or in extreme cases even pickups are used every now and then e.g. due to accessibility of end destination. Due to significantly smaller package dimensions and higher density of stacking, effect on delivery times is especially positive in these cases. Positive effect [redacted] In total, depending on transportation types used and amount of distribution centers/quantity of transports, in extreme cases delivery times [redacted]	
	Goods delivered intact	See transport1 / road for details	See transport1 / road for details
Supply chai	Easy to handle packaging	In general reduced worktime: 1. Pallets with four-way handling 2. Easy open and reclosing of packaging (lid). 3. Cardboard sleeves easy to take off, handle and fold. 4. Accessories and options concentrated into a box which is always on the same place in pallets. Box is easy to handle and carry manually. Especially in dark, confined places eases small items finding, handling and preventing them from getting lost.	1. Pallets with four-way handling. 2. Hard to open packaging, hard to re-close. 3. Cardboard materials hard to handle and take a lot of space, hard to fold away 4. Accessories and options less easy to handle, due to being packed to different places depending on product and package variant and no "concentrated" accessories box used. 5. Orientation, location and amount of modules and accessories change between package variants, which might cause extra challenges in confined spaces or compact installation areas(lifting equipment placement, reorientation needs etc.)?

Table 10. Outbound logistics improvements from customer/site point of view 1/2

When taking products into use, packaging is easier to handle in confined spaces and to dismantle compared to before, which should also help in keeping the protective packaging elements in place longer, and therefore reducing risk and frequency of “last moment” damages right before installation of products. Easy and intuitive location of product accessories and products within packaging can improve site personnel experience. Lastly, as smaller packaging components and less materials are used compared to before, disposal of delivery packaging is easier and cheaper after they are no longer required. See table 11 for more detailed information about improvements.

Supply chain	Identification of products	One package= one module together with it's associated accessories and options, very logical. Reduced risk of losing items.	One package= one, two or three modules or only a lot of accessories and other items. Orientation and location of modules change on between package variants, so need to pay attention what variant is where now.
	Identification of accessories	Reduced risk of losing items & ease of use: inside packaging all accessories and options are in a separate box, so they can all be searched through from same place. Box always in same spot inside packaging.	Accessories and options separately, can be in different locations on the packaging, need to carry accessories "one by one" or gather together by personnel on-site
	Products easy to unpack, lift and install from packaging	Reduced work time, improved installation ergonomics, easier to work in confined spaces: 1. Easy removal of lid & sleeve in seconds by one person. 2. When cardboards removed, don't take much space. 3. Removed sleeves and lids could even be put on the floor to act as a "mattress" for installation workers (installation phases where laying on floor and on knees). 4. Alternatively components placed leaning against wall-->not obstructing working	1. Removing cardboard packaging is relatively hard and requires two persons to lift it away. 2. When cardboards removed, need to cut taping with knives and break cardboards into smaller parts, so that materials can be put away. (2. If cardboards are not cut, they take a lot of space which is problematic in often small installation areas with limited available free floor space) 3. Removed cardboards either need to be carried away somewhere else or use extra time to make them less obstructing
	Goods protected "until last moment"	Less/smaller risk of damaged products or accessories on-site (and therefore smaller risk of having to wait for replacement unit: 1. Due to easy open and close function of main cardboard packaging (sleeve + lid) and small dimensions, it's estimated that protective packaging is kept in place longer than before as it's not as restricting anymore. 2. Cardboard components are also easier to remove, handle and temporary store in a very confined space. This reduces damage risk e.g. for accidental impacts from falling tools, debris, sparks, liquids and rain what can be experienced every now and then on installation areas.	1. Alternative scenario to above section scenario: packaging is taken out already much before installations, leaving products prone to "last minute" damage before installations, in some cases have been cases where products left even for days "in the open".
Downstream	Disposal of packaging	Smaller temporary storage space, less worktime required, easier and faster: 1. Less materials to dispose 2. Cardboard components can be folded in seconds into original "Danfoss storage" form, therefore taking massively less space on-site and when disposing-->massively reducing expensive site installation personnel worktime and/or disposal costs due to smaller space usage	1. More and heavier materials. 2. Big space usage. Cardboard construction is hard to lift, handle and move. Disassembling is hard and time-consuming, due to tight fit of sleeves, taping of flaps and physically big construct etc.
	Environmentally friendly	Less equipment and services required: 1. Less materials used 2. recycled plastic in dust covers instead of normal PE plastic, 3. No extra metal transport supports from product's standing orientation used 4. Cardboard glues and coatings are environmentally friendly and compliant	

Table 11. Outbound logistics improvements from customer/site point of view 2/2

6.11 Reverse logistics

Reverse logistics is mainly improved by reducing frequency of damaged products during transportation and storage, which would lead to reclamations and additional back-and-forth shipments together with new substitutive products required to be made. Reverse logistics costs are enormously higher than other costs due to logistics chain being less optimized to this direction and making new products from scratch multiplies the overall original costs. Therefore, even small reduction in the reverse logistics brings significant savings.

6.12 Analysis and results of design processes related to packaging design and improvement suggestions

The following acknowledgements apply at least to new product design & implementation projects, based on discussions with persons taking part in NPD projects in question in this thesis. But it is reasonable to estimate that the same would apply also for R&D and production personnel working with existing products already in production.

In the following list are presented observations and conclusions regarding issues, which are complicating, hindering and/or preventing design and creation of optimized packaging and logistics.

1. There has been a general feeling that packaging related issues are kind of a "necessary evil", and therefore packaging related issues have traditionally been designed and finished very late on the projects, close to product releases when they must be done, and product design does not take so many resources anymore. Therefore, it can be said that packaging and logistics related issues in R&D department have not been as important compared to the many other product design related aspects. Designing product features from customer functionality point of view is very challenging and time demanding as it is, so "secondary" logistics issues are easier to leave to wait for later time.

2. When packaging related evaluation, design and implementation are left to a later phase of a project, possibilities to alter or change designs of parts, products or the product framework based on logistics needs, are small. This leads to a reactive packaging logistics design with limited possibilities for optimization. As development processes in general are usually iterative, lack of time and short time span left for these issues can easily lead to superficial optimizations or just making solutions which “work”, i.e. you can get goods from point A to B.
3. Often insufficient information and understanding in R&D about production specific issues, and which features are important for Supply Chain, is the reason why something might end up being not very good from logistics point of view.
4. Know-how is lacking for evaluating what are best choices for cost-efficient transportation both in inbound and outbound logistics.
5. R&D does not have a good visibility or knowledge about operational logistics costs and how they are formed.
6. Existing knowledge regarding structure of logistics costs and size are very strongly centered around the logistics engineer. Partial, incomplete knowledge is also centered around individual manufacturing engineers (including underwritten) working on new product projects.
7. Due to matrix organization model used in new product development, especially logistics engineer’s possibility to take part into the project is limited (resourcing). And on other hand, project personnel often might not think about logistics related issues in detail and they will not even try to contact logistics engineers.
8. There is no summarized and easily available “fact-packs” related to packaging and logistics, which would facilitate ongoing design evaluation from logistics point of view for R&D and other project personnel. Especially for R&D personnel (lead design engineers, mechanical engineers etc.) such would be helpful, as they are “separated” from daily operations and therefore lacking visibility. E.g. easy “rule of thumb” guidelines and information one-pagers with most crucial guidance would at least help designers to consider logistics issues and quickly point to right direction when making design choices.

9. There are not specialized, dedicated tools (e.g. Excel based) which would help to evaluate logistics costs and make comparisons between different design choices and their impact (between e.g. different package types, sizes and volume).
10. Earlier involvement of production and manufacturing specialists to early product development phases with their inputs would improve results and quality of designed solutions from logistics point of view (e.g. logistics engineers, manufacturing engineers, and material coordinators).
11. So far official organizational model has placed responsibility for outbound packaging design more on R&D personnel in projects, which is not optimal for reasons listed earlier (e.g. "distance" from shopfloor, operations and logistics processes). I think R&D is not natural location for the responsibility as R&D lacks direct, genuine interest and even visibility to optimize packaging due to being far away from daily operations and production issues as pointed out earlier. Therefore, in practice designing is done by manufacturing engineers in collaboration with logistics engineers. This makes sense from responsibility point of view as packaging has big effects also to production processes and layouts, not just on transportation costs and delivering products unharmed to their destination.
12. Better clarity to responsibilities regarding packaging development, together with changes to the allocation of responsibilities between supply chain and R&D personnel (and related resourcing), would improve current design processes and organizational structure. Making such changes would also facilitate achieving better outcomes from the design processes (i.e. packaging solutions and logistics related issues).

Most of the issues listed above work greatly against gaining holistic benefits for the operations from logistics cost-efficiency, general productivity, and ease of operations point of view. Many points are in direct contradiction with e.g. many of the main principles of DFL and Lean. Also, generally from management point of view things are not optimal: responsibilities are not completely clear, responsibilities are not situated “closest to the right persons”, and natural “incentives for development” are lacking for persons officially responsible for development.

If logistics related things are not considered also in the product design, or early enough, it can easily lead into a situation where the product design cannot be changed or improved later during the project anymore, even when some issue is found out. This in turn results into a situation where a less than optimal “add-on” fix needs to be made, or issue originating from product design is left largely to solve (or not) by production means. It could be i.e., adding new fastening items, support bars, cushioning materials, more screws, creating extra processes etc. These almost always end up as “permanent costs”.

6.13 Recognized synergies with current production and further development potentials

Reduced number of variations and interchangeability of constructs (variants) brings new possibilities for taking advantages of economies of scale in the production. Old packaging constructions did not scale e.g. during inbound transportation pipeline, and during outbound transportation pipeline ready packages had a lot of variations area wise– now space usage is much more efficient throughout supply chain. It was also concluded that there should not be significant obstacles preventing from taking the new outbound packaging constructions into use with old, existing benchmark products. Therefore, by unifying pallet sizes, significant overall volume increases per remaining pallet items would be gained. Same effect also trickles to related cardboard items of box pallet variants.

This is because the old/current box constructions use a sleeve + outer sleeve with lids + corner board construction (more parts) and these are divided at least over four different pallet sizes. Therefore, every different pallet size currently results to two new inner sleeves + outer sleeve combinations, per height introduced. Further, every new height further leads to two or three new items (sleeve + outer sleeve + corner board). Therefore, it is evident that copying the new construction to existing product families would bring benefits and should be relatively easy. On top of volume, cost, and scale benefits throughout supply chain, also planning, management and monitoring activities would be made easier. This in turn could release personnel resources into other more productive tasks. Examples of personnel which would be positively affected include e.g., sourcing managers, material coordinators (purchasers) and production logistics personnel.

Smaller amount of packaging materials and goods reduce risks and improve the probability of being able to run operations smoothly in abnormal situations. Tendering and changing suppliers could be easier due to smaller amount of work for both sides and volumes per tender item would be higher. From risk management perspective there could be some benefits: e.g. in a theoretical case of catastrophic event at the supplier (e.g. factory burning down), Danfoss could source substitutive suppliers and packaging material supplies easier. There would also be higher chances of being able to run Danfoss production without interruptions for a short period of time, as same pallet box constructions could be re-directed and interchanged between different production lines, taking advantage of the modular construction and interchangeability.

7 Conclusions

It can be said that the holistic design for logistics (DFL) approach is a good method to improve, optimize and create new capabilities for supply chain operations on a wider scale, as many costs in supply chain are greatly packaging dependent. DFL should be combined with other theories for maximum effect, as packaging and its interrelation with wider systemic supply chain level activities is an issue requiring multi-disciplinary approach. Some approaches and skills supplement DFL especially well, e.g.: Lean philosophy, Lean tools, project management know-how, and product development know-how combined with general logistics knowledge. One of the main challenges is to correctly identify the critical success factors and related driving features in real-life for the optimization of overall logistical and/or production concepts. One must be able to consider the bigger picture and various processes taking place throughout the supply chain, identifying the critical bottlenecks, while balancing conflicting requirements. It is likely that trade-offs need to be made during the development and at that point it becomes critical to understand causes, effects and benefits taking place in different phases of supply chain, to be able to make right choices regarding critical trade-offs.

Research findings are valid and reliable, as they have been designed, prototyped, tested and piloted according to case study framework and action research cycles in a multi-disciplinary team. Most research findings and new developments are already partially implemented to operations. New overall packaging concept has been evaluated successful in all phases: package construction and modularity, costs, delivery time improvements, number of variations, storage space improvements, ergonomics improvements, more than halving worker need, enabling introduction of automation due to dropped variations, creating semi-automated packaging operations etc. As before mentioned issues are measurable and quantifiable in practice, and financial metrics have been evaluated by different personnel during the projects, results are valid and reliable.

Research question 1: Could current package design be improved in some way for the new upcoming products from NPD project?

During the research it was found out that there were multiple areas in packaging design which could be improved, especially by applying a combination of DFL and Lean with thorough understanding of supply chain logistics. Due to diverse evaluation methods, improvement areas were found in all logistics steps from material supplier through factory operations until the customer, and finally the reverse flows. Many forms of Lean waste were present in most main logistical processes, packaging could be optimized from BOM and transport costs point of view, main functions of packaging could be improved, packaging introduced complexity to production operations and prevented introduction of automation. Also, general R&D and packaging development process weak points and improvement areas were identified.

Research question 2: How to minimize transportation and other packaging related costs by package design?

By creating a new packaging concept accounting for whole supply chain based on defined high-level DFL targets and a clear strategy for achieving the targets. In order to achieve best overall costs, efficiencies and create new capabilities without falling for partial optimizations, such as e.g. overweighting BOM or transport cost optimizations. Creating packaging and process design in unison and utilizing synergies, best results were (and can be) achieved. Results include creating and introducing a unified, cross-changeable modular packaging design into simultaneous use for multiple product lines, optimizing costs and reducing delivery times in external logistics, while reducing complexity and process variance inside the factory.

Research question 3: How could current packaging process be improved for the new upcoming products from NPD project?

Answer to this research question is strongly related to the answers for research questions one and two, and the related results. In general, by conducting current state analysis using Lean and DFL, significant amount of waste and process improvement areas were able to be identified. Many of packaging design features related to modularity, construction and concept philosophy enabled significant overhauls to packaging process by helping to remove existing process limitations and process variance. New packaging area layout and processes were made, accompanied with development and introduction of new material handling equipment and machinery. These new processes, concepts and technologies were then further iterated so that packaging function could be placed in-line with product production line, instead of having to use separate packaging areas. Lastly new processes, technologies and layout designs were combined to form a completely integrated packaging cell, where automation is introduced. End result and solution to the research question therefore is the semi-automated packaging cell, which is placed in-line with the production, and taking enormously less workforce, production logistics, time, layout space and physical operator strain to operate.

Research question 4: How to reduce worktime and worker need in packaging process for the new upcoming products from NPD project?

Answer is the combination of answers for first three research questions, but there are few especially critical answers so that worker need was able to be reduced from two to one (per package being made) and making packing time significantly shorter: reducing individual package component sizes and weights, reducing package and process variations, and lastly introducing new machinery, equipment, and automation.

I think that it is evident from the case study, that potential of innovative packaging and logistics design is significant for industrial organizations. Total improvements from modular packaging design, production area and process innovations, and overall logistical chain improvements are estimated to total into hundreds of thousands of Euros savings per year just with the case projects in question. Also transport delivery times, availability of different transport options, sustainability, technological know-how creation and various internal takt- and lead-times are improved on top of cost savings.

8 Discussion and further research suggestions

Subject was much more challenging and complex than originally anticipated and what one would think, due to better-than-expected potential identified. In my opinion packaging related issues are overlooked and underappreciated in general theory literature, where e.g. inventory optimization, insourcing or outsourcing of logistics services, transportation services tendering etc. takes much more attention than anything packaging related. Those are also often thought as main ways to improve logistics costs after strategical level supply chain design is done. This traditional focus is missing a great deal of value potential. Packaging related considerations can easily take only half a page or couple pages from logistics books with hundreds of pages. This is interesting, as it is evident from DFL and results achieved, that you can create significant benefits and impact on a supply chain wide scale by implementing smart packaging designs. This was proven in my thesis, even exceeding the original expectations. One can also look up "Ikea is obsessed about their packaging" news stories, published a few years back, and the achieved dramatic impact to their operations and profit margins, due to designing and redesigning complete products with heavy focus on packaging (logistics).

Therefore, it would be justified to give more attention to packaging design, its relationship and significance for the whole supply chain, and especially the logistics processes taking place during the supply chain. It seems that viewing packaging as an integral core part of value steams, production efficiency and customer value is not a widespread and emphasized issue. Based on the research findings, I believe it should be.

Products should be designed so that packaging is considered already in design phase, so that most optimized supply chain model and cost levels can be made. Introducing DFL as systematic evaluation dimension could significantly optimize lifecycle costs and creation of new processes. Design for manufacturing (DFM) and assembly (DFA) frameworks are already common and widespread design practices in numerous industrial companies.

DFL is not widespread yet, but it should be implemented into use as common practice.

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Empirical research case company's sources [restricted availability]:

Current state analysis of packages and packaging process:

1. Danfoss productivity improvement program's documentation for benchmark production areas and processes (2017)
2. Worktime study for old packaging process made by researcher (2018)
3. Cost calculations
4. Existing PDM data (including manufacturing drawings)
5. Existing work instructions for benchmarks, 73 pages (MAD01407 & MAD01459)

Transportation damages information: factory's transportation damage related emails/reclamation emails and summarized information from a dedicated go-through meeting (2019)

Historical product volume data for benchmark (2017-2019)

Product volume and transportation estimations for new products (2018-2019)

Factory historical transportation and transportation cost statistics for benchmark (2017-2019)

Listing of basic production costs documents (2018, 2020)

9 pcs 2–4-hour package design workshops on 12/2017, 3/2018, 6/2018, 1/2019, 2/2019, 6/2019, 8/2019, 6/2020, 11/2020

8 pcs 1–3-hour packaging process design workshops in 1/2018, 3/2018, 6/2018, 7/2018, 8/2018, 3/2019, 1/2020, 2/2020

Over hundred 0,5-1 hour package design bi-weekly, monthly, and dedicated design meetings between 2018-2021

Employee sources/participants:
Industrial Engineer (1 pcs)
Lead design engineers (3 pcs)
Logistics Engineer (1 pcs)
Maintenance and Serviceability Manager (1 pcs)
Manufacturing Engineers (2 pcs)
Mechanical Development Engineers (5 pcs)
Product Managers (2 pcs)
Production Director
Production workers (5 pcs)
Product Managers (2 pcs)
Reliability testing/validation Engineers (2 pcs)
R&D Project Managers (2 pcs)
Researcher
SC Project Managers (2 pcs)

External packaging consultants (2 pcs)

9 pcs 1-3h practical testing of prototypes -events between 1/2018-8/2020

6 pcs Laboratory and other durability testing reports

Logistics cost calculations Excel (2017)

Alternative package and transportation scenarios' unit cost calculation Excels made during research project by researcher (2018-2020)

3D-models of different inbound transportation, production storage and outbound transportation scenarios for old and new designs and their processes (2018-2020)

3D- model of new packaging area layout (2018-2020)

3D- models of new packaging equipment, packaging process and material flow (2018-2020)

3D-models of old and new package designs, product variants and product placements (2018-2021)

3D-models of alternative package combinations, product, and options placements (2018-2021)

Project A delivery packaging specification (2020)

Project B delivery packaging specification (2020)

Investment calculations for semi-automated packaging cell (2018)

Specification for semi-automated packaging cell and related equipment and systems (2019)

22 pcs packaging related manufacturing drawings for new designs (2020-2021)

Appendices

Appendix 1. Main research methods and data sources used in case study

Research Question 1: Could current package design be improved in some way for new upcoming products from NPD projects?
Research Question 2: How to minimize transportation and other packaging related costs by package design**?**
Research Question 3: How could current packaging process be improved for new upcoming products from NPD projects?
Research Question 4: How to reduce worktime and worker need in packaging process for upcoming products from NPD projects?

RQs	Data sources	Main investigators & participants	Data and analysis
1-4	Framework and targets creation based on transportation, Lean and DFL theory	Antti Mikkola	Analysis of theory and combining best parts into a new entity presenting targets/requirements
1-4	Current state analysis of packages and packaging process	Antti Mikkola	Data: documents, observations, numerical data, and comparison to theory. Analysis of existing variations, process variance, waste, and limitations.
1 & 2	Transportation damages information	Logistics and Quality Engineers, External consultant, Antti Mikkola	Data: documents Analysis: damage frequency, types, root causes and potential corrective actions
1-4	Historical and estimated product volumes data	Product and Project Managers, Antti Mikkola	Data: documents. Analysis: volume, product, and transportation mix
1-4	Factory transportation statistics	Logistics Engineer & Antti Mikkola	Data: documents. Analysis: costs, transportation, and lot size mix
1-4	Costs and billing statistics	Production Director, Logistics Engineer, Project Managers, Antti Mikkola	Data: documents. Internal and external SC costs (descriptive statistics)
1-4	interviews	Antti Mikkola	Data: various interviews as part of other events. Analysis: content analysis
1 & 2	External package design consultants/specialists	Antti Mikkola, S&C Project Managers, Logistics Engineer, occasionally R&D lead design Engineers	Data: general transportation information and design know-how for package and material design technicalities via discussions, interviews, and documents. Analysis: contents analysis
1 & 2	Multiple package design workshops	Changing group of project and stakeholder members	Data: experimentation, discussions, observations, and notes. Analysis: new insights, information gathering, and innovations; making design choices and "peer review", approvals
3 & 4	Multiple packaging process design workshops	Production Director, Manufacturing Engineer, Operations Manager, Project Manager, Antti Mikkola	Data: discussions, feedback for process design and notes. Analysis: information gathering, feasibility analysis, peer review, approvals

1 & 2	Bi-weekly & monthly meetings	Changing group of project and stakeholder members	Data: discussions and notes. Analysis: New information, problem solving, decisions, peer review
1-4	Design meetings and approvals	Changing group of project and stakeholder members	Data: discussions and notes. Analysis: New information, problem solving, decisions, approvals, peer review
1, 2 & 4	Prototyping rounds	Changing group of project and stakeholder members depending on subject	Data: experimentation, testing, observation, and documents Analysis: validating practicality of models, design features, new information for improving designs, validation, and reliability
1, 2 & 4	Practical testing of prototypes	External consultant, Antti Mikkola + changing members	Data: experimentation, observations, and notes. Analysis: validation and reliability of design choices, new inputs, and information
1, 2 & 4	Laboratory testing of prototypes	Changing group of project and stakeholder members	Data: testing documents (statistics, pictures, videos) Analysis: validation and reliability of designs' properties and durability
1-4	Lean tools and principles	Antti Mikkola	Data: theory. Analysis: Utilization in package and packaging process design to enhance set DFL drivers
2, 3 & 4	Existing & new worktime studies	Antti Mikkola	Existing data for benchmark, new data made for establishing capability of new processes
1, 3 & 4	Existing work instructions	Antti Mikkola	Data: documents. Analysis of existing process, process variance, waste, and limitations
1 & 2	Existing PDM data	Logistics Engineer, S&C Project Manager, Antti Mikkola	Data: documents. Analysis: technical, price and product relationship information gathering
1-3	3D-modeling of alternative package combinations and product placements	Antti Mikkola	Data: various 3D-models. Analysis: Package design hypotheses, concepting, experimentation, observation, support and context with other data, validation purposes
2-4	3D-modeling of new packaging layout, process, and equipment	Antti Mikkola	Data: various 3D-models. Analysis: Ideation, concept design, development, general analysis and validation for new layout, process, and equipment
1-4	Cost calculations for new and old packages and packaging processes	Antti Mikkola	Data: cost calculations. Analysis: cost estimations and comparisons
2, 3 & 4	Cost calculations for new and old packaging processes	Antti Mikkola	Data: cost calculations. Analysis: cost estimations and comparisons
2, 3 & 4	Investment calculations and presentations for new equipment	Antti Mikkola	Technical and economic feasibility and validation for new designed processes and technologies (semi-automated packaging cell)