TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

TOMMI VÄYRYNEN

IMPROVING FULL CHAIN EFFICIENCY IN ELEVATOR DELIVERIES BY DEVELOPING DESIGN FOR PACKAGING PRINCIPLES FOR PRODUCT DESIGN PROCESS

Master of Science Thesis

Examiners:
Professor Jurkka Kuusipalo and assistant professor Tero Juuti
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ABSTRACT

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The aim of this thesis is to define what functions are required from packaging in the supply chain of elevator products. It is possible to fulfill these requirements with package design and product design that supports the packaging solution. In order to have both, consideration of the supply chain must be ensured in the product development process. This can be achieved by increasing the packaging development team's role in the process and presenting what kind of benefits are possible to achieve with logistical packaging. Concept of logistical packaging and packability were studied in this thesis to benefit logistics and the installation process. Scope of this study is in new elevator business.

In a complex product such as an elevator it is challenging to optimize package sizes due to large variety in component sizes and weights. In order to control the package sizes, fixed and semifixed space reservations were set for each delivery module. Design for packaging guidelines were created to guide product designs towards logistical package sizes and packaging solutions that are suitable for the whole supply chain. With controlled package dimensions it was possible to create loading models that are based on modular measurements. Loading models were created for two case company's elevator products with the aim to increase transportation efficiency and improve the installation order. Study's results show that logistic efficiency and delivery process harmonization can be improved if package sizes are optimized for transportation. Package size harmonization and increased logistic efficiency are necessary in order to develop more environmentally friendly packaging solutions such as returnable packaging.

The product development process and tools of the case company were studied in order to find ways to improve the role of the packaging development team in the process. An implementation plan was created to ensure the implementation of the Design for packaging -concept as a part of the case company's product development process. The Design for packaging guidelines present implementation steps in addition to product design instructions.

TIIVISTELMÄ

TOMMI VÄYRYNEN: Toimitusketjun tehokkuuden parantaminen hissitoimituksissa kehittämällä Design for packaging -ohjeistus tuotesuunnitteluprosessille
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Työn tavoitteena oli selvittää, millaisia ominaisuuksia pakkauksilta vaaditaan hissitoimituksissa. Nämä vaatimukset on mahdollista toteuttaa pakkaussuunnittelulla sekä tuotteilla, jotka tukevat pakkausratkaisuita. Toimitusketju tulee paremmin huomioida osana tuotesuunnittelua, jotta tällaisia tuotteita voidaan kehittää. Tämä voidaan saavuttaa kasvattamalla pakkauskehitystiimin roolia tuotekehitysprosessissa, sekä osoittamalla millaisia hyötyjä voidaan saavuttaa logistisilla pakkauksilla. Logististen pakkausten ja pakattavuuden konseptia hyödynnettiin tässä työssä hyödyttämään logistiikkaa sekä asennusprosessia.

Hissien typpisissä monimutkaisissa tuotteissa pakkauskokojen optimoiminen on haastavaa, johtuen tuotteiden suuresta variaatioista ko’oissa ja painoissa. Pakkauskokojen kontrolloimiseksi jokaiselle toimitusmoduulille määriteltiin kokonaan tai osittain kiinteitä tilavarauksia. Design for packaging -ohjeistus luotiin ohjaamaan tuotesuunnittelua kohti logistisia pakkauksia ja pakkausratkaisuja, jotka olisivat toimivia koko toimitusketjussa. Kontrolloiduilla pakkauskoilla oli mahdollista luoda modulaarisiin mittoihin pohjautuvat lastausmallit. Lastausmallit luotiin kahdelle tapaustutkimusyrityksen olemassa olevalle hissituotteelle tarkoituksena logistisen tehokkuuden parantaminen ja asennusprosessin kehittäminen. Tutkimuksen tulokset osoittivat, että logistista tehokkuutta ja toimitusprosessin harmonisointia voidaan parantaa, mikäli pakkauskoot optimoidaan kuljetusvälineiden mukaan. Pakkauskokojen harmonisointi ja logistinen tehokkuus ovat tarpeellisia, jotta tulevaisuuden pakkausratkaisuja, kuten palautettavia pakkauksia, voitaisiin kehittää.

Implementointisuunnitelma luotiin osana tätä diplomityötä, jotta Design for packaging -konsepti voitaisiin liittää osaksi tuotekehitysprosessia. Tämä vaati tapaustutkimusyrityksen tuotekehitysprosessin ja -työkalujen tutkimista. Design for packaging -ohjeistus sisältää tuotesuunnitteluohjeistuksen lisäksi implementointiprosessin vastuualueet ja -tehtävät.

PREFACE

Looking back to the beginning of this writing process, it is great to see how much I have learned during this thesis. This has been an interesting challenge with its ups and downs. I want to thank Riitta, Mika and especially Timo for their guidance for this thesis. I believe that we managed to achieve the goal set for this work. For now, I can move towards new challenges awaiting me in Japan.

I also want to thank Tero Juuti and Jurkka Kuusipalo for providing assistance during this work. It is necessary to give special credit for Anna for all the help and support during this thesis and all these years. I am also happy to follow the footsteps of my brother. I also think that I can give some piece of mind to my dear parents who have always encouraged me in my career choice.

Tampere, 10.8.2017

Tommi Väyrynen

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ABBREVIATIONS AND DEFINITIONS

B2B	Business to Business
CAD	Computer-aided design
CWT	Counterweight
DC	Distribution center
DfP	Design for packaging
DfX	Design for X
EMI	Electromagnetic field
EPA	ESD protected area
ESD	Electrostatic discharge
IC	Integrated circuit
IPPC	International Plant Protection Convention
LTL	Less than truckload
MAP	Maintenance access panel
MRL	Machine room-less
NPPO	National plant protection organization
OSB	Oriented strand board
PE	Polyethylene
VCI	Volatile corrosion inhibitor

1. INTRODUCTION

Elevators are key parts of modern buildings. Elevators are used to provide vertical movement for people and cargo. Due to the high value of land in densely populated city areas, high rise development is beneficial. Apartment buildings and offices often require an elevator to provide modern living standards. In 2015 for example, 35,3 % of Finnish population lived in apartment buildings which shows that there is a demand for new elevators and modernizations (Suomen virallinen tilasto (SVT) 2016).

As a product elevators are complex, containing a large number of components that vary in size, shape, weight and sensitivity. In order to deliver such a product there has to be multiple packages also varying in the dimensions, weight and level of protection. Package variation causes challenges in the supply chain and therefore should be minimized or standardized. The concept of logistical packaging was studied in order to improve the elevator packages.

Existing researches about logistical packaging focus on packaging levels and modular packaging. Modularity allows a great level of optimization in transportation, storage and in retail markets. Saghir (2004b) points out the importance of concepts that allow a smoother handling of packages throughout the whole supply chain. Developing such concepts requires tools, methods and techniques to be implemented in the early stages of the product development process. Loading efficiency optimization is more complex with elevator packages than with fixed package sizes like palletized products.

Logistic operations aim to move and locate the inventory to a preferred place in preferred time with the lowest possible costs (Klevås 2006). According to Kim (2010) logistics is one of the most important factors in business competitiveness. Efficiency in logistics is pursued to achieve reduced costs and competitive advantage. Saghir (2004a) points out that as packaging is the interface with products and the supply chain, it should be designed in a way that it supports the logistic process. The used space and fill ratio in deliveries are relative to transportation efficiency. In order to achieve logistical packaging, product design should support and follow optimized package dimensions. This requires to have the package as a vital part of the product's design. IKEA's policy for example requires that product and packages are developed simultaneously in order to fulfill logistical demands (Bjärnemo et al. 2000). The result is a highly logistical packaging which is one of the reasons IKEA has such a great competitiveness in prices.

In the elevator deliveries, packages should be loaded according to the installation team's requests. This is an additional and specific demand compared to retail products. The installation process has great costs compared with the other phases of the supply chain. For example 1 hour of work on a construction site is much more expensive than 1 hour of work in a factory. If changes to packing process increases process time in a factory but reduce the installation time on site, it is most often beneficial. (Case study (1): Pitkänen) Therefore packaging should support both logistics and installation processes. Logistical packaging supports the installation process with harmonization, but the packability of components should be also considered. A high level of packability supports the access order and ease of component handling on the construction site.

The main results of this study were product development process update to improve the role of the packaging development team in the product design process, an improved fill ratio and harmonization in the elevator deliveries and implementation plan for the Design for packaging -concept. The concept was created with design guidelines and process improvements to change product design principles towards package based design.

1.1 Research questions and goals

In the focus of this research, the main members are the packaging development team, logistics, installation and product designers. Logistics operators and installation workers are the members who interact with packaging and can be considered as inner customers for the packaging development team. To be able to support the elevator installation process and logistics with packaging solutions, it is necessary to understand what kind of requirements they have for packaging. With packaging design, it is possible to fulfill these requirements only up to a certain level. Product design has an influence on packaging design and therefore greatly affects the final packaging solution. By understanding requirements, it is possible to review current solutions and develop new ones.

Another side of the problem is to understand how improved situation can be achieved. In order to introduce new ideas that guide products and packages towards logistical packaging, there has to be also an implementation plan and tools. The main research problems of this work can be summarized as following:

- How logistics and the elevator installation process can be improved with packaging solutions?
- How product design affects the packaging solutions?
- How and why packaging development should be implemented in earlier steps of the product development process?

In the current process there is no adequate influence in the product design by packaging related aspects and therefore the aim of this work is also to develop a solution that increases the packaging development team's role in product development projects. In order to do so, the following goals are set for this study:

- Identify and document requirements of logistics and installation for the packaging.

- Identify and document product design factors that affect the packaging.
- Analysis of the current state of the product development process from the packaging development team's point of view.
- Suggestions for future actions to improve packaging solutions and the development process.

The key element of this research is to find how current packages and delivery module structure could be improved. A case study is made to understand what kind of benefits and challenges there would be in the supply chain if packaging would be one of the design drivers in product development. Process improvements aim to increase the packaging development team's role in concept level projects. Tools and process improvements are mandatory factors enabling change in the organization.

The goal of this study was to identify how existing knowledge and best practices in the area of packaging and logistics can be implemented to case company's operations. Research focuses on current solutions and product development process and finding ways to improve the situation. Outcomes from this thesis are the identified requirements of the supply chain members for packaging, process improvements, product design guidelines from packaging perspective, an implementation plan for the Design for packaging -concept and comparison of loading models between logistical packaging and current solutions.

Study from business impact of created solutions and the creation of the training material for the implementation of the Design for packaging concept was left outside of the scope of this thesis. The Design for packaging document is not presented in this thesis. The cost effects of the packaging design changes were not studied in this work. Work focuses on the European market area so other continents' transportation equipment were not closely studied.

1.2 Research methods

As this thesis was made for a case company, identifying research was used for research problems in order to find problems areas and new solutions. Research was conducted as a qualitative research. Even though this research focuses on packaging, it was done in the consideration of the whole supply chain. Research from a wider point of view is substantial part of a qualitative research. (Hirsjärvi et al. 1997)

Case study was used as a research strategy for developing concepts which help facilitate the process of change in a concrete environment (Cunningham 1997; Hirsjärvi et al. 1997). The case study is used in this work because it answers the "how" or "why" questions (Yin 2003). The "how" question is answered by finding ways to achieve improved situation in the supply chain. The "why" question is answered by comparing current situation with the solution created in this thesis. It also enables to study how packaging affects the whole supply chain and how products affect packaging. The Design for packaging concept was chosen as a solution creation method because the products are the main challenge in the package size optimization.

The case study has two current elevator products that can be used as example cases. Examples show the basic idea, benefits and challenges of DfP (Design for packaging) principles in elevator products. In new products, the same ideas can be followed but project specific development and design choices have to be also made.

Literature review was first conducted to understand an elevator as a product and its installation process and supply chain structure. Structure of an elevator showed product's complexity in the supply chain and from the packaging design point of view. Review from existing studies provided information about the requirements, features and regulations for packaging. Other studies were reviewed starting from 1960 to this day in aim to understand the concept of logistical packaging. The concept of logistical packaging aims to improve all logistic operations and therefore it was suitable as a theoretical concept for this thesis (Saghir 2004b). It was also necessary to understand packaging requirements by the supply chain members in the elevator business. Information from literature review supported the empiric study of this thesis.

Second phase was conducted with theme interviews. All of the interviews were semi-structured interviews with widely varying questions due to different fields of the expertise and responsibilities of interviewees. Interviews were the main data source and the starting point for analysis which is one of the key elements in qualitative research (DiCicco-Bloom & Crabtree 2006). In this phase, the goal was to understand the case company's delivery structure, used transportation vehicles, the installation process, the product development process, demands and restrictions for packaging. Data collection was an iterative process to understand research questions, where eventually a saturation point was achieved with no new themes emerging. This signaled that data collection was complete. (Kuzel 1999, cited in DiCicco-Bloom & Crabtree 2006) From vehicle information it was possible to define how much space there is available for packages in different stages of the supply chain. Installation order and logistic measurements were key information in order to review the current module structure.

Third phase was to analyze the collected data. In this phase current packages were reviewed and compared with modular measurements featured in existing studies and standards. Three main goals were to reduce package sizes, reduce the time that packages are open on site, and harmonize packaging dimensions. 3D-modeling was used to achieve loading models. Case study was made to understand how the concept of logistical packaging would affect existing elevator products.

Fourth phase included deeper understanding about the principles of the product development process. The case company's own development process was compared with the development process presented in literature. By understanding the tools, methods and phases of the case company's processes, it was possible to develop an implementation plan for the DfP-concept. The goal was to ensure that packaging aspects are always considered and possible development opportunities are not missed. An implementation plan was made in order to guarantee that DfP-concept can be integrated as a part the product development process.

2. ELEVATOR

There are different elevator solutions for providing vertical movement for people and freight. Elevators are used in various locations on land, sea and in airplanes. Most commonly elevators are used in buildings. Elevators can be divided by their function method to cylinder and rope elevators. Cylinder elevators are mainly used for shorter lifting distances. The cylinder is located at the bottom of the elevator shaft and its other end is connected to the bottom of the car. Fluid is used to control the movement of a piston inside the cylinder. When fluid is pumped to the cylinder, the piston rises and pushes the car upwards. Markets for cylinder elevators are both in passenger and freight lifting. (Strakosch & Caporale 2010; Sachs et al. 2015)

Modern rope elevators are called traction elevators which are used for mid- and high rise buildings. The name originates from the groove used to control the traction of the ropes. Traction elevators have a counterweight compensating the weight of the car. Car and counterweight are connected to each other with a rope. Different roping arrangements can be used between the car and counterweight. Different arrangements result in different lifting weight and speed. (Strakosch & Caporale 2010) Example roping configurations are presented in Figure 1.

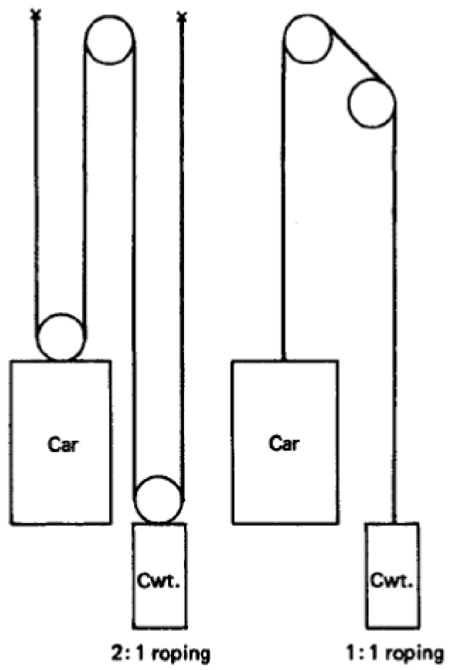

Figure 1. *Roping arrangement (Strakosch & Caporale 2010).*

Traction elevators can have a separate machine room on the top of the elevator shaft. However the modern mid-rise traction elevator trend is moving towards MRL (machine room-less) solutions. MRL solutions have machinery placed in the shaft. (Sachs et al. 2015) An elevator as a product is composed of multiple parts that work independently or with other components. These parts can be divided by their function and installation phase. The main parts of an elevator are presented in Figure 2 and in Table 1. In Figure 2 is presented an elevator which has a separate machine room on top of the shaft.

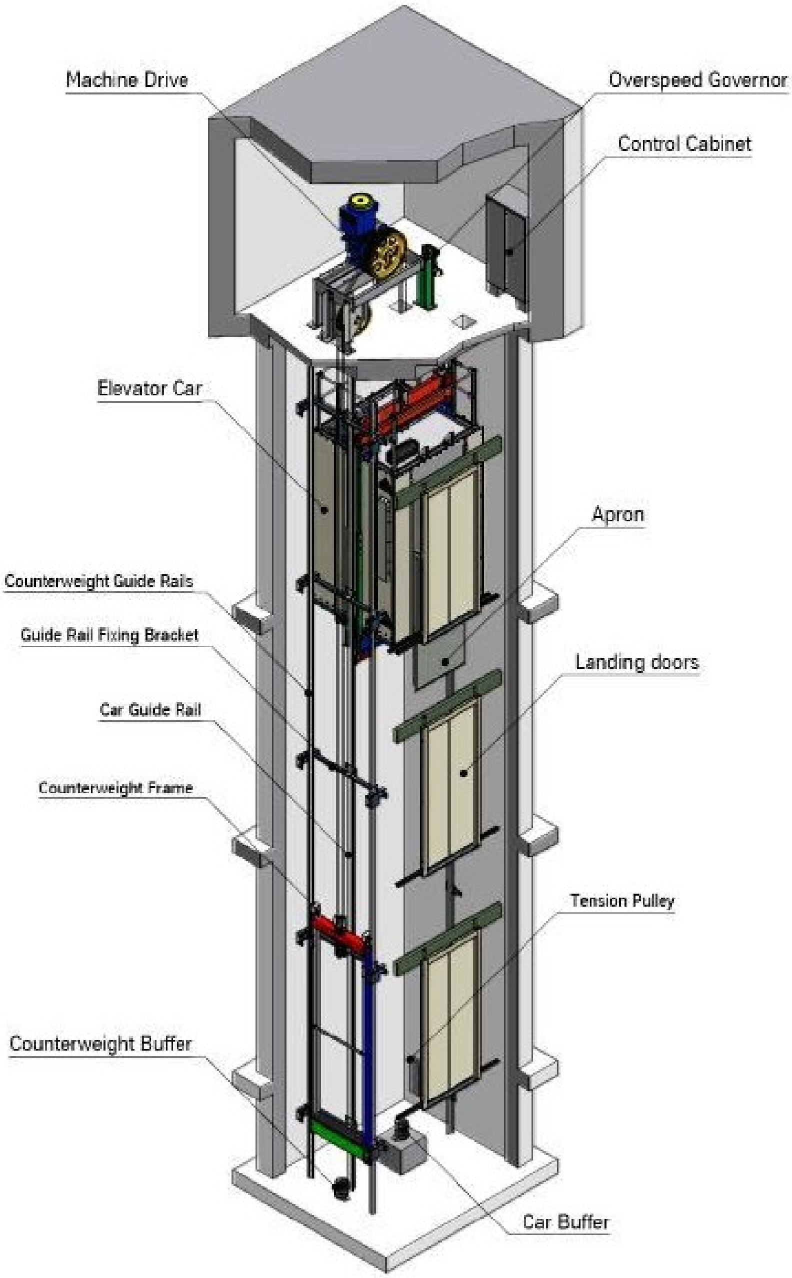

Figure 2. *A structure of an traction elevator (Basic Elevator Components - Part One).*

Table 1. *Elevator's main parts and their functions.*

Part	Function
Machinery	Used for moving the elevator car and counterweight. For heavy machinery there might be need for a bedplate.
Shaft equipment	Consists ropes, guiderails and other structural parts required in elevator shaft.
Car	Elevator car is the used structure for passengers. Car connects to ropes with a sling which is a support structure around the car.
Counterweight	Works as a counter load for the car to enable more efficient lifting. Filler weights are placed inside a counterweight frame so that the required weight is achieved.
Door systems	Door systems work both in car and in landing floors. Door operator is used to control door movement.
Electrification	Control panels, drives, wires and other electric components required for an elevator to function. Signalization provides user interface for passengers and consists for example elevator order buttons and floor displays.
Safety equipment	Vital parts of an elevator for ensuring safe usage.
Construction elements	Construction elements for the shaft.

Different parts are often manufactured by different production cells or suppliers. Parts must be packed for transportation and therefore it is reasonable to pack these parts already at their manufacturing location. This is one factor affecting the formation of the module structure for deliveries. Different parts presented in the Table 1 can also be placed under the same delivery module.

3. INSTALLATION

Elevator installation is a process where the packed elevator components are assembled into a fully operational elevator. This process can have variation due to different working methods or product types. Also the location where the elevator is installed has a major role in the process. Different countries have different rules concerning construction sites. In addition to the site regulations construction projects often have different schedules and elevator installation is integrated into some phase. The schedule of different projects can vary substantially. Some projects can have a single elevator installation to a residence building whereas other project can have an installation of tens of elevators to a whole metro line.

3.1 Installation process

The installation process starts with arrival on site and receiving the delivery. After this, the mandatory pre-inspections of the installation area are conducted. Pre-set requirements for the installation have to exist in order for the installation work to begin. Measurements of the elevator shaft and other key points are checked so that the ordered elevator can be installed without problems. This way possible errors can be detected initially and not faced in the halfway of the installation. After inspections, materials are prepared for installation according to installation manuals. All components have to be checked before installing to be sure that they are not damaged or deformed. At the end of the installation process, several checks are conducted to ensure a safe and correct operation of the elevator.

Installation processes can be divided into three main types. These types are presented below:

- Residential buildings
- Major projects
- Marine

Projects are placed under these types by the type of the product, installation location and by the scale of the project. Major projects can have a large number of basic residence elevators or only few special elevators. High rise projects such as skyscrapers are considered major projects.

Installation is a supply chain phase with potential for cost savings and therefore it is studied and improved continuously. The whole development and supply process aims for a situation in which the time needed to the installation process is as minimal as possible.

Time is more valuable on the construction site than in the factory (Case study (1): Pitkänen).

3.1.1 Residential buildings

Elevator products for residential buildings are the largest segment based on the volumes. The same type of products can be used in public buildings like office buildings or shopping malls. Single elevator installations to a residence building can be planned easier than more complex projects. Installation time for a single elevator is around one week (Case study (2): Baker et al.).

Elevator products in this segment are the main focus of this thesis due to the high volumes. Process improvements affect a large number of projects and major annual savings can be achieved. Because these type of elevators have relatively similar installation environments, common installation and site manuals can be created. The example procedure can often be followed from one project to another. Working methods are optimized for a safe and a less time consuming process.

Residential building elevators are simple from a process point of view because in most cases there is only one elevator to be installed. Site logistics require one area where all the packages can be stored. The handling of the packages on site does not cause a lot of time consuming problems because all the components are installed in the same elevator and packages are also easily identified. (Case study (1): Pitkänen)

3.1.2 High rise buildings

High rise buildings are more complex construction projects usually with massive amount of different parties involved in different phases. These projects often have a remarkable financial and publicity value. High rise buildings are in most cases located in key locations and considered as landmarks. The publicity value of an elevator in a single skyscraper is much greater than in multiple residence buildings. These projects and buildings are often used as a reference in advertising.

Every major project is different from others and instructions can be created and followed only to a certain limit. These projects can have special made elevators or other solutions that have not been used before. Duration of these projects can last up to around one year. Being a part of a construction project for this long requires a lot of applied solutions and flexibility. Site conditions and access areas may change, and installation steps might have to be carried out from different locations than initially planned. (Case study (1): Pitkänen)

In major projects it is possible to have tens of elevators. There are often few different elevators for different usage or lifting height. When the number of floors rise in elevator products, also the number of guiderails, brackets, doors and signalization etc. rises. There is a huge difference in the amount of material when comparing an elevator covering five floors with a 40-floor elevator. Effects multiply when the number of elevators increase. This results in a much more challenging planning of site logistics. Immense amount of time in the installation process is used to moving packages on site and trying to find correct packages. This work effort does not produce any value and can be considered as a waste of time. When unloading, the packages should inform initial installation location, so that packages can be grouped correctly right away. Installation location or the elevator name should be easily identified and understood. Unloading done by following elevator numbers does not result in a fast and wanted outcome. One solution would be to use color markings to indicate elevator group. By doing so the truck driver would know right away which package should be unloaded to which area. (Case study (1): Pitkänen)

Depending on the location and site there are different ways to deliver and store packages. Packages can be stored on site if adequate amount of storage space is available. In city areas it is not common to have large storage areas, so therefore packages are transported from reloading point to the site in groups. It is up to the project management to decide what, when and how these packages are delivered. A common way is to collect the packages of a certain installation phase from all the elevators belonging to the same elevator group. This way the installation of for example five elevators can be started instead of installing elevators one by one. In reloading point package groups can be collected and loaded according to installation phase and not by elevators like in DC. (Case study (1): Pitkänen)

Installing elevators in this way would require different packaging solutions. If elevator groups' components are delivered step by step, it means that reloading point works as a picking warehouse. For example transporting door components from reloading point to the site requires collecting door components for each landing floor from the packages of five different elevators. The same picking can be done on site if packages are there. If doors are packed into a single package, it means that by taking a single door from each package, components are transported without packages. This is an undesired option because it often results in damaged or lost components. To support this kind of material handling, doors should be packed in individual landing specific packages that could be picked from pallets when needed. On the contrary solution like this adds used packaging materials and waste. (Case study (1): Pitkänen)

3.1.3 Marine elevators

Marine elevators have a different installation environment. These products are installed inside a shaft which is located on a ferry or a cruiser. Dimensions, regulations and requirements are different than in elevators that are installed into structures on land. Fire regulations for example are stricter because cruisers do not have a concrete shaft blocking the spread of fire. When an elevator is located inside a cruiser, it has a foundation that moves. This has to be taken into account in design to ensure safety and ride comfort.

Marine elevators are so called C-process elevators, meaning they have special specifications or solutions like some elevators in high rise projects. In marine projects, the working environment is a shipyard instead of a construction site. Shipyards are well-equipped working environments and cranes can be utilized for material handling in some phases. Elevator installation has to follow the phases of the shipbuilding. Therefore the whole installation process can take months. In some cases the company that installs elevators has to organize and be in charge of other work conducted in that area of the ship. Work of other contractors in the area poses additional challenges to the process. (Case study (3): Karppinen)

Marine projects can have a large number of elevators. In ferries, the normal number of elevators is from 7 to 10 and in cruisers it is from 20 to 40. Material management is challenging due to the large number of packages. Shipyards have often limited storage areas and these areas have to be rented. Therefore planned shipments are made from reloading point to the shipyard. Packages can be on site for months in a humid environment, posing a challenge on packaging. Heavy duty packages are preferred. (Case study (3): Karppinen)

Installation process of marine elevators can be divided to three main types:

- Block
- Plug-in
- Backbone

Block-type process closely follows the phases of shipbuilding. The shaft is built from large segments which are placed one by one to build the ship. Installation of shaft components follows behind. The whole shaft is built in front of the installation process so a scaffold has to be used. When key components are installed to the full height shaft and the car is lowered from the top, the final ship segment is placed which seals the shaft. Other installation phases can be conducted after this key phase which is tightly bound to the building of the ship. (Case study (3): Karppinen)

A Plug-in installation is an installation process where a steel shaft is built and shaft components are installed inside the metal structure on land. After shaft installations are done, the whole shaft is lifted to its final place. A fully assembled car is lifted and lowered to the shaft from the top. (Case study (3): Karppinen)

Backbone is close to the plug-in type installation. Backbone supports the installation of two or more elevators to the same shaft. Instead of lowering a full shaft only a single wall is lowered. This wall has shaft equipment and machinery installed on both sides and it is lifted to the middle of the shaft. Solid walls and lifted wall form a full shaft for a single elevator on both sides of the wall. (Case study (3): Karppinen)

Marine elevators can also have elevators with a machine room when heavy or high lifting is needed. In machine room elevators, a separate bedplate is installed on top of the shaft. Machinery and control devices are installed on the bedplate. Walls are assembled according to drawings of the ship to form the machine room. (Case study (3): Karppinen)

3.2 Installation order

Installation is conducted in pre-defined steps. In Table 2 is shown the installation order of the main parts of an elevator. Variation between different products might occur. Installation phases are listed in the order where parts are installed in the shaft or landing floors. Overspeed governor's place for example changes during the installation process.

Table 2. *Installation order of an elevator.*

Phase	Components
1.	Overspeed governor (1st to the hoisting tool)
2.	First guiderails & brackets
3.	Buffers & CWT (Counter weight)
4.	Sling
5.	Car exterior & filler weights
6.	Car interior
7.	Machinery & rope fixings
8.	Landing doors
9.	Car front wall & car door
10.	Last landing door
11.	Electrification and control panels
12.	Wiring (shaft & car)
13.	Rope
14.	Balancing and safety checks

Installation starts from setting a hoisting tool which is used throughout the installation. A hoisting tool is used for moving heavy components and the elevator until machinery is installed. A security device called overspeed governor is also installed. Overspeed governor is connected to the hoisting tool for safe operation. (Case study (2): Baker et al.)

The first elevator components to be installed are the first brackets and guiderails. Guiderails provide a base for the car to move in a controlled way up and down in the shaft. Because elevator moves along these guide rails, more guiderails and brackets need to be installed as the installation process continues upwards. (Case study (2): Baker et al.)

After installing the first guiderails, safety buffers are installed to the bottom of the shaft. Buffers are used to stop the elevator car in case it does not stop to the bottom floor for some reason. A counterweight frame is also installed. Bottom part of the sling is installed which works as a foundation on which the car is assembled. Before fully assembling the car and sling, an initial loading of the counterweight is done. A fully assembled sling forms a frame around the car and works as support structure. Balustrades are installed on top of the car because the roof is a working area for the rest of the installation done in the shaft. A hoisting device is connected to the car sling so the car can be moved and installation continued. After the car and the sling are assembled car interiors can be installed. Materials used inside the car can vary depending on the customer's preferences. (Case study (2): Baker et al.)

Rest of the guiderails and guiderail brackets are installed so that the car can be moved to the top of the shaft. Overspeed governor is moved to its final location before installing the machinery. Rope hitches are installed with machinery. After the machinery installation is completed, door parts to the car and to the landing floors can be installed.

The next phase is the installation of electrification components and wiring. Drive, control and maintenance panels are installed. Their locations vary between MRL elevators and elevators with a machine room. Wiring is started from the top of the shaft and installation process moves downwards. Signalization is installed in landing floors. The last electric components are car electrification and COP (Car operating panel) which are installed inside the car. (Case study (2): Baker et al.)

The final component to be installed is the roping. Ropes are checked, installed in the rope hitches and routed. Remaining filler weights are placed in the car and balancing of the car and CWT is conducted. After rope installation final inspections and cleaning are conducted. Mandatory testing is carried out to ensure the correct and safe operation for the product. When the product is confirmed to work as required, handover to the customer can be made. After the handover, the elevator is maintained according to maintenance regulations and agreements. (Case study (2): Baker et al.)

4. LOGISTICS

According to Rushton et al. (2006) logistics is defined to be the efficient transfer of goods throughout the whole supply chain in a cost-effective way. Packages are important part of logistics because they are involved in every stage of the supply chain. Reason why packaging affects the supply chain is because it is an interface between supply chain and its main customer (Saghir 2004a). Costs from storage and transportation for example are directly related to the size and density of packages. (Twede 1994; Rushton et al. 2006)

4.1 Module structure

The elevators studied in this work are divided into 10 different delivery modules (Case study (5): Räisänen 2011). These modules have formed from manufacturing, logistical and installation reasons. In most cases modules have only a single delivery unit but in some modules there can be multiple packages under a single module.

Some of the modules are completely delivered by a single module supplier. In a product such as an elevator that has a large number of components, it is not often reasonable to manufacture everything in the company's own production facilities. Company's own production is focused on key areas with the strongest expertise. Both own manufacturing facilities and suppliers order components and pack them with self-manufactured components to have a full delivery module. This is part of the factory inbound presented in Figure 3.

4.2 Supply chain

The case company operates at global markets. Production locations are focused in Europe, North America, China and India. Elevator products do not have a continuous delivery flow to a certain customer destination. Customer locations vary between large city areas, suburban areas and towns. This makes delivery planning more challenging than for example in retail business where delivery destinations are fixed.

DCs (distribution centers) are used in order to control material flows, storage and shipping. DCs are located at key points for both domestic and international operations. Logistics operations in DCs are often outsourced and operated by 3rd party logistics companies. Logistics processes in DCs are receiving, storing, picking, shipping and handling of packages (Hellström & Saghir 2007). In case company's delivery method, the parts are packed at manufacturing locations to the final packages and delivered in larger package groups to DCs. For example multiple machineries are delivered in the same shipment to the DC. Module suppliers deliver modules in the same way. This is called inbound logistics from DC's point of view. Inbound logistics is usually easy to plan and optimize because there are larger quantities of packages of the same kind.

From various inbound deliveries packages are stored and eventually grouped according to the elevator numbers for outbound delivery. Delivering products from DC to installation sites or to an additional warehouse is more complex than inbound deliveries. Reason for this is the large variation in package sizes and weights. To achieve the best situation for the supply chain, packaging solutions need to be optimal for all delivery phases.

DCs are in certain locations from which the shipments are not always the most practical to deliver straight to the site. Elevators also have an installation schedule, which is a limited time in the construction project. Materials and installation staff must be in the location on time. In some cases the delivery's time window on site can be only around 30 minutes. To make timing easier additional warehouses can be used which are located closer to the customer areas. In some countries, deliveries are made straight from DC to the site even though distances would be over 1000 km. (Case study (4): Latvanne) Delivery structure is presented in Figure 3.

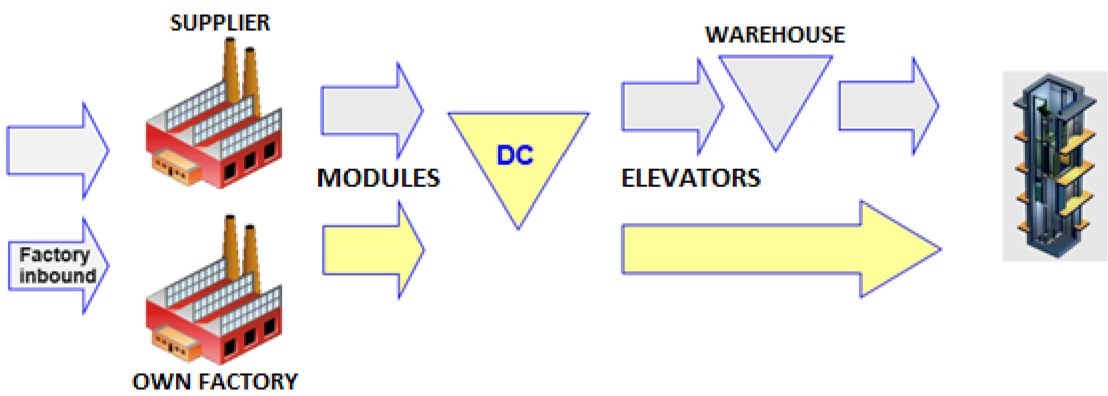

Figure 3. *Full chain structure in elevator deliveries (adapted from Case study (6): Ahava 2013).*

The delivery model varies between projects and locations. Countries like Australia or New Zealand that require long sea transportation often have warehouses next to harbor areas. From these warehouses deliveries are made directly to sites. In some countries it is reasonable to operate a larger warehouse. Country specific warehouses can be used for example due to strict custom regulations which might substantially increase the delivery time. Uncertainty in deliveries can be decreased by using a larger warehouse. (Case study (4): Latvanne)

In special cases products can be ordered or delivered outside the supply chain structure. Urgent deliveries like in case of damaged components are conducted for example by courier services. Some special components can be ordered from suppliers directly to the site or to a site specific warehouse. (Case study (4): Latvanne)

4.3 Transportation

Variation in delivery solutions occurs when operation and customer area is global. This results in the usage of different transportation due to variety between continents. When optimizing packages for logistics, transportation is a vital element to be focused on. In Table 3 are shown used trailer solutions for road deliveries.

Table 3. *Typical truck trailer dimensions (adapted from Case study (7): Rinne 2016).*

Trailer	Length internal (mm)	Width internal (mm)	Height internal (mm)	Volume (m^3)
European	13 350	2430	2550	82
USA Flat bead	16 150/14 630	2438-2590	-	-
USA LTL (less than truckload)	16 640	2440	2590	105
US Van trailer	15 849-16 0002	2489-2590	2682-2794	-
12,5 m Truck (China)	12 500	2250	2500	70
16 m Truck (China)	16 000	2700	2700	117
17,5 m Truck (China)	17 500	2700	2700	128
FTL (India)	5 800	2200	-	-
Taurus (India)	6700	2400	-	-

Flat beds are often more expensive than van trailers due to low offering in some regions. The downfall with flat beds is that capacity of the cargo area cannot be fully used like in boxed vans. Curtain-sided trailers should be favored for faster loading and unloading. Cargo space must be enclosed to maintain protection for packages during transit but if closed trailers can't be used, other covers like tarpaulin should be applied. Usage of tarpaulin is an additional loading phase that vans do not have and it takes more time to load flat beds in DCs. There is also a higher tendency for packages to get damaged in open space trailers when transportation slings are tightened. Despite the defects in flatbeds, they have to be used for unloading convenience and regional regulations instead of van trailers in DC to site deliveries. (Case study (4): Latvanne)

Truck dimensions shown in the Table 3 are for transportations which are mainly used for deliveries to DC and from DC to other warehouses. Larger vehicles are not suitable for site deliveries in most cases and therefore smaller vehicles are used. Dimensions of smaller trucks are shown in Table 4. These trucks are often equipped with a crane so unloading can be done without additional equipment required on site. This type of delivery structure is common in Europe. For overseas deliveries sea containers are used and their measurements are presented in Table 5. (Case study (4): Latvanne**;** Case study (8): Leppä)

Table 4. *Dimensions of last mile trucks used from warehouses to site.*

Trailer	Length internal (mm)	Width internal (mm)	Height internal (mm)	Volume (m^3)
Finland	6500-13600	2480-2510	2200-2820	46,4
Europe	6000-13000	2400-2500	Open / 2450	-

Table 5. *Typical freight container dimensions (adapted from Case study (7): Rinne 2016).*

Container	Length internal (mm)	Width internal (mm)	Height internal (mm)	Door opening (mm)	Volume (m^3)	Max payload (kg)
20 ft	5890	2330	2380	2330 × 2280	33	21 600
40 ft	12010	2330	2380	2330 × 2280	67	26 700
40 ft, High cube	12010	2330	2690	2330 × 2560	76,3	26 460

Sea containers are an efficient handling unit in international trade. Containers can be handled and transported with different vehicle types on road, sea, and on railroads. Metal body of these containers offers excellent mechanical protection. On the other hand closed containers can have high humidity and cause mold or corrosion problems. Design principles for packaging should be optimized for 40’ container instead of 20’ containers. 20’ containers are not used as much and therefore due to slower rotation they might be even more expensive than 40’ containers. (Case study (4): Latvanne)

4.4 Modular measurement system

The aim for the modular system is to standardize different components in the transportation chain so viability and safety can be optimized in transport operations. Packages, cargo units, pallets, containers and transport vehicles are all part of the system. The modular measurement system offers economic advantages when the payload area can be utilized efficiently. (Transportation Information Service) Packaging, starting from the primary package level, should be designed in a way that the tertiary level is suitable for the modular measurement system. Pallet adaptability has effect on both volume and area efficiency in transportation and by using modular measures and standardized pallets, empty space in transportation can be minimized. (Järvi-Kääriäinen & Ollila 2007; Hellström & Saghir 2007)

According to Saphire (1994) cost-efficient transportation requires the optimum utilization of available space inside transportation. To achieve this, the packaging development has to focus on logistical packaging, where functionality as part of the logistics is a key factor (Saghir 2004b). Hellström & Saghir (2007) pointed out tertiary packaging being the most important level for logistics.

Transportation systems are mainly based on the usage of standardized pallets and containers. The advantage of pallets is the ability to use them in the same transportation system regardless of the product, excluding special situations which would require extensive protection or weight durability. Pallets are an internationally used solution for material handling, but there are size variations between areas. Increased harmonization of pallet sizes and other logistic measurements would be beneficial. The regional usage of pallets is shown in Table 6 and an example pallet structure in Figure 4. (Järvi-Kääriäinen & Ollila 2007)

Table 6. *Usage of intercontinental pallet sizes (Flat pallets for intercontinental materials handling 2003).*

Europe		North America		Pacific rim	
Metric (mm)	Imperial (in)	Metric (mm)	Imperial (in)	Metric (mm)	Imperial (in)
1 200 × 800	$47^{1/4} \times 31^{1/2}$	1 219 × 1 016	48 × 40	1 100 × 1 100	$43^{1/4} \times 43^{1/4}$
1 200 × 1 000	$47^{1/4} \times 39^{3/8}$	1 067 × 1 067	42 × 42		
1 140 × 1 140	$44^{7/8} \times 44^{7/8}$				

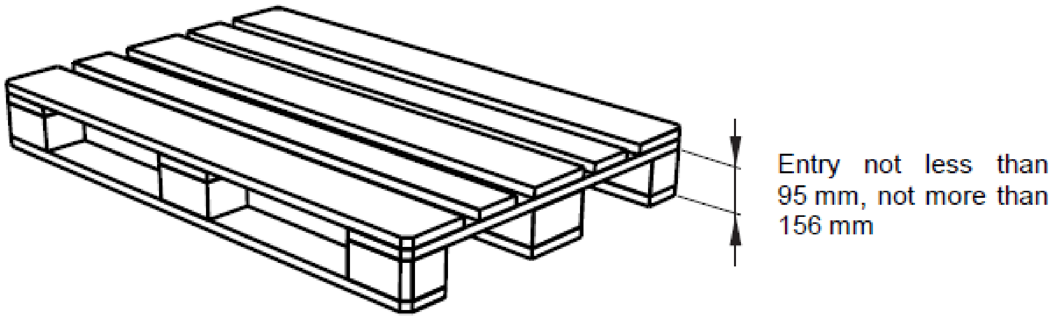

Figure 4. *EUR-pallet (Flat pallets for materials handling 2002).*

In addition to pallet size, standards also define required height under the pallet. Measurements are set to ensure convenient handling. This allows different pallet jacks, forklifts and other handling equipment to be used. For automatic storage, a minimum height of 100 mm is recommended. (Flat pallets for materials handling 2002)

The modular measurement system is based on mm 600 × 400 mm module which is optimized for the metric system. A EUR-pallet with measurements of mm 1200 × 800 mm follows this measurement system. The benefits of a EUR-pallet are the ability to be loaded efficiently inside a truck and moved through most doorways. Up to three EUR-pallets can be loaded abreast into a Euro-trailer. With ISO-pallets it is only possible to load two side by side. The problem is that EUR-pallets and the presented module measurement systems are not optimized for ISO-standard containers. This is why there is less empty space in containers when it is loaded with ISO-pallets compared with EUR-pallets. The problem is presented in Figure 5 where on the left side is a EUR-pallet and on the right side is a EUR2-pallet.

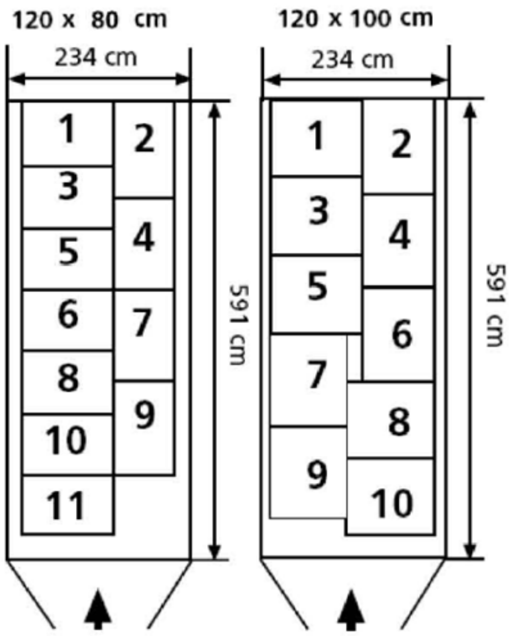

Figure 5. *Loading plans of EUR-pallet and EUR2-pallet in a 20’ container (DHL).*

Loading efficiency with EUR-pallet is 76,4 %. EUR2-pallet has a better fill ratio of 86,8 %. EUR2-pallet measurements are closer to ISO-pallet (1219 mm × 1016 mm) which is optimized for ISO containers. (DHL)

Variation and different measurement systems make optimization more challenging. Optimizing a package for the dimensions of a trailer poses challenges when the package is transported in a container. Sea containers are slightly too narrow so that EUR pallets could be loaded perfectly side by side. This results in an inefficient usage of space. If the container would be slightly wider, 14 EUR-pallets could be loaded on the floor instead of 11.

5. PACKAGING

Packaging has been defined in many ways. Natarajan et al. (2015) define that packaging can be described for example as the art, science and technology of preparing goods for transport and sale. According to Hellström & Saghir (2007) packaging is a coordinated system for preparing products for safe, secure and efficient handling, transport, distribution, storage, retailing, consumption, recovery, reuse or disposal. Twede (1994) points out the importance of packaging by stating that every factory and/or logistical organization receives and ships products packed.

Usually the product inside is concealed from view, which makes the package the sole interface between the product and the customer. Main difference to retail packaging is that industrial packages do not have to sell the product. Quality and appearance should not be understated because packages might be the first contact to the customer after business agreements. Everything related to the product gives impressions from service and product quality and therefore packaging has an important role for company's brand image. Same rule applies to B2B (business to business) packages. Damaged package or product with poorly designed package cause issues to the customer company's own operations. (Rod Sara 1990; Natarajan et al. 2015)

5.1 Types of packaging

There are two types of packaging: *consumer* and *logistical.* Consumer packaging is governed by sales and marketing aspects. Logistical packaging provides foundation for product flow during manufacturing, shipping and storage. (Twede 1994) According to Saphire (1994) and Hellström & Saghir (2007) packaging can be generally divided into primary, secondary and tertiary packaging. These packaging system levels and functions are presented in Table 7 and Figure 6.

Table 7. *Packaging system levels (European Parliament and Council 1994).*

Package level	Other terms	Description
Primary	Sales / Retail Consumer	Contains the product. The sale unit at the point of the purchase
Secondary	Display Merchandising	Packaging used to contain or present a number of primary packages
Tertiary	Distribution Transport	Used to facilitate handling and transport for primary or secondary packages in order to prevent damage

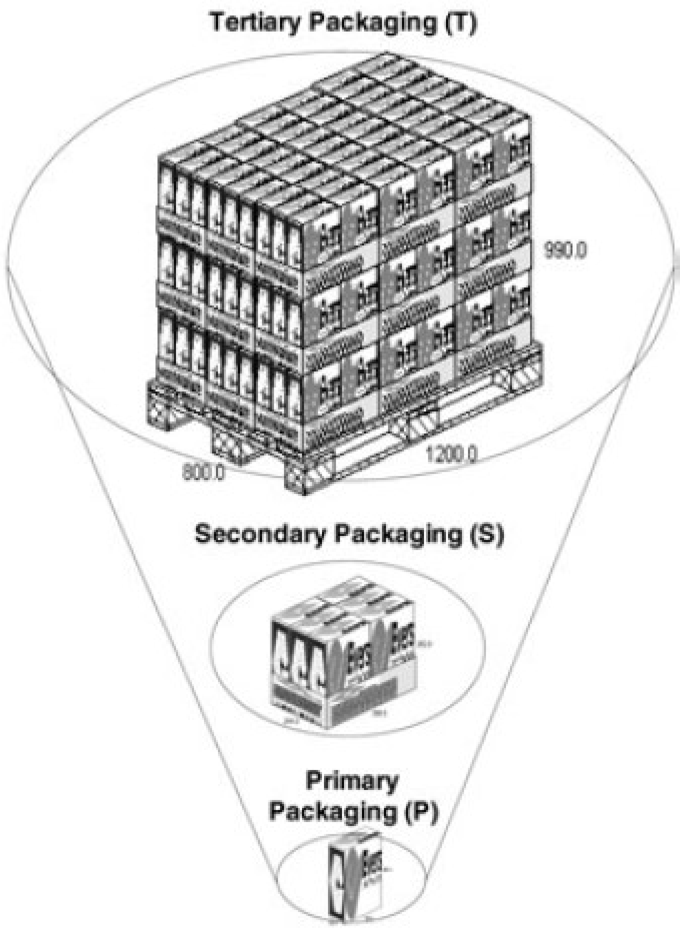

Figure 6. *Packaging system levels (Hellström & Saghir 2007).*

Hellström & Saghir (2007) state that packaging system's performance is affected by performance of each level and by the interactions between these levels. From logistical point of view tertiary packaging is the most important because transport activities interact mainly with tertiary packaging. Transportation packaging can be for example pallets, containers, roll containers and boxes. (Hellström & Saghir 2007).

Inside elevator packages there are both components which are packed to primary packages and not packed at all. Therefore it is easier to divide packaging to outer and inner packaging. Outer package is the transportation package which has the necessary logistical qualities for transportation and warehousing. Inner packages are used for single or few devices or components. Inner packaging provides containment and protection from other components inside the transportation package. Depending from the products it is not always necessary to use all packaging levels. General rule is that the outmost package has to be able to withstand storage and transportation. For weather protection additional protection such as plastic sheets are used to cover the transport packaging. Packaging levels are illustrated in Figure 7. (Case study (7): Rinne 2016)

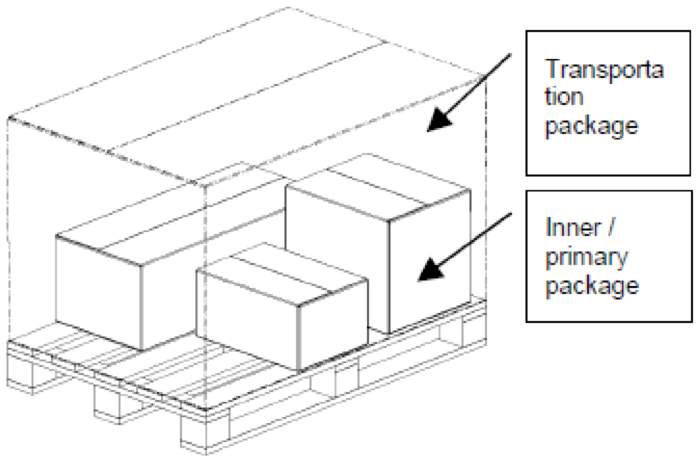

Figure 7. *Elevator packaging levels (Case study (7): Rinne 2016).*

Elevator packaging can be made from wood, metal, cardboard, polystyrene, different wrappings or more technical materials like VCI (volatile corrosion inhibitor) -films. Often packages are made from a combination of different materials where each material plays a specific part (Graedel & Howard-Grenville 2005). For example, wood can provide the structural properties and PE (polyethylene) –film protects from environmental factors such as rain.

In global markets packaging has to withstand different weather and transportation conditions. Shipping in intercontinental deliveries usually requires more rigid and protective packaging due to exposure to dust, extreme humidity and salt water. Therefore in addition to the normal package design there might be also a need for a heavy-duty solution to provide better protection. Heavy duty solutions can be used for example if the package is transported by a container ship or stored in demanding conditions for a longer time. (Case study (7): Rinne 2016) In Figure 8 are shown examples from a normal and a heavy duty package.

Figure 8. *Examples from normal and heavy duty solution (adapted from Case study (9): Haajanen 2015).*

In global business the sourcing of packaging materials presents a challenge. Different areas have regional materials available and reasonable to use. The challenge is to ensure that the same packaging specific requirements are fulfilled. This is why guidelines and restrictions are used for controlling the material usage of own manufacturing units and external suppliers.

5.2 Functions of an elevator packaging

Supply chain members' demands for packaging have to be understood to be able to fully answer to the demand. Requirements set by the packing process, installation and logistics teams are the main drivers for packaging design because these members are also the main users of the resulting packages. Table 8 shows all the phases in which the supply chain members interact with packaging. There is interaction with both inner and outer packaging in different phases.

Table 8. *Interactions of packaging and processes (adapted from Hellström & Saghir 2007).*

Process	Supply chain members												
	Manufacturer				Distribution center / Reloading point					Installation			
Logistics processes / Package level	Forming package	Packing	Loading	Transport	Unloading	Storage	Picking process	Loading	Transport	Unloading	Storage	Unpacking	Disposal
Inner package	X	X										X	X
Transportation package	X	X	X	X	X	X	X	X	X	X	X	X	X

All the X markings shown in Table 8 present the process steps in which packages are being handled. There can be an additional warehouse between DC and installation site which would increase handling steps even more. Steps in these warehouses would be the same than in DC. The number of handling steps show that packaging has to withstand great amount of handling. If a package is damaged in the first transport phase, the damaged package has to be handled in all the other phases. Handling in all phases can be improved with well-designed packages.

The goal for the packaging development team is to produce designs that support all members in the supply chain so that maximum efficiency can be achieved. Functions and features required by the supply chain member from packaging are presented are listed below:

- Containment and protection
- Production performance
- Logistical dimensions
- Stacking possibilities
- Handling possibilities
- Communication
- Eco-friendliness
- Safety

5.2.1 Containment and protection

In the manufacturing stage products are packed and from there the packaging holds products within the unit and together. According to Chan et al. (2006) containment has to be achieved before products can be moved. For the supply chain some kind of container is needed. In the manufacturing phase product can still be bulky and has to be subdivided to more convenient units. Level of subdividing is highly dependent on the product being packed. (Natarajan et al. 2015)

Protection is the main reason why packaging is used. If packed products are not in desired condition when delivered or sold, packaging can be considered useless. Packaging must provide protection against physical, chemical and environmental hazards. The degree of protection depends on the nature of the product. Fragile products need a high degree of mechanical protection as where some industrial products need to be protected also against environmental factors like moisture. (Natarajan et al. 2015) Miscellaneous hazards like contamination from pests or pilferage have to be considered also (Friedman & Kipnees 1960). To optimize the level of protection and material costs, over- and underpacking must be avoided. Overpacking results to less damaged goods but profits gained may be drained off by the costs. Underpacking does not provide adequate protection for the whole product and therefore costs from damaged goods and reclamations may exceed the economical packaging. (Chan et al. 2006)

Elevator components need protection during the delivery chain and on the construction site. In most cases there is no covered storage area on site for packages. Therefore the packages need to protect the products all the way to the point where the last component is removed from the package. In order to do so packaging materials have to be suitable for the climatic zone. For example a protective plastic sheet on top of the packages can be used as a cover throughout the whole process. Packages need to be also able to be easily opened and closed to maintain protective features of the package. This way the remaining components are not affected by rain if only one of the components is taken out of the package. Final protection on site is a sum from storage conditions, package and installation workers steps to protect components. (Case study (2): Baker et al.; Case study (1): Pitkänen)

ESD (Electrostatic discharge) protection is one requirement for the electric components in an elevator. ESD is a threat damaging semiconductor devices. ESD is a discharge of electrons to or from a charge that had been static. Immobile electrons can be on a non-conductive surface or on a conductive surface which is isolated. For example if screw-driver's metal part has a charge and it is brought close to an IC (Integrated circuit), ESD occurs between components. The two main failure mechanisms are heat- and dielectric failures. Heat failure occurs when the ESD pulse causes very high transient current. This leads to increased temperature both in metal and semiconductor material which results in localized thermal defects. Dielectric failures are caused by high electric field inducing electric breakdown. (Kolyer & Watson 1996; Wang 2002)

ICs need to be protected throughout the manufacturing, packing, distribution and installation processes. Manufacturing areas should have an EPA (ESD protected area) where damage risk from ESD is at an acceptable level. Packing process should also happen in EPA. When products are moved outside from EPA, there should be both packages removing static electricity or conductive package and structure protecting from ESD. Figure 12 shows marking for ESD packages. Code under the mark shows more details about level of protection. Codes are shown in a list below after protection in brackets. (Staattinen sähkö. Osa 5-1 2016)

Figure 9. *ESD packaging marking (Staattinen sähkö. Osa 5-3 2015).*

There are several packaging solutions to provide protection against ESD. Protection can be divided into ESD and EMI (electromagnetic field). Most of the packaging materials are insulating which results in charge building up around the packaging. When packages are made more conductive this charge can move to surrounding materials. Materials can be surface and/or volume conductive or insulating. (Packaging Materials for ESD Sensitive Items, 2003; Staattinen sähkö. Osa 5-3 2015) Packaging types and ESD marking codes are listed below:

- Low charging material (anti-static) (S)
- Resistance:
  - Conductive (C)
  - Dissipative (D)
  - Insulative
- Shielding:
  - Electrostatic discharge (S)
  - Electric-field (F)

Low charging materials have the ability to resist the generation of triboelectric charge. These kind of materials minimize the generation of a charge. They don't protect product when the charge comes from another source. Static shielding packages protect the product from ESD because the charge will not be able to easily penetrate the packaging. Shielding attenuates the energy from electrostatic discharge. Packages protecting from ESD have to be able to attenuate discharge to less than 50 nJ inside packaging. EMI protective packaging are attenuating electric field when formed into a package. (ESD Control for Electronic assembly; Packaging Materials for ESD Sensitive Items, 2003)

5.2.2 Production performance

Packing process is the first interaction between packaging and products. Packages and packaging materials need to perform economically in the packing process and not cause interruptions in production. This means the ability to perform in handling, filling and closing process. (Natarajan et al. 2015) Packing as a process is not the key phase that needs to be optimized in cost point of view, but results from this process are affecting the installation process. Therefore it is necessary to have packaging solutions that enable good level of packability so that the installation process and unloading of components can be supported.

5.2.3 Logistical dimensions

More efficient space usage in transportation can be achieved when the package dimensions are controlled. According to Natarajan et al. (2015) packaging must fit well to transportation and meet the needs of the warehouse or DC storage. Trailer and container space is limited and to keep transportation costs lower, cargo space should be filled as full as possible. This is valid also for storage. The ideal situation would be to have same shared dimensions for all packages. This would help storage planning, handling and space reservation planning in transportation. With current elevator products and components this is not possible or reasonable. Therefore in this thesis' case study size harmonization is used as a solution to optimize package sizes.

A key transportation measurement is the width. It is usually the first limiting factor in loading. The second one is the height and the last one is the length of the cargo space. Measurement limits can be created by inspecting typical dimensions of trailers and freight containers presented in chapter 4.2. For trailers, module measurement system's multipliers should be followed. For example 4M pallet with dimensions of mm 1200 x 800 mm can be loaded two or three next to each other depending on which way they are placed (Flat pallets for materials handling 2002). Total measurement of package or group of packages loaded side by side should be 20-30 mm less than width of the trailer (Case study (7): Rinne 2016). If package's length is 2400 mm it can still be loaded sideways. This should be the maximum measurement for package's length in the European trailers. In Table 9 are the maximum package measurements which are based on the trailer measurements presented in Table 3. Measurements presented in Table 9 show that while packages with width of 600 mm can be loaded four abreast, only two 1200 mm ones can be loaded abreast. These measurements are valid for European transportation. For other continents package dimensions should be based on local transportation's measurements. Table 10 presents measurements of optimized package dimensions for a sea container used in overseas deliveries.

Table 9. *Measurement limits for packaging in a Euro-trailer.*

Maximum length (mm)	Widthwise loading	Maximum Width (mm)	Maximum height (mm)	Stacking / Side by side loading
1200	2	600	600	4
2400	1	800	800	3
		1200	1200	2

Table 10. *Measurement limits for packaging in a sea container.*

Maximum length (mm)	Widthwise loading	Maximum Width (mm)	Maximum height (mm)	Stacking / Side by side loading
1140	2	570	570	4
2280	1	760	760	3
		1140	1140	2

Sea containers have smaller dimensions and therefore packages optimized only for trailers are not optimal for intercontinental deliveries. Internal width of freight containers shown in Table 5 is 2330 mm. Maximum length stated in Table 10 is defined to be such that packages can be loaded sideways inside the container. When the handling marginal is taken into account, a divisible length of 2280 mm is used. The measurement limits can be calculated by dividing the available width or height with the number of packages.

5.2.4 Stacking possibilities

Stackability for packages is a key feature to ensure efficient space usage in transportation and storage. Stacking value for packages is a sum of component features, available space in transportation and packaging solution. Weight and height of the components often define if it is reasonable in terms of safety to have a stackable package. To ensure possibility for stacking, the gross weight of the package should not exceed 1000 kg. Stacking causes mechanical stress to the packages on the bottom and they have to withstand not only the load on top of them but also effects caused by the vibration and forces created by movement during transit. Some components can hold the weight by themselves or take a part of the load inside the package but most of the components require rigid packages to have stackability. Packages have to also provide adequate support inside the package. Components can be placed in different layers, and none of these layers can collapse under the load. Different levels in stackability can be achieved with packaging solutions but it will always have an impact to the packaging costs.

Basic rule for stacking is that the same type of packages are stacked on top of each other. In reality also different types of packages are often stacked on top of each other and therefore packaging solution should take this into account. Logistic workers follow stacking rules guiding to load heaviest packages on the bottom. Only packages that the lower package can support are allowed to be loaded on top. Stacked packages are also required to have the same footprint so that the piles are stable enough. If a smaller package with a different footprint has to be loaded on top, it has to follow safety regulations and be placed on top of as many support points as possible. For safety reasons packages should always have stacking information. (Case study (10): Training and Documentation 2016) With predefined loading models there should be no need to stack unintended packages on top of each other. Loading models can work as loading instructions.

5.2.5 Handling possibilities

Packaging must be convenient in terms of handling, storage and usage. Packaging has to provide easy opening and ability for stacking as well as being convenient to handle in transit. According to Friedman & Kipnees (1960) size, weight, quantity and cubage are the factors affecting handling convenience. Size and weight efficiency is obvious and often overlooked by many parties. Volume and weight relation has to be designed to be in balance so that the package is convenient and safe to handle. With gross weight limitations can be ensured that packages can be handled with pallet jacks that often have a lifting capability around 1000 kg. (Chan et al. 2006)

Easy handling of packages can be provided if packages follow earlier presented dimensions and gross weight limitations, and also offer sufficient handling possibilities. Pallet structures with different handling possibilities are presented in Figure 9. 4-way pallet has an access from all directions, which provides better handling than 2-way pallet.

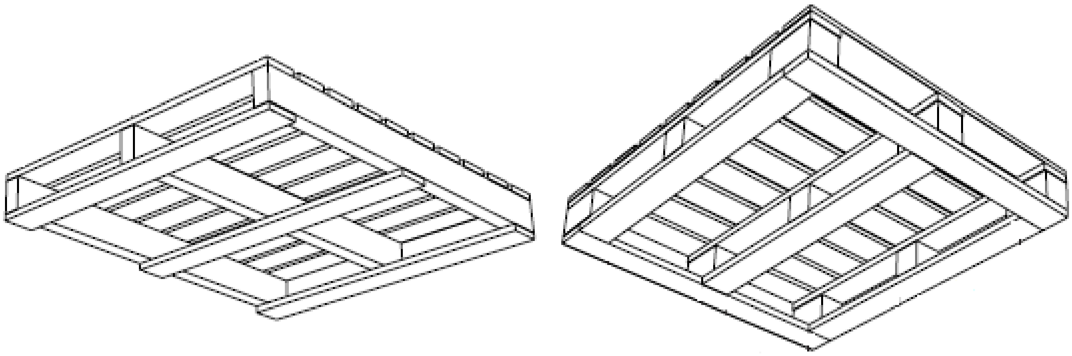

Figure 10. *Pallet structures with 2-way and 4- way handling (Flat pallets for materials handling 2002).*

To support handling during the supply chain the option for 4-way handling should always exist. It does not matter what kind of transportation is used if there is a possibility to handle packages from all directions. 4-way packages are easy to handle in trailers and containers no matter if they are opened from the side or from the rear.

Installation sites are often the most challenging to move packages around. Site equipment for moving packages is not often as good as in other logistical phases of the supply chain. On site it is therefore very important that packages are safe to handle, have excellent handling possibilities and offer possibility for 4-way handling. The size of the packages cause also concerns in installation sites due to doors or hallways. EUR-pallet has the advantage because it fits through most of the doorways and can be stored in corridors if necessary. In Europe for example the guidance for minimum width of an office door is 930 mm (Office for Infrastructure and Logistics 2011). Packages that are too large to be moved through doorways are unpacked so that components can be moved. This exposes components to a higher risk to be damaged or lost. (Case study (2): Baker et al.; Case study (1): Pitkänen; Case study (3): Karppinen)

During the installation process packages have to provide efficient platform for picking of components. Extra movement of components or packages and searching of components is additional work that produces no value to the process. Protection and support structures inside the packaging must be removed during the picking. This should be considered in the product and packaging design processes.

5.2.6 Communication

Identification of the company and content are necessary for the user, whether it is a customer or a logistics worker handling the packages during delivery. Packaging has to provide necessary information relevant to the product. Transportation packages require shipping information (i.e. consignee and consignor). Methods for correct handling, storage and safety instructions and cautionary information are also important information. (Natarajan et al. 2015) With adequate information costs from handling incorrect goods, product damages from incorrect handling and reclamations can be decreased. In international trade these instructions have to be easily understandable and unambiguous symbols or coding. (Chan et al. 2006) To ensure efficient information flow throughout the whole supply chain standardized markings are often used. In Figure 10 are presented handling markings for correct upright position, indicated lifting places and fragile content from the ISO 780 -standard. Markings like these help to ensure that packages are handled correctly throughout the whole supply chain.

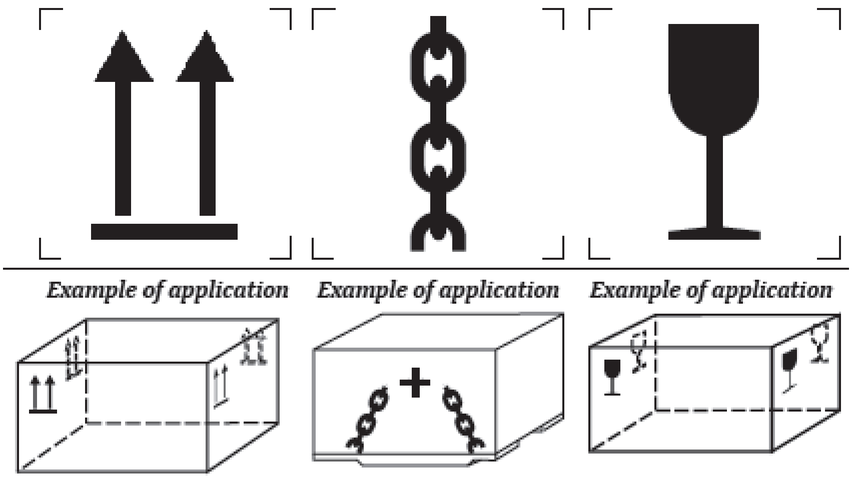

Figure 11. *Example handling markings (Packaging. Distribution packaging 2015).*

Information is one of the key factors affecting the installation process. When packages arrive on site it is extremely important to be able to easily identify each package. Identification is easy in a single elevator delivery but when a delivery contains 10 elevators simple and unambiguous information is a must. Packages should always inform the installation location, elevator information and most importantly contents. Components inside the package must be able to be identified without opening the package. Components should also be easily identified when the package is opened. This concerns components packed inside primary packages such as plastic bags or cardboard boxes. More complex packages are also packed in installation order with inner support structures. It is important to open these packages from the correct side. By using instructional stickers or other markings, packages can be stored in a correct way so that the access side is facing the open area. (Case study (2): Baker et al.; Case study (1): Pitkänen)

5.2.7 Eco-friendliness

Dharmadhikari (2012) points out that community concerns, government regulations, customers' increased environmental awareness and image reasons drive companies to focus more on environmental aspects of packaging. Packaging regulations are set to increase sustainability because the amount of packaging waste is increasing (Verghese et al. 2012). One example is the European Parliament and Council Directive 94/62/EC which aims to reduce packaging waste and increase recycling. Companies are forced to change their own regulations and strategies to follow these restrictions. Designing packaging for sustainability adds one more layer to the demands for packaging design. Figure 11 shows an example waste reduction strategy in packaging.

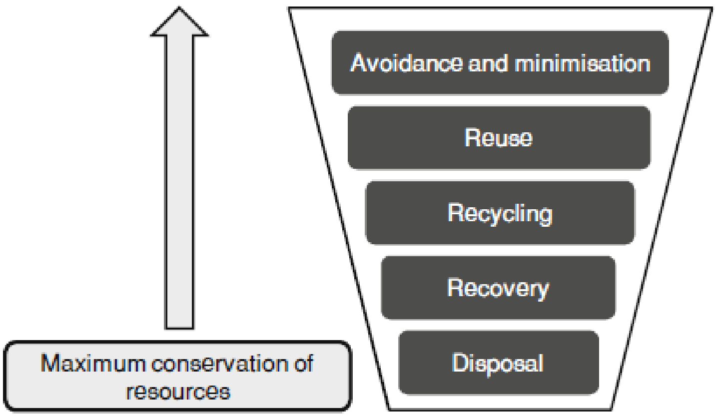

Figure 12. *Waste hierarchy (Verghese et al. 2012).*

The best results in waste reduction can be achieved with avoidance in material usage and reusing packaging. Material usage should be minimized in every situation. (Verghese et al. 2012) Inner packaging such as box-in-box solutions are not desired. This increases the amount of used packaging materials which affects to the packaging costs and the installation process. Removing all the empty packages from site is a process step and affects the total time required to the installation. In small components these inner packaging solutions are often required to keep components together, protect them and prevent loss.

To achieve even more environmental friendly packaging concepts, focus from waste reduction thinking has shifted towards 'sustainable packaging' (Verghese et al. 2012). In order to achieve eco-friendly and sustainable packaging design, packaging has to be both effective and efficient. This means that packaging has to effectively deliver functional requirements and also be efficient in its use of materials and energy throughout the whole life cycle. (Dharmadhikari 2012; Lewis 2012)

When delivering packages abroad the possibility of the spread of quarantine pests associated with wood packaging has to be considered. This is important especially in overseas deliveries. In international trade phytosanitary regulations concerning spread prevention of flora and fauna have to be followed. Wood packaging excluding plywood and OSB require phytosanitary treatment and IPPC-marking (International Plant Protection Convention) to inform that a treatment has been performed. Treatments approved by NPPO (National plant protection organization) are different heat treatments and methyl bromide treatment. Plywood is heat treated in manufacturing process and therefore does not need additional heat treatment. Aim for this treatment is to exterminate quarantine pests and prevent their negative impacts to forest health and biodiversity. (International Plant Protection Convention 2009) Example marking is presented in Figure 13.

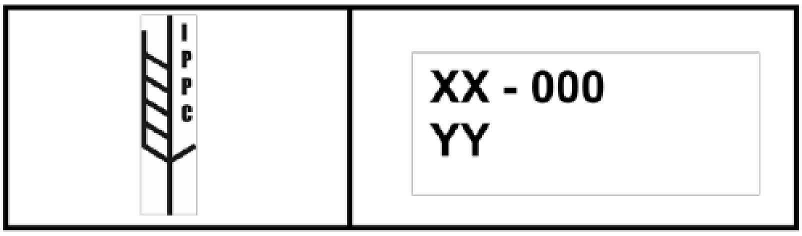

Figure 13. *One of the approved IPPC markings (International Plant Protection Convention 2009).*

Aim for these treatments is to exterminate quarantine pests and prevent their negative impacts to forest health and biodiversity. Bi et al. (2008) and Morin & Liebhold (2015) showed in their studies that unwanted pests can cause major damage for example to forest areas. As a preventative actions customs can stop wooden packages if they are not marked with IPPC marking. (International Plant Protection Convention 2009)

5.2.8 Safety

Safety is the most important factor also in packaging. Packaging solutions cannot cause safety issues or dangerous situations during packing process, supply chain or installation process. Most crucial requirements for safe handling are:

- Robust structure for stacking
- Low center of gravity to prevent tilting
- Fixing of the components so that they do not fall when package is opened
- Adequate strength to ensure safe lifting and handling

According to Sutela (2016) tilting of tall packages can be prevented with a larger footprint, but it is not the desired solution. Horizontal packaging should be favored with components with high center of gravity. One way is to warn about the possible tilting danger with labels. Falling risk of packages can be analyzed for example with ASTM D6179 standard, which states that the package should not fall when it is tilted 22 degrees and released. (Sutela 2016)

Safety issues are more serious on site due to the construction site conditions and limited handling equipment. Especially safe lifting on site must be ensured with clearly marked lifting points and possibilities. Installation workers have to have also a safe opening of the packages. Use of “open this side” sticker or another solution is required to inform which side of the package is intended to be opened. Components inside the package have to be fixed and secured in a way that they cannot fall out when package is opened. This is important especially with packages that have inner support structures. There should be clearly marked screws that can and cannot be opened.

5.3 The role of the packaging development team

The packaging development team works as matrix unit and controls packaging related operations. In the case company team operates under logistics organization and aims to support company’s operations in the whole supply chain’s point of view. The team supports internal customers and also co-operates with external suppliers. Internal customers are logistic and installation teams and product owners in the same company who require packaging designs or packaging related guidance for their products.

Main tasks for the packaging development team are managing packaging standards and regulations and designing or updating packages. Outputs for projects are mainly packaging drawings and instructions. Common projects are the ones with packaging updates and below are listed example reasons for starting these kind of projects:

- Pursuing cost reductions in packaging
- Improving existing packaging design to meet requirements from different stakeholders’ changed requests
- Reacting to product changes
- Packaging is updated to reduce the amount of damaged goods due to issues with quality
- Planning to implement existing packaging to an country where available materials are different
- Updating suppliers packaging to meet company’s own requirements.

The packaging development team is also conducting development. Development work aims to improve packaging solutions and the supply chain processes in a larger scope. Process development can involve studying of new installation methods or some other process which would need completely new packaging designs.

6. DESIGN FOR PACKAGING GUIDELINES

The reason for improving case company's packaging solutions and deliveries is the inefficiency caused by the variability in the current package sizes. With a large amount variation in package sizes, it is highly challenging to achieve controlled and harmonized loading structure. The following issues result from the aforementioned problem:

- Inefficient loading & fill ratio in transportation
- Partly controlled stacking of packages
- Increased amount of damaged goods due to incorrect stacking
- No adequate support for installation order in deliveries

The Design for packaging –concept created in this thesis has the tools to improve the supply chain. The concept has design guidelines as well as process improvements for the product development process. Process improvements are presented in chapter 7.4.

Component features are partly defining how well a packaging can fulfill the requirements set by the supply chain members. The Design for packaging guidelines are made to instruct product designers in order to support achieving packaging solutions required by the supply chain members. The Design for packaging guidelines are instructions guiding product designers to consider products as part of the delivery chain. Guidelines are combined from the needs of logistics, installation and packing process. The goal is to prevent the design of components that are challenging to pack or do not enable the usage of logistical packaging.

6.1 Component effects on packability

Packability defines how easy it is to pack different components. Factors affecting packability are the need of additional support structures, protective materials, weight and shape of the component, fixing possibilities and safety features. To improve processes, material usage and quality, packing should be considered in the component's design. The goal is to have a good level of packability so that packing process can be done in the same way every time. This improves the level of harmonization that can be forwarded to the installation process. Figure 14 presents component features' effects on packability and the supply chain.

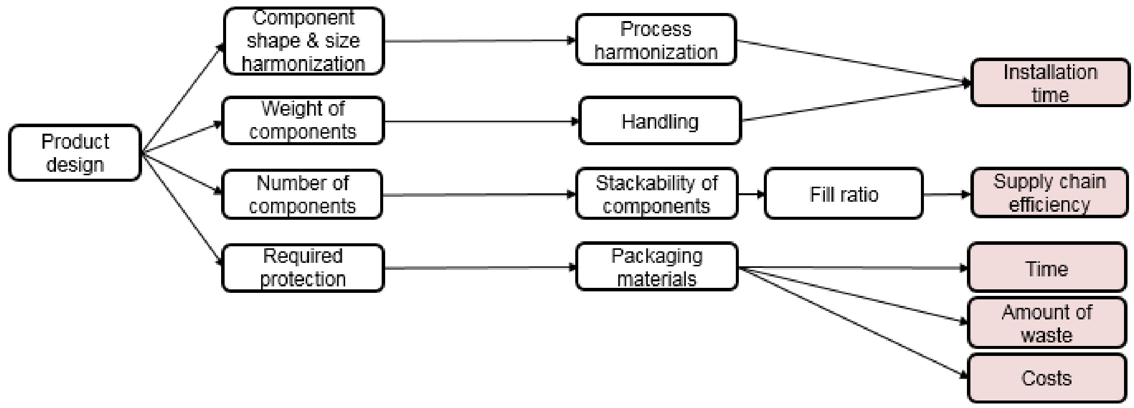

Figure 14. Effects of packability on processes and packaging solutions.

If component design takes packing into account, components could be for example designed in a way that they can be packed layered and firmly. This would reduce the required space, improve the fill ratio of packages and provide support for the components as they are compactly packed. Packing models could be used as instructional tools but it would require harmonization of the product designs and consideration of how components fit together inside the package.

6.2 Component effects on outer package

Component features also define what kind of package is required. Component and climate factors define the level of protection required. The most important factor is the size of the package and components' size is solely defining it. In order to achieve logistical component sizes, it is necessary to follow the package size limits presented in tables 9 and 10. Component sizes are smaller and instructed more specifically in the Design for packaging document. Figure 15 presents the effects on the packaging and the supply chain.

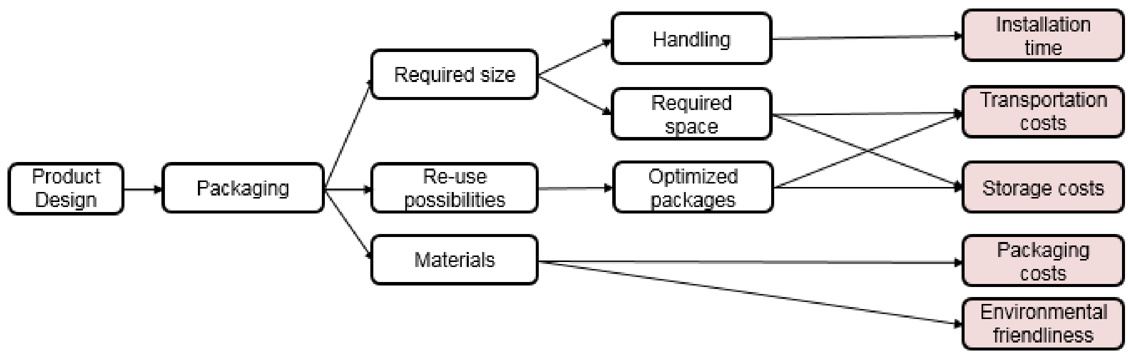

Figure 15. Effects of outer packaging on the supply chain.

If the size of the components can be controlled, it enables the harmonization of the packaging solutions. Already existing packaging designs that are optimized for transportation can be utilized in new projects more often. By being able to use same sized packages, it provides better possibility for stacking and cost reductions in transportation and package sourcing. When volumes for certain sized packages increase, it is possible for the sourcing organization to negotiate better prices for the packages.

6.3 Design for packaging guidelines

The guidelines were made in the consideration of the good principles of a DfX (Design for X) tool. Principles ensure an efficient usage of the tool and suitability for the development process. The following ideas were used while creating the guidelines (Huang 1996):

- The document clearly defines specific area of concern.
- The usage of DfX document teaches designers about the subject and clarifies the relationship between product and the package.
- Effective usage of the document by the designers with little additional time and effort in the process.
- Usage of the tool should provide visible and measurable benefits.
- Provide redesign advice on how a design can be improved.
- The guidelines stimulate creativity and encourage innovation in balance with design restrictions.

The first idea of the Design for packaging guidelines is to inform product design organization about optimal package sizes for different market areas. These measurements would ensure efficient space usage in transportation and storage. In the design organization it has to be taken into account that if these measurements cannot be followed in a single module, it will influence the whole elevator delivery. Loading models presented in chapter 8 are demonstrative tools showing what kind effects there would be if preset space reservations are exceeded.

In order to guide product designers it was necessary to understand how different component features affect packaging. This idea was then possible to forward to the product designers. This is the second idea in the Design for packaging guideline -document. Following component features are discussed in the created document:

- Sensitive components
- Shape and size of the components
- Long components
- Heavy components
- Safety
- Fixing

From product designers' point of view the space reservation is a number based restriction and therefore easy to follow. Elevator specific loading models created in this thesis are demonstrating the space reservations in transportation. The most challenging part of the

Design for packaging guidelines are the design guidelines which instruct product designers to consider and avoid certain features in components' design. Loading models and instructions about space reservations give concrete limits to the dimensions of components and can be easily followed, but guidelines about component features have to be understood to enable the development towards more logistical packaging.

7. PRODUCT DEVELOPMENT

Product development is the entire process required to bring a new concept to a market ready state. This process includes product vision, analysis, marketing, design activities, manufacturing planning and validations. The product development process can be simple projects where designs are only updated or complex development projects that can last multiple years. (Otto & Wood 2001)

Before finalizing the design for a new product, it is a standard procedure to consult managers from different areas to ensure their views and possible problems are taken into consideration. From this input it is carefully considered if changes to the design are necessary. In this phase packaging engineers should be consulted also to ensure packability and safe distribution for the product. It is useless to design a product and to find out that economic packaging is not possible. It might be also impossible to achieve a product which could be easily packed and transported. The end result for the design usually lies somewhere between these two extremes. (Evan-Cook 1962) The packaging development team has usually many stakeholders and it is difficult to fulfill all the requirements. This leads to possible compromises and conflicts due to different needs. The design process therefore involves balancing different roles that the packaging is required to fulfill. (Simms & Trott 2010)

7.1 Product design process

According to Otto & Wood (2001) a product design process is a set of technical activities within the product development process. The aim of these engineering activities is to transform visions into technical specifications and concept development. This process is transforming inputs to a set of outputs (Ulrich & Eppinger 2012). Ulrich & Eppinger (2012) state that a generic product development process can be divided into 6 steps which are shown in Figure 16.

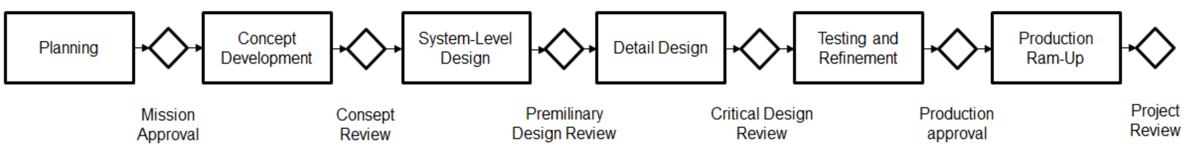

Figure 16. *A generic Product Development Process (adapted from Ulrich & Eppinger 2012)*

Planning starts with opportunity identification and setting milestones and a schedule (Otto & Wood 2001). Corporate strategy, technology development assessment and market objectives are taken into account when planning the product development process. The output from this phase is to have a target market for the product, business goals and assumptions and constrains for the process. (Ulrich & Eppinger 2012) The question here is whether the vision can be transformed into a product at a worthwhile profit (Otto & Wood 2001).

Concept development requires the identification of the target markets and evaluation of alternative concepts. In concept development it is necessary to determine what the product has to do to supply the customer satisfaction (Otto & Wood 2001). A concept describes the function and features of the product. Analysis from the competitive products is done to analyze the feasibility. If the project does not have adequate solution readiness for critical factors, it won't be beneficial to continue the project to next development phases. (Case study (11): Hänninen; Ulrich & Eppinger 2012)

In the system-level design phase the product architecture and component levels are defined. The design for key components is also drawn out. In this phase, the development starts to move towards a concrete product because the production systems and assembly are defined. The output holds the specifications of the product and its subsystems, the specification of the product's functions and a preliminary process flow diagram. (Ulrich & Eppinger 2012)

In the detail design phase the specifications are completed. The process plan and tooling for manufacturing are designed. In this phase, the designs are finalized by setting the component standards so that the parts can be purchased from suppliers. The output from this phase is control documentation like drawings for the product. In this phase the material selection, production cost and robust performance are finalized. (Ulrich & Eppinger 2012)

Testing and refinement is a phase with prototype testing. Tests are conducted to see if the product can perform like intended reliably. (Ulrich & Eppinger 2012) This is the last development phase with a final decision whether to proceed or not with the launch of the product (Otto & Wood 2001).

Reviews are conducted between different phases. These are milestones where tasks and required information are checked so that process can be carried on to the next phase. Changes to the design and decisions about cancelling the product launch are always cheaper to make in the early stages of the development process. If changes are made in the late stages, it can greatly extend the project schedule. (Case study (11): Hänninen; Ulrich & Eppinger 2012)

7.2 Design for X principles

Customer needs are the driving force behind design. Performance-related metrics is answering the customer demands. In addition to the preferred design configuration there are additional engineering specifications that must be considered. (Otto & Wood 2001). As a result of a high number of different design principles, the design process can become unclear and slow. To be able to maintain efficient development and design processes, project management concepts and tools must be utilized. All the requirements for design cannot be followed and they often conflict with each other. The design process is about compromising and choosing the most important factors. The main goal with these design principles is to ensure a safe and reliably operating product that can be manufactured cost efficiently. (Case study (12): Nevavuori; Case study (13): Laitinen) Below are listed example Design for X principles that are used to guide the design process:

- Design for environment (sustainability)
- Design for installation
- Design for manufacturing
- Design for maintainability
- Design for reliability
- Design for safety (end user)

Logistical aspects are not considered the most relevant. The idea of taking the packaging aspects, which are considered the last thing done in the development project, to the concept development phase can cause rejection mentality due to not fully understanding the reasons for doing so. Therefore it is important to point out reasons why packaging aspects should be considered and what kind of effects they have.

7.3 Case company's product design process

The case company's product development process is divided into *concept development* and *solution development.* Both development phases have a number of milestones. Concept development projects follow the same rules as defined in chapter 7.2. All the way up to prototype testing can done in this phase as a part of the solution readiness assessment. When a concept reaches a certain level of readiness, handover to the solution development project can be done. The transaction from concept development to solution development is around the system-level design phase presented in chapter 7.2

Solution development is a development phase turning a concept into a product ready to be manufactured and delivered. Only small changes can be made to the product design in this development phase. In the case company's current product development process, the packaging development team is a part of the operational project team starting from the solution development phase. Packaging development team's task is to create a packaging design for the product. In this development phase it is possible to have only small packaging development tasks during the operative work. Usually, the packaging development is done by implementing the best practice findings to new packaging designs.

In order to have a suitable environment for the packaging development, the packaging development team should operate in co-operation with product designers in the concept development phase. The key design guidelines of the product are created in the concept development projects and therefore it is the most suitable phase to influence the design. In the solution development phase, there is no more adequate influence to the product design.

7.4 Implementation plan of the Design for packaging concept

To ensure that the Design for packaging guidelines are followed and to improve packaging development's role in the product development process, there has to be an implementation plan for the Design for packaging -concept. The plan is divided into two sections. The first one is to develop a link between the packaging development team and concept development projects. This was done by updating the development process. The second one is to generally improve knowledge about the importance of packaging aspects and eventually achieve the mindset of logistical products in the product design organization. The Design for packaging guidelines document is one of the tools for improving knowledge about packaging aspects.

7.4.1 Product development process update

The case company's concept development tool measures the uncertainty of the solution from various points of view. (Case study (11): Hänninen; Case study (13): Laitinen). The problem is that uncertainty can be in some areas close to zero, if a new concept is relatively close to an existing product. This may lead to an unwanted situation where existing problems in the current product might not be solved in the new one because the current product is considered being well functioning. To ensure the possibility for improvement in every project, it is necessary for the project manager to contact field experts in different areas. This way the project managers receive input from people who are well aware of the possible issues with current products. Information flow to the concept development projects has to be guaranteed so that problem areas are well known. This can be achieved by inserting a process step into the project management tool which requires contact with relevant professionals. This would not only be beneficial for packaging aspects but also for other areas as well.

Other chance to ensure consideration of the Design for packaging guidelines in the early phases of the product development process is to add a packaging related check point to the end of the concept development process. This way could be ensured that product design has to have a certain level of consideration about packaging requirements before the project hand over can be made to the solution development project team. The development process should be driven in a direction where there should be a valid reason for not utilizing the optimized packaging solutions. (Case study (14): Nyrhinen)

7.4.2 Co-operation

By ensuring contact between project manager and the packaging development team it is possible to discuss the relevance of the concept development project to the packaging development. This enables visibility to current development projects and a decision can be made whether packaging development team participates in the project or not. Many projects are not relevant from packaging perspective and therefore participation is not mandatory. The packaging development team's level of input can depend on the scope of the project. (Case study (11): Hänninen)

This kind of procedure would increase the packaging development's role in concept development phases. Development results from the packaging development team can be improved if it operates together with product designers. Product designs can be influenced and packaging design tasks can be conducted in earlier phases (Case study (15): Haajanen). When project shifts from the concept development phase to the solution development phase, packaging development work could already be done and final packaging design tasks would be left.

In the supply organization, the packaging development team should be seen more as a supply chain development team than a packaging design team. The packaging development team's responsibilities could be divided into development and operational tasks. Concept development phases offer suitable environment for packaging development tasks. Packaging design operation can remain in later design phases. By changing the packaging development team's operations, it is required to ensure that adequate contribution can be provided by the packaging development team to both processes (Laajaniemi & Vesola).

7.4.3 Training

Second method in implementation of the Design for Packaging -concept is to increase knowledge about packaging aspects. The concept has to be well assimilated to the development process. Concept and solution development's process owners are responsible for implementing the training material. Example introduction steps for the Design for packaging concept are listed below:

- Ensure that the Design for packaging guidelines are added to the process description
- Ensure that the Design for packaging guidelines are implemented as part of the company's design principles
- Training material is built by training specialists in co-operation with packaging development team and process owners
- Construct a training plan
- Establish a communication channel between R&D and packaging development team
- Training material is to be implemented to concept and solution developments' internal training programs for new employees.
- Additional training provided (events, online-training) for all product development employees
- Update, manage and improve visibility of Design for packaging guidelines for design process.

Due to multiple design guidelines and variation between the goals of projects, compromises have to be made between different requirements. Projects often define the design principles to be prioritized and designers follow these guidelines based on their own understanding about the subject. It is extremely challenging to measure how much each design guideline has been followed.

To improve understanding and introduce a new design guideline, there has to be a well-prepared training material for all participants involved in development projects. Professionally made training packages provide adequate information about the new design guidelines and importance of packaging aspects. This is the most important part of the implementation in order to increase knowledge.

Instructional documents work as the first source of information after the training packages and therefore they should provide information as simply as possible. Also there has to be a well-known contact channel with the packaging development team if additional information is needed. Information about packaging aspects can be implemented not only through the Design for packaging document, but also as part of other Design for X documents. Packaging aspects are highly connected with installation and environmental guidelines.

8. CASE STUDY

Case study is made from two elevators called Product A and Product B which are both commonly used in residential and public buildings. The aim of this case study is to apply the Design for packaging principles to actual products, optimize current package sizes and create loading models that present space reservation for each delivery module. This follows the first part of the Design for packaging guidelines where package size limits are set. This study shows what benefits could be achieved in logistics and the installation process if package dimensions are considered in product design. Second part of the case study is to review how optimized package sizes can be achieved with component design changes.

The Design for packaging guidelines can be used the most effectively in a design of a new elevator product. This would enable the creation of loading models. For existing products it is more challenging to implement logistical packaging solutions and the same type of optimization is not possible. With new products it is possible to start the design based on the space reservations. The optimal situation would be to have both existing and future products with logistical package sizes.

8.1 Optimization process

Key elements guiding the optimization process were installation order, the time that packages are open on site, measurement of transportations and manufacturing and sourcing structure. Component and package review was done first in order to understand what package sizes are possible. With 3D-modeling and optimal package measurements presented in tables 9 and 10, it was possible to define the package sizes that would be optimal within the component size range. With optimized package sizes it was possible to create exemplary loading models which follow the unloading order required by the installation process. The creation of a new module structure was necessary in order to enable package size reductions. A comparison between the current loading situation and the newly created loading models was made in order to show the benefits.

8.1.1 Package review

The goal in the optimization was to have package sizes that would be multiples of a modular measurement size of 600 × 400 mm. The optimal solution would be to have standardized package sizes. Current packages were reviewed in order to understand which ones follow modular packaging measurements and which don't. With modular and standardized solutions it would be possible to reduce package size variations. If packages are based on the same modular measurement rules, they can be loaded well side by side and on top of each other. This was the baseline for creating loading models in this case study. Figure 17 presents the idea how packages were reviewed and solutions created.

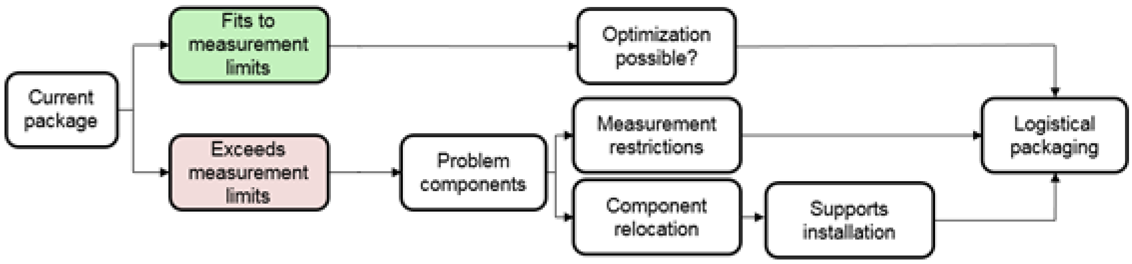

Figure 17. *Review and improvement process of current packages.*

Many of the current packages are close to modular measurements and some modules already have a standardized packaging solution. Packages which were close to the optimal measurements had to have a small size reduction. Packages that were clearly oversized required a more thorough review. It was necessary to understand what aspects or components define the size of these packages.

Usually inside the packages there is only a single or few components that define the package dimensions. Reduced package sizes can be achieved if the size of these components can be reduced or components are moved to another module with a large package. Component size reductions can be achieved by increasing the amount of foldable, attachable or integrated designs. Designs can be changed easier in components that have visual functions instead of structural ones.

Major problem with the current packaging is that there is a large amount of size variations in almost each module. If components have a lot of size variation it means that also packages have similar amount of variation or only few fixed sizes are being used. In the first option the amount of package sizes would be close to the amount of component sizes and the second solution would increase the amount of transported air. Both options are not ideal and therefore product design should increase the component size harmonization in order to achieve more harmonized package sizes. Optimization process was challenging due to the amount of package size variation in each module and between modules.

8.1.2 Module review

A module review was necessary to understand what components define package sizes and how module division supports the installation process. Components are needed in different phases of the installation process according to the installation order. This means that multiple packages are open at the same time because components are taken from various modules. Figure 18 shows a single man installation process with phases in which components are taken from different modules. This information was gathered by reviewing component level installation order and modules' delivery contents. (Case study (5): Räisänen 2011; Case study (16): Training and Documentation 2014)

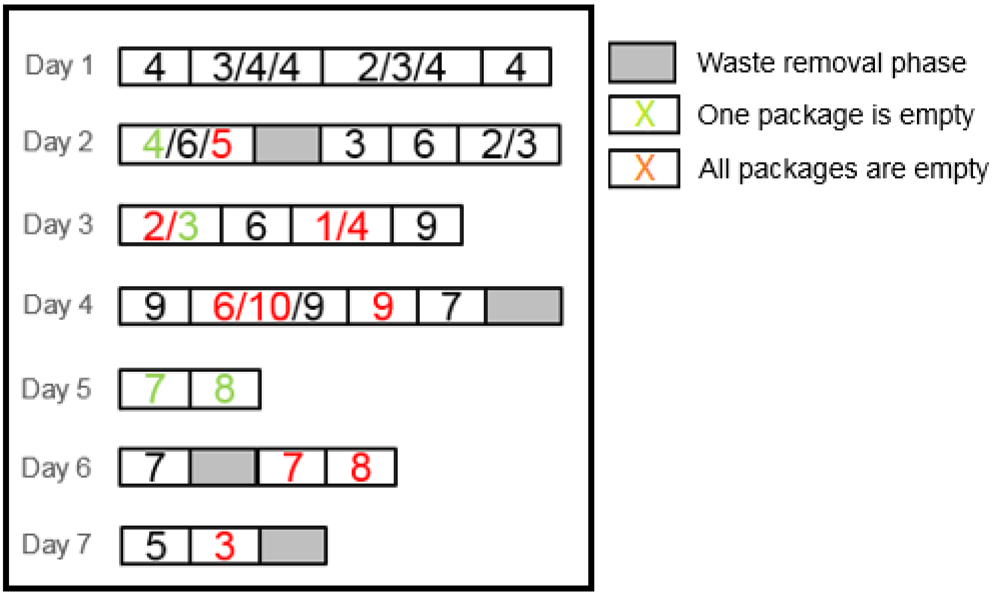

Figure 18. *Module need in installation process.*

When a module number in Figure 18 occurs the first time, it represents the phase when a package is opened. Gray blocks in Figure 18 represent the waste removal phases in which working area is cleaned and already emptied packages can be removed. In some modules there are multiple packages and therefore green numbers show the phase when one of the packages in that module is empty and ready to be taken away. Red numbers present the phases when all the packages in a single module are empty.

Module 4 is also marked in green on day 2 even though the module consists of only one package. In this case there are only a few smaller components left in the large package after the day 2. The package is often disposed already during the 2nd day which leaves these components exposed.

In module 3, there is variation in the location of ropes. In some cases, the ropes are packed into their own reel package but in smaller elevators ropes are packed together with other components in module 3. The package of module 3 can be disposed during the 4th day if the ropes are packed separately. In module 5, most of the filler weights are placed in the CWT during the 2nd day. Some fillers are used in the calibration on the 7th day but regardless of the time between, all filler weights are taken inside the building during the 2nd day so the package can be disposed on the 2nd day. (Case study (2): Baker et al.)

One key information that can be seen from Figure 18 is the time that packages remain open on site. The time from opening the package to the moment when final component is taken from the package should be minimized because components in opened packages are exposed to environmental factors, pilferage and other problems. By relocating components between modules it is possible to reduce the time that packages are open on site.

For example in current installation process the package containing the car is open for 3 days which is not an optimal situation. The most crucial components are the ropes. If they are packed inside module 3, they are exposed almost for the whole installation process. In situations like these it is reasonable to use primary packaging for the ropes to ensure adequate protection. The presented schedule is the installation time for a single elevator. When the same study is made from more complex installation projects, packages might remain open for a much longer time.

Another essential information that can be inferred from Figure 18 is the order that modules are needed in the installation process. Modules 4, 3 and 2 are needed during the first phases of the installation. Because these modules are needed first, they should be loaded in a way that they can be unloaded last and stored closest to the site storage area's access point. When installation starts, these modules are the first to be accessed. Figure 19 shows an example of the arrangement of packages on site.

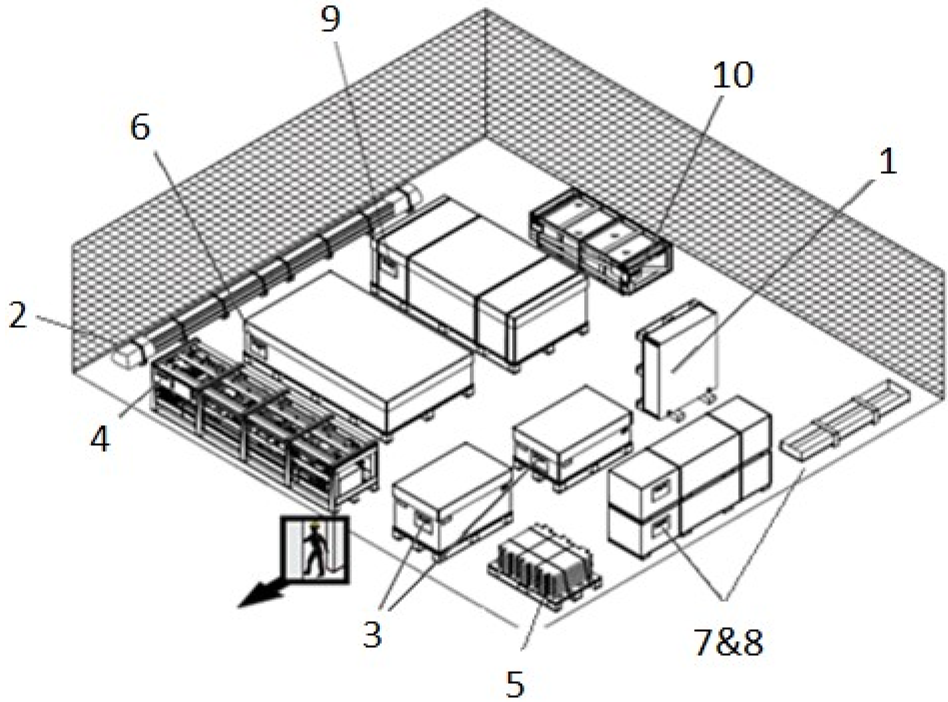

Figure 19. *Arrangement of modules in site storage (adapted from Case study (16): Training and Documentation 2014).*

By unloading packages to the arrangement shown in Figure 19, there is an easy and free access to the packages of modules 2, 4, 5 and 3. When the packages of modules 4 and 5 are removed during the 2nd day, access to modules 6 and 7 package is open. Storage order is one factor influencing the smoothness of the installation process.

Module structure was also reviewed in aim to support the size reduction of packages. All elevator components were listed by their installation order and after that by their size. The list enabled the examination of groups of longer components in different installation phases. By comparing this list to the current module division, it was possible to define which modules support the installation order and which not. The list also showed which components define package's length and if there was unnecessary number of large packages. Components were then relocated to minimize the number of large packages while following the installation order.

Completely changing the module structure to support the installation process was restricted by existing supplier field and manufacturing sites. Solutions were pursued in a way that would not increase complexity of the supply chain or bring additional costs. If components are ordered from a component supplier to own manufacturing facility or to a module supplier, there is no obstacle for changing the order location of these components. In case of too long transportation distance and increased costs, local sourcing can be considered. Relocating components manufactured by a module supplier would not be beneficial because delivering to another module supplier would require completely new transportation phase and it would increase costs. The component origin aspect requires to review relocation ideas to understand which components would be reasonable to relocate.

8.1.3 Solution for the module structure

Information from manufacturing & supplier field, components' installation order and modules' package sizes were used to create a solution for a module structure which would support the shift towards logistical packaging and improved installation process. Primary method for enabling the use of modular packaging sizes is having smaller components. In some cases design changes were not possible or reasonable. Therefore component relocations were crucial in order to achieve the desired outcome. Ideas were discussed with product owners and installation professionals in order to understand what challenges proposed changes would have. Solutions for module structure created in this thesis are possible to implement but changes require component design updates and updates to the supplier field. Table 11 shows proposed changes to the current module structure.

Table 11. *New module structure.*

Module number	Changes
1	-
2	-
3	Components added from mod 4
4	Components relocated to mod 3
5	-
6	Components added from mod 8
7	Components relocated to mod 10
8	Components relocated to mod 6
9	-
10	Components added from mod 7

The list below explains in a more detailed level what kind of changes were necessary in the module structure in order to achieve logistical packaging solutions presented in this case study:

1. Components in module 1 were kept in the current module due to the heavy weight of the products and for manufacturing reasons. Components are stock items and therefore should not be mixed with elevator specific components.
2. Module 2 remained the same due to manufacturing, size and weight reasons. The long length of the components is preferred by the installation team even though the size presents challenges throughout the whole supply chain. Reducing the component size would increase the installation time with the increased number of components to be installed.
3. Module 3 had few additional components added from module 4. These changes did not have major effects on the supplier field or the installation process. Changes were made to reduce the time module 4's package would be present and open on site.
4. All the components that were not installed before the first waste removal phase were moved to module 3. By relocating these components it is possible to dispose module 4's large package from the site during the first waste removal phase. In current installation process the package is often already disposed at the same time but as a result these relocated components are left unprotected before their installation takes place a day later.
5. Module 5 did not go through any changes because the current packaging solution is already a standardized EUR-pallet. Due to the weight of the components it is not reasonable to add them to another module.
6. The solution for module 8 required to relocate structural parts of the COP into module 6.

7. The goal for module 7 was to have a EUR-pallet sized package. Trunkings are one of the longer components and ordered from component suppliers. They were moved to module 10. The relocation would only affect the suppliers' delivery location changing to a module 10 supplier. Trunkings and the components in module 10 are also installed almost after each other and therefore it will not have a negative effect on the installation process.
   Another longer component in module 7 is the MAP (maintenance access panel). There are two types of MAPs and the smaller one's size can be reduced with design changes to fit to a EUR-pallet sized package (Case study (17): Kantola). The longer MAP cannot fit inside a EUR-pallet so a different solution is required. The solution could be to separate the electric components and the frame. The electric components can have for example a foldable assembly panel or be delivered as separate panels. As a result the electric components of the MAP can be packed with other components in module 7. The long frame can be delivered in modules 9 or 10. Change like this would require a design update for a better plug-in installation to ensure that the installation time would not increase. Also it would have to be ensured that the electric panel would have adequate protection inside the package as the frame is no longer protecting it. If the frame needs to be made from a single part for visual reasons, there is no possibility to pack the frame with electrification. With foldable or two-piece design also for the frame, the whole MAP could be delivered with other electrification and with adequate protection for electric components.
   In order to reduce the time that module 7 is open on site, shaft lighting was also relocated to module 10. This enables the opening of module 7 on the 5th day if MAP electrification is not installed with the frame on the 4th day.
8. Module 8's package was also reduced to a EUR-pallet size. COP is the only component that prevents this change. The installation team requires that all electric installations are made at the same time and when there is no more heavy installation to be made inside the shaft that would generate dust and possible vibration (Case study (2): Baker et al.). Therefore the whole COP cannot be installed with components in module 6 and delivered in the same module. As a result, a design change was proposed where the electric panel of the COP would remain in module 8, but the structural part of the COP would be delivered inside module 6. Some structural parts of the COP are already installed with the components from module 6 so this change would not cause issues to the installation process. From a design point of view this solution requires design updates to ensure a smooth installation of the panel in the structure. The optimal situation would be where the COP would be small enough that it could be packed into module 8. If longer visual elements are required for the COP, they should be integrated into the components in module 6.
   Structural parts of the COP are not manufactured in the same location as electric components so the change does not complicate the supplier field. The COP's solution would be similar to the proposal for the MAP. With current products, solution for COP is easier to implement. The final solution for modules 7 and 8 would be to have

2 EUR-pallet packages delivered as a single delivery unit to have cost savings in the handling of packages. Package contents would have to be well divided according to the installation order so that only the upper package is needed first.

9. The content of module 9 remained the same. In order to achieve the preferred package sizes it is necessary to increase the modularity of components inside the packages. Doors are the most challenging in terms of variety. There is also variation to the number of packages depending on the product. In some cases additional components are required for the façade of the landing to ensure that the hole to the shaft is completely covered. Two different door products that are both used in elevator products A and B are examined in this case study. These doors are referred as Door 1 and Door 2.
10. Components were added to module 10 from module 7. Trunkings are optional components and therefore not present in every delivery. Shaft lighting is ordered from a component supplier and therefore relocation to module 10 does not cause issues in the supply chain. If a longer MAP was ordered, the frame of the MAP would be delivered in module 10. Other option for the frame would have been in module 9, but due to the complexity of the module and packaging rules, the structural frame is easier to relocate to module 10. All the components in updated module 10 are installed in a close time frame which supports the installation process.

8.1.4 Updated module structure in the installation process

Changes to the module structure will influence the installation process. Components' installation phase stays the same but changes in component locations affect the order of needed modules. Figure 20 shows comparison between current module structure and the newly created one.

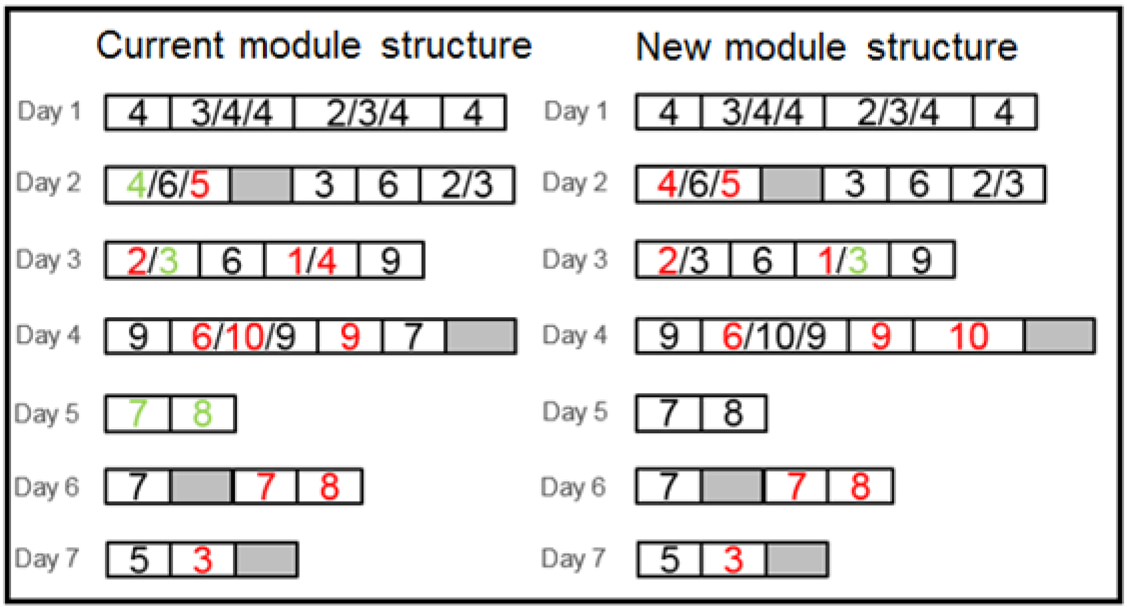

Figure 20. Module structure comparison in installation process.

In the new module structure it is guaranteed that module 4's package will be disposed in first waste removal phase. This gives more room for installation workers to operate. Module 3's package has a minor increase to the time that package is open on site. However, this does not increase the actual time if ropes are packed into the same package. This change does not affect the time in which the package can be disposed from the site even if the ropes would be packed separately.

Another change is that module 10 has more components. If longer MAP is delivered, it needs to be installed with the last landings doors on 4th day, if module 10's package is to be disposed during the 4th day. If module 7 is meant to be kept sealed until the 5th day, it would call for the installation the MAP in 2 phases. The aforementioned solution is not preferred by the installation team. Smaller MAP can still be installed on 5th day like in the current structure. The best situation would be to have a small MAP that could always be packed inside module 7 and installed on 5th day. This way it would be possible to reduce the time that module 7's package is open on site by 1 day. With the correct access order between modules 7 and 8 it is possible to have the upper package empty before the waste removal phase during the 6th day.

8.1.5 Modeling process

The aim of the modeling was to create loading models that would demonstrate how packages could be loaded if they would follow modular measurements. Modeling was based on the European truck dimensions and therefore models are not suitable for other continents. Models were created for whole elevator deliveries from DC to site.

In the beginning of the optimization process it became evident that guiderails are challenging due their length. Guiderails are not stackable with other products due to the package's dimensions and the product's sensitivity. Therefore the guiderail package requires all the available vertical space over its footprint. First step for the space reservation was to define a need for the guiderail packages to be stackable on top of each other. This was necessary in order to minimize the length in transportation that had limited transverse space because of the guiderails. The space reservation for the guiderail packages was slightly wider than the current package size to provide more stable package size for stacking.

Packages of modules 4, 6 and 9 were the largest so they were set to modular measurements. In order to load larger packages abreast, it was necessary to rethink the package of module 6 as a vertical package. This was also the installation team's request to ease the unloading of the heavy components. After optimizing the size of modules 2, 4, 6 and 9, only smaller size packages were left. The goal was to have smaller packages in EUR-pallet dimensions (1200 × 800 mm). All the packages were manually arranged with CAD (computer-aided design)-software to see how they would have maximum fill ratio and be in correct unloading order. Study like this would be challenging to execute with software created for loading optimization due to also having other requirements than just the efficient usage of space. One software was tested during this thesis but it was not suitable for the optimization process.

It was necessary to define how many floors can be covered with the created loading models. Therefore module 9 needed more studying because the increased number of landings have the greatest effect on the number of door components. In addition, module 9 has complex packaging selection rules and large variety in products which posed challenges for the optimization process.

The same door products are used in both elevators. These products are referred to as Door 1 and Door 2. Both door products have an option for frame or front type of door components. The delivery content and packages of Door 1 and Door 2 are listed below:

- Door 1:
  Package 1: Door panels & frames (if frame doors) & top track
  Package 2: Fronts (if front doors)
- Door 2:
  Package 1: Door panels
  Package 2: Frames or Fronts
  Package 3: Top track

From logistical point of view Door 1 is a better solution because it has less handling units. In Door 1 top tracks are delivered inside the same package than door panels and frames. Door 2 requires additional package for top tracks.

The created loading models have fixed width for door packages. As the number of landing floors increase at some point a second package is required whereas with current solutions only a single larger package would be required. Current door packages were more closely studied to understand how number of landings affect the package size. Table 12 presents the maximum number of landings that can be covered with the current package sizes that are 750 mm and 1120 mm wide. Same numbers were used for case study's package sizes because it was not possible to precisely define if a greater number of components could be packed to 800 mm and 1200 mm wide packages. Red X in the Table 12 presents variable dimension. (Case study (18): Skovran & Mikota 2017)

Table 12. *Door types and packages.*

Door 1	Package dimension	Maximum number of landings
Panels + frames Fronts	X ×800×800 X ×800×800	5* 6
Panels + frames Fronts	X ×1200×800 X ×1200×800	7* 7-10
Door 2	Package dimension	Maximum number of landings
Panels Frames Fronts	X ×800×800 X ×800×800 X ×800×800	5 2-4 2-3
Panels Frames Fronts	X ×1200×800 X ×1200×800 X ×1200×800	8 4-8 4-6
*= Requires 2 packages to achieve this number of landings.		

Table 12 shows that with Door 1, 2-3 800 mm wide packages are required to have an elevator with 5 landings. If frame type doors are used, then only 2 packages are required. With same sized packages in Door 2, 3 packages are often needed to be able to have an elevator with 4-5 landings. With certain configuration in Door 2 4 packages are required to deliver doors for 5 landings. In addition to these packages Door 2 requires always an additional package for top tracks.

If the elevator has a greater number of landings, 1200 mm wide packages can be considered instead of increasing the number of 800 mm wide packages. With 1200 mm wide packages 7-8 landings can be always achieved by using 3 packages. The structure of the loading model will change if wider packages are used. This should be studied more thoroughly in an elevator delivery level. Models in this thesis are created with 800 mm wide door packages and without Door 2's top track package. Created models are therefore suitable for elevators with 4-5 landings.

The difference in door types 1 and 2 is that Door 1 requires 2 packages for door panels and Door 2 for frames or fronts. This information led to a solution of having 3 packages with same dimensions. This allows all doors to be packed to the same kind of packages and ensures stacking between different door components' packages. Inner structures might vary depending on the door design. Also the top tracks should be able to be packed inside these 3 packages regardless of the door product.

8.2 Product A

Product A is smaller than the Product B and therefore has smaller packages. The optimization for the Product A was made by using European packaging solutions and transportation. The main goal was to optimize deliveries in road transportation. The Product A is sometimes also delivered overseas and therefore solution's suitability for sea containers was modeled.

With component and module structure updates it was possible to harmonize packaging sizes. Table 13 presents space reservations for the Product A's packages. Measurements in the Table 13 do not stand for fixed package sizes but space reservations, as the actual packages can be smaller than the presented sizes. The loading models define more specifically if a package requires certain size to ensure stacking with other packages. Table 13 also presents a color coding for the modules in the loading models. Modules 4, 6 and 9 have variable length due to component variation. Other dimensions are fixed to ensure the loading efficiency. Width and height are more important than length when maximizing the fill ratio.

Table 13. *Space reservations for Product A.*

Module number	Additional packages	Measurements (mm) (L×W×H)	Color
1	-	1200×1200×600	
2	-	5000×400×300	
3	-	1200×800×800	
4	-	X×800×800	
5	-	1200×800×600	
6	-	X×1200×1800	
7 & 8	-	1200×800×600	
	-	1200×800×600	
9	-	X×800×800	
10	-	2400×800×600	

The number of handling units is essential information because it affects the handling costs. In product A's case the number of handling units can increase compared to the current situation. The number of handling units remains the same in most of the modules. Modules 7 and 8 remain as a single handling unit. Other modules have a single package each but in module 9, the number of packages vary depending on the number of landing floors. The number of handling units in a delivery for 4-5 floors is 10-11 units depending if 2 or 3 door packages are required. In addition there can be additional handling units like oil buffers, a separate travelling cable package and other components.

8.2.1 Loading models for road transportation

By defining modular package sizes, it was possible create efficient loading models. Different restrictions had to be considered during the iterative modeling process. The stacking limitation of certain packages had to be considered which resulted in decreased fill ratio. More efficient space usage could be achieved if rigid packaging solutions would be used. This is not always reasonable due to the heavy weight of components. Packaging costs might be so high that savings from efficient space usage are not enough. Loading models had to support the installation team's site storage plan.

Figures 21, 22 and 23 present loading models for road transportation. Models are for a standard elevator delivery content and created with 3 door packages. If the number of door packages is less than 3, the models are still valid as loading guides but common loading rules must be followed with package placements. The following package sizes were used in modeling for modules with varying lengths:

- Module 4: 3200×800×800 mm
- Module 6: 2650×1200×1800 mm
- Module 9: 2600×800×800 mm

The trailer measurements used for modeling were 13 600×2430×2680 mm. The dimensions of 13 600×2400×2400 mm was used as an available space for packaging. Smaller dimensions available for packages ensure a handling margin inside the trailer.

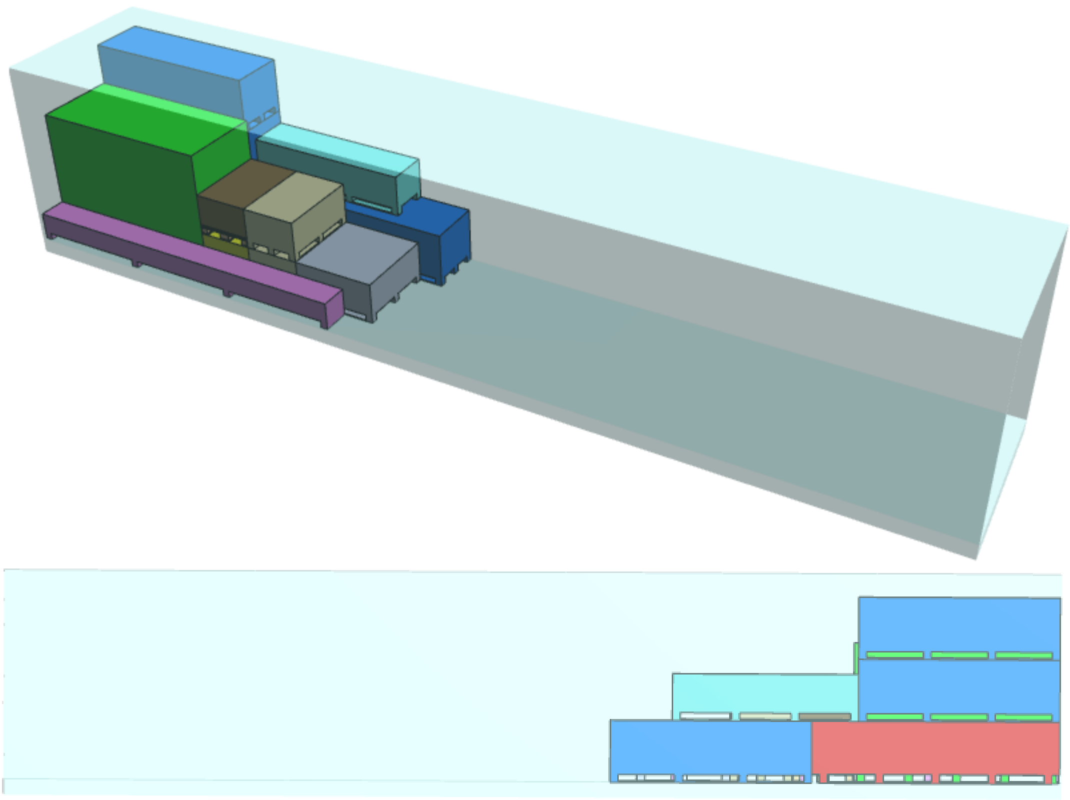

Figure 21. *Loading model of a trailer with one Product A.*

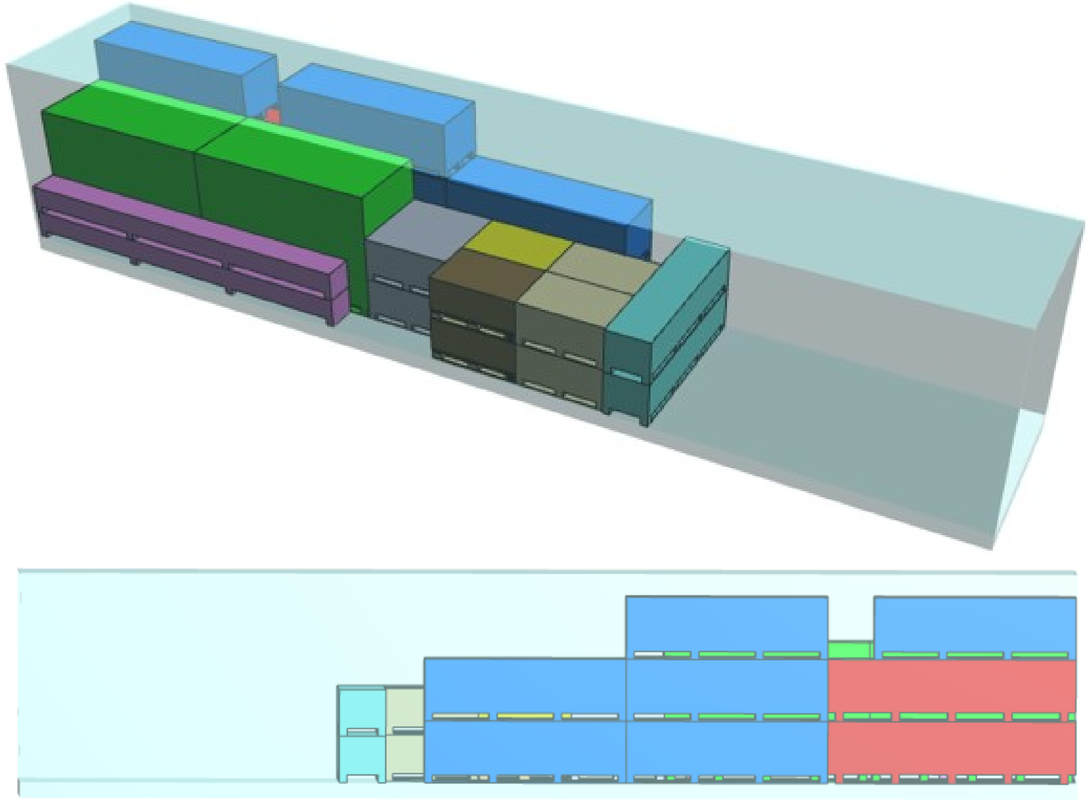

Figure 23. Loading model of a trailer with three Product A elevators.

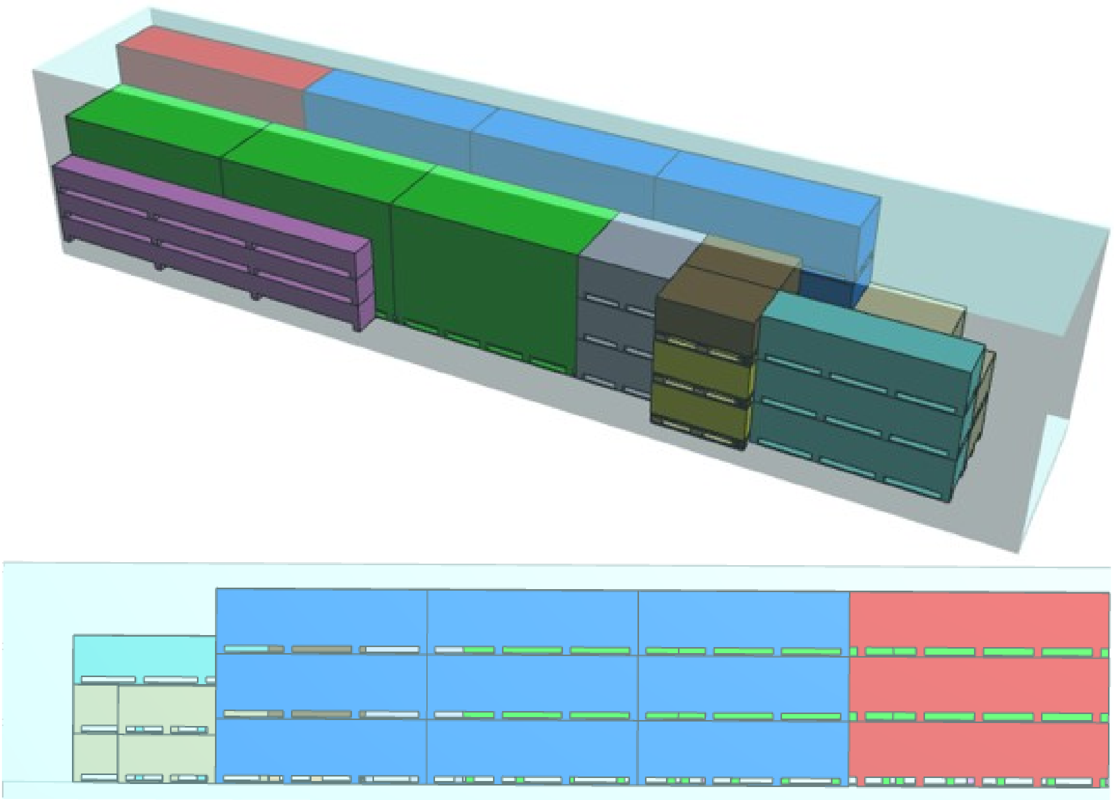

Figure 22. *Loading model of a trailer with two Product A elevators.*

The loading models are based on the idea of the cargo being loaded from one side and unloaded from another. Pictures below in figures 21, 22 and 23 shows the unloading view. This idea is eligible for site deliveries having access from both sides of the cargo space. As trailers are not used for site deliveries, installation order is not as important in these cases. The same type of loading model still ensures a certain level of harmonization. Modules 7 & 8, 9, 10 and 1 are the first ones to be unloaded. The last ones to be unloaded are modules 2, 3, 4, 5 and 6.

Fill ratio with three elevators in a trailer is around 47 %. It is possible to load four elevators inside a trailer if existing 2420 mm long door packages are used for Door 1 frame doors. Fill ratio with four elevators is around 62 %. Loading four elevators would require rigid packages to enable a high level of stacking. The loading model for four elevators is not presented in this thesis because it only covers a small amount of deliveries and requires expensive packaging solutions.

8.2.2 Loading models for sea containers

The trailer optimized package sizes were modeled in a sea container to study if packages can be loaded efficiently for overseas deliveries. Figures 24 and 25 present loading models in a sea container. Sea container measurements used in the modeling were 12 010 × 2330 × 2380 mm. It was possible to load two elevators inside a 40’ sea container with a fill ratio of proximately 42 %. In sea containers loading meters are not as important as in road transportation because costs are not based on the used loading meter but for the whole container.

Unloading in common sea containers is possible from the end of the container. Therefore lower pictures in Figures 24 and 25 are not unloading views like in road transportation models. There is no possibility to lift packages on top of each other inside a container. Packages need to be stacked outside and loaded inside as a pile. In sea containers it was challenging to maintain an unloading order, so the models are created from the space usage point of view.

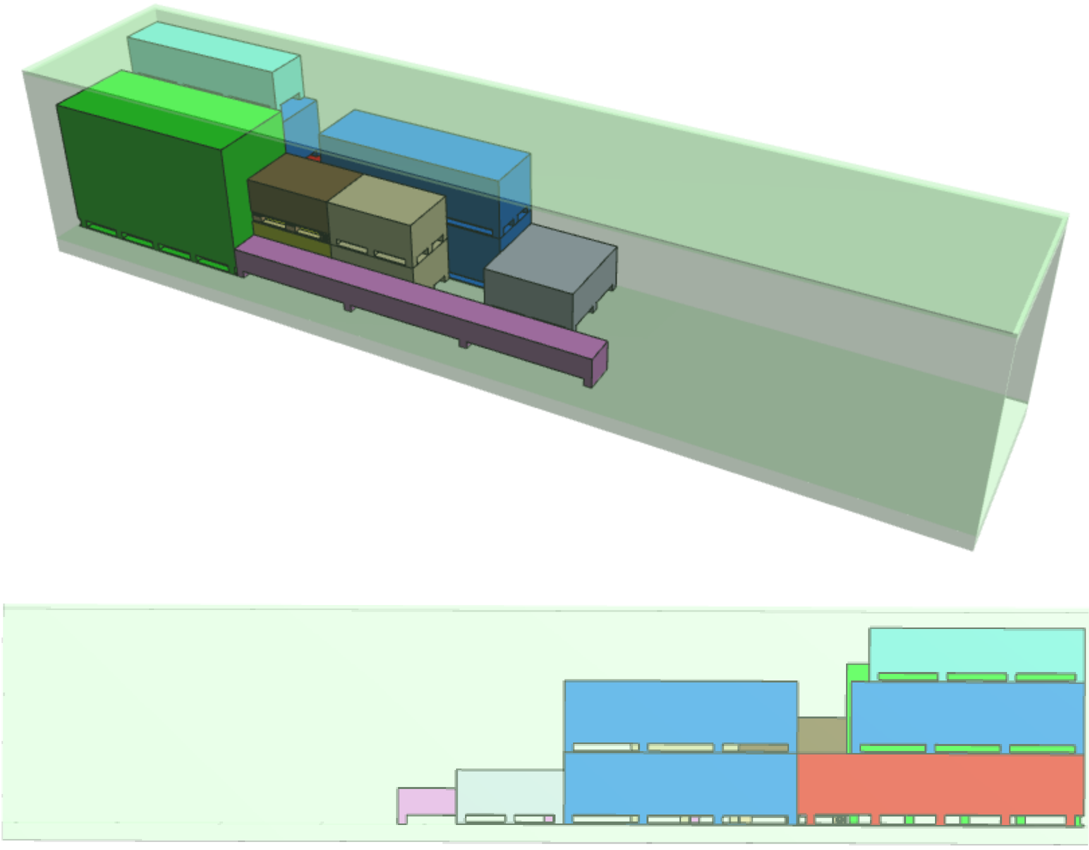

Figure 24. *Loading model of a sea container with one Product A.*

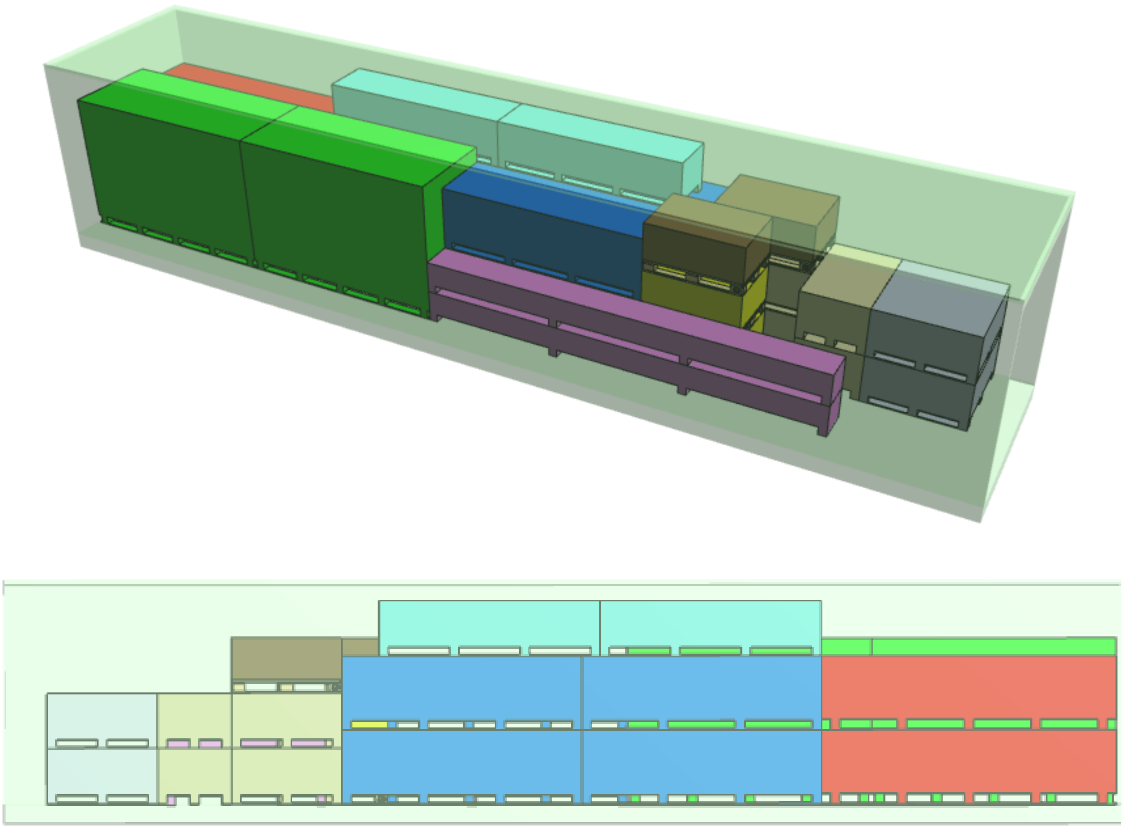

Figure 25. *Loading model of a sea container with two Product A elevators.*

The same number of elevators cannot be loaded into a sea container than into a trailer. There is also a lot of free transverse space that is not used because the package dimensions are not optimized for a container. To optimize loading for sea containers, package measurements presented in the Table 10 should be preferred. Packages with sea container optimized dimensions on the other hand have more empty space in trailers and require increased amount of support structures and fillings to protect the packages during transit.

8.3 Product B

As Product B is a larger elevator, it makes the package size optimization more challenging due to a larger size of the components. Modules 4 and 6 require larger packages. The size of modules 4, 6 and 9 still vary but other modules' package dimensions are the same size as in product A. Table 14 presents space reservation for Product B's packages.

Table 14. *Space reservation for Product B.*

Module number	Additional packages	Measurements (mm) (L×W×H)	Color
1	-	1200×1200×600	
2	-	5000×400×300	
3		1200×800×800	
	Ropes	*1200×800×600*	
	Oil buffer (optional)	*705×400×1000*	
4	-	X×1200×800	
5	-	1200×800×600	
6	-	X×1200×2000	
7 & 8		1200×800×600 1200×800×600	
	Travelling cables	*1200×800×600*	
9	-	X×800×800	
10	-	2400×800×600	

The number of handling units is greater in the Product B. This is because travelling cables are not delivered inside module 7. Also ropes are delivered in their own package. In addition to the standard delivery content, there is also a possibility for additional components. Models for Product B were created with an additional oil buffer package. Additional packages such as the oil buffer are usually smaller and can be placed in the remaining space in the standard delivery model.

8.3.1 Loading models for road transportation

The same restrictions and principles as in Product A were used in Product B's loading models. With larger package sizes it is more challenging to achieve high fill ratios. The following package sizes were used in modeling for modules with varying lengths:

- Module 4: 3200×1200×800 mm
- Module 6: 3200×1200×2000 mm
- Module 9: 2600×800×800 mm

Module 4's package length is from the smallest end of the size range. Product B has different machineries that affect the loading models due to varying size and possible stacking limitations. Loading models in this thesis were created with the same stackable machinery packages than in Product A's models. Only this machinery package enables the loading of 3 elevators in a trailer. The same trailer size and available space for packages were used as in Product A's case. Figures 26, 27 and 28 present the loading models for Product B in road transportation.

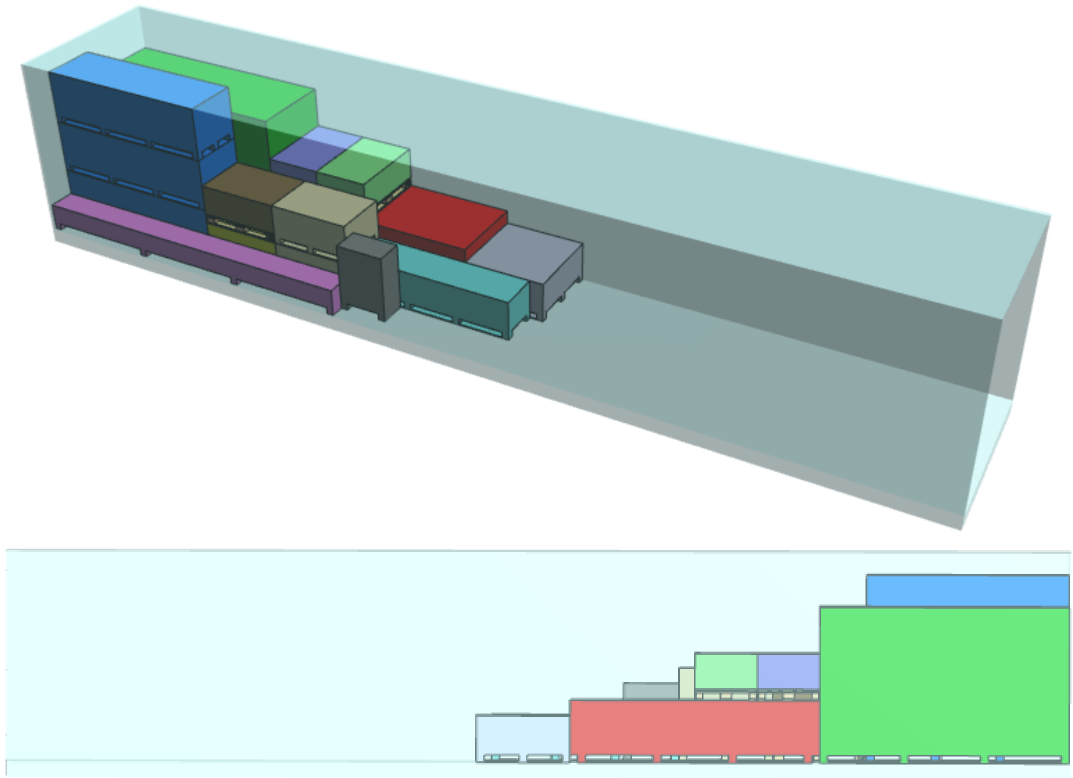

Figure 26. *Loading model of a trailer with one Product B.*

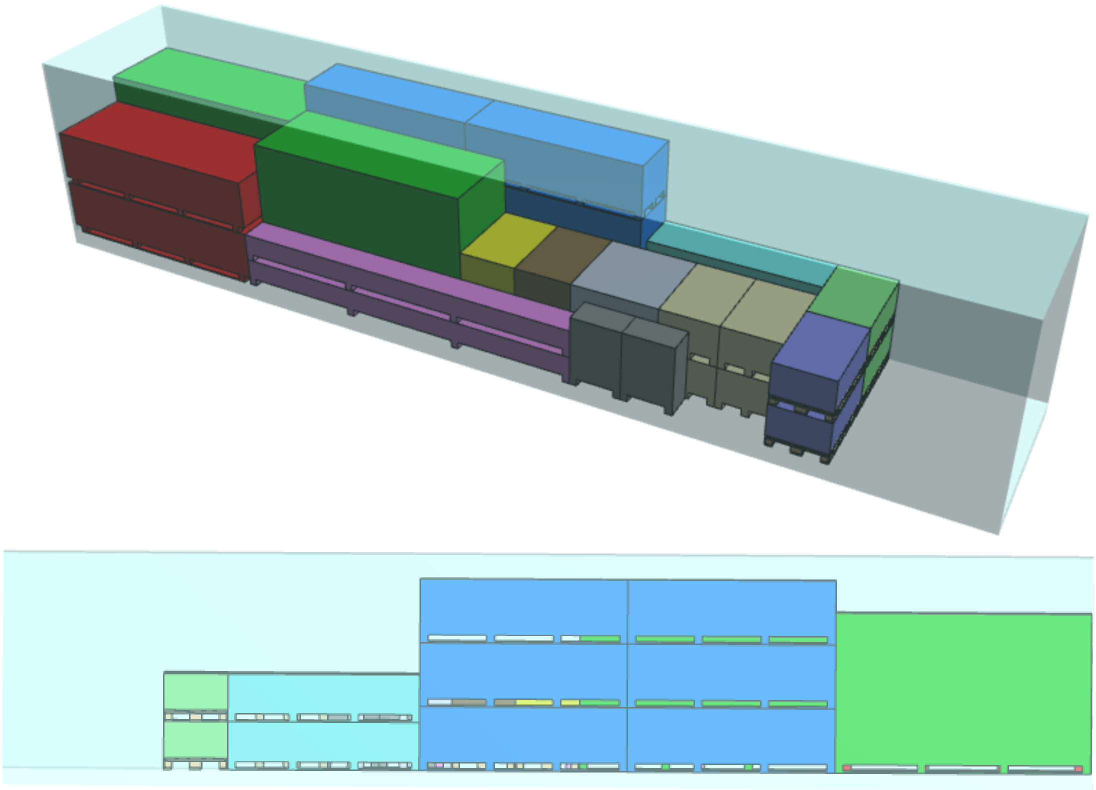

Figure 27. *Loading model of a trailer with two Product B elevators.*

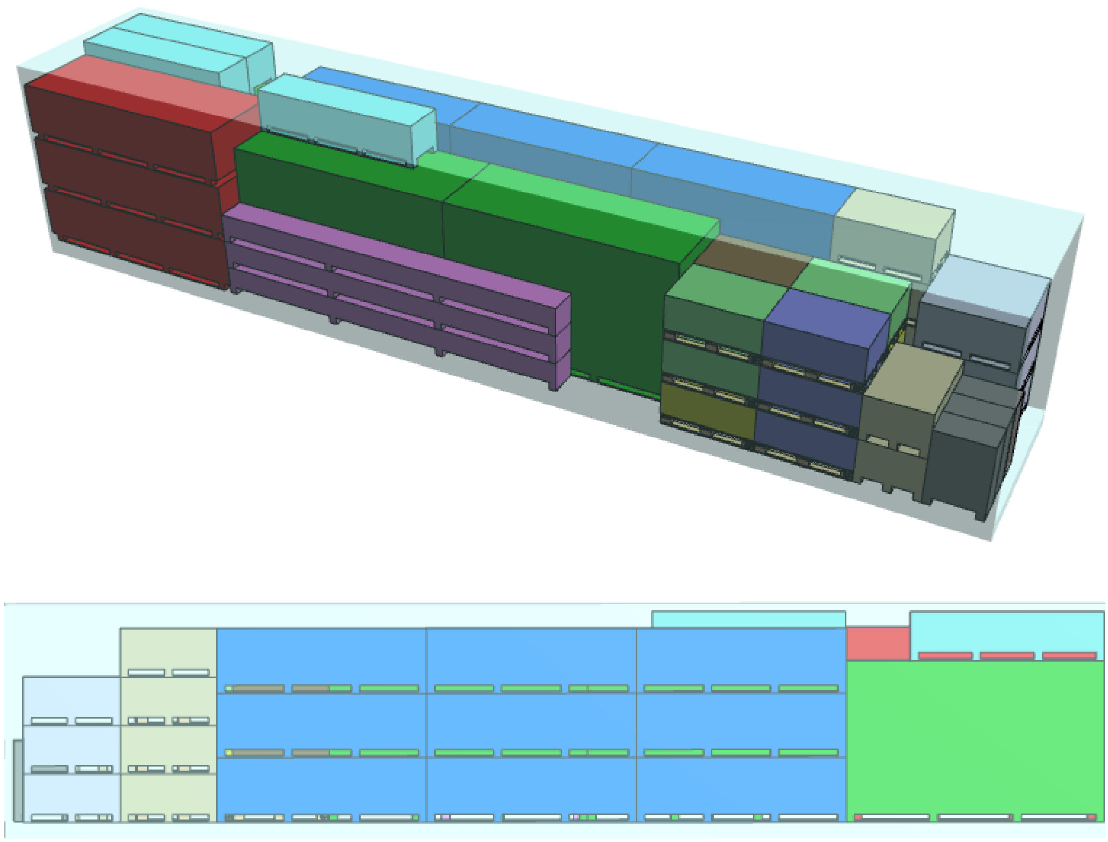

Figure 28. *Loading model of a trailer with three Product B elevators.*

The loading model for one elevator does not follow the rule where unloading is conducted from the opposite side than loading. Correct access order can still be maintained with site delivery trucks that have a crane. Lower pictures in figures 27 and 28 show the unloading view but in Figure 26 unloading should be done from the same side as loading is done.

In the Product B it is possible to load up to three elevators inside a trailer with a fill ratio of around 56 %. This would require a small end elevator and rigid packages to enable heavy stacking. Among the road transportation options only the trailer has the sufficient height of cargo space for loading module 10 package on top of the car package. The model for two elevators in a trailer is more realistic with current packaging solutions. Two elevators are possible to load into a site delivery truck if the stacking possibilities of the smaller packages (presented in Figure 27) are further improved.

8.3.2 Loading models for sea containers

Sea container loading is even more challenging in Product B's case because of the increased package size of the modules 4 and 6. With both packages having the width of 1200 mm, they cannot be loaded abreast. Only a single elevator can be loaded into a sea container.

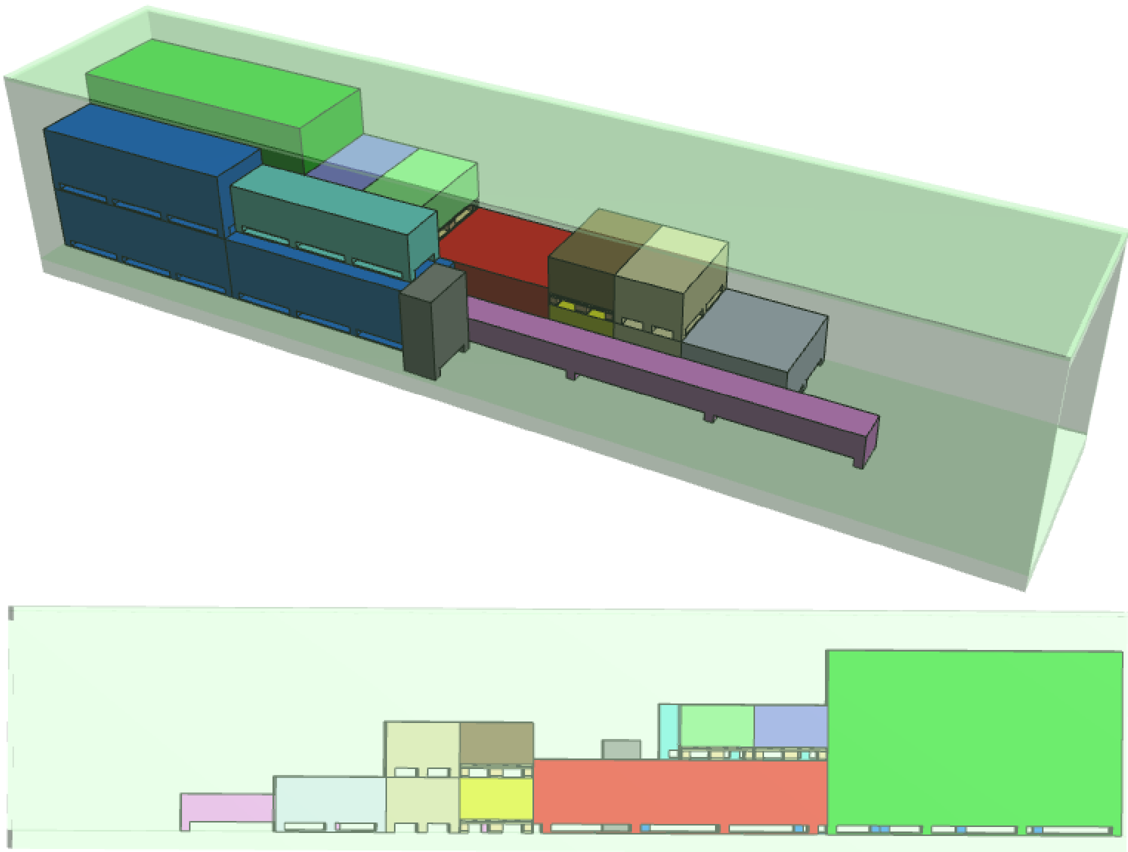

Figure 29. *Loading model of a sea container with one Product B.*

The sea container model for Product B does not have an efficient space usage. With the larger package sizes of product B, it is not possible to load two elevators even though there is a lot of free space in the container. If two elevators need to be loaded into a sea container, some of the packages must follow the measurements optimal for a sea container.

9. RESULTS AND DISCUSSION

The case study presents what kind of benefits can be achieved by following the Design for packaging guidelines. Benefits can be seen in the different processes during the supply chain. In order to understand the effects of the optimization, it is required to compare results with current situation.

9.1 Module structure update

The review of the module structure and the installation process provided information about the time each module is open during the installation process. Modules 3 and 6 are the most crucial in terms of site protection because they are open for the longest time period. This information is important for the packaging development and the installation teams. If corrosion or other damages occur in components during the storage on site, packaging solutions and installation procedures must be checked to ensure protection for the components. Component protection on site could be improved by relocating components between modules. Relocations made it possible to decrease the time that packages are open on site. These improvements are presented in Table 15.

Table 15. *Benefits in the installation process from the component relocations.*

Module number	Changes in the installation process
1	-
2	-
3	Increased time that the package is open on site (Product A). Nevertheless the change provides improved protection for components that were previously in module 4.
4	Package can be always removed during the 2^{nd} day waste removal phase.
5	-
6	The COP frame can be installed from the same package as other structural components of the COP. Small end COP enables to have the whole panel in the module 8.
7	Reduced time that the package is open on site.
8	If the COP is currently packed separately from other signalization, it is possible to remove a single delivery unit from the delivery content with the updated solution (Product B).
9	-
10	All the components inside new module 10 are installed in a close time frame.

Components that were relocated between modules are delivered by different component suppliers so changes would not increase the complicity of the supply chain. In COP and longer MAP it was required to have more complex solutions than current ones. These ideas require more study with installation professionals in order to create solutions that would not increase the installation time. Solution should ensure that module 7's package can always be opened on the 5th day. This can also be achieved by using only the smaller MAP. With the solution created in this thesis there is still variation in the opening of the package between 4th and 5th day.

Module 9 also requires more study in order to understand if the width of 800 mm is reasonable for a door package. With the width of 1200 mm, more landing floors can be covered and in some cases reduce the number of handling units compared with the 800 mm wide package. Volumes for each landing floor should be compared with the door package sizes in order to define which package size would be the most reasonable to use. With three 800 mm wide packages it is possible to cover a certain percentage of the deliveries. If a higher percentage can be covered with 1200 mm wide packages, it might be reasonable to use a wider size.

9.2 Loading models

The module structure update was necessary in order to have logistical package sizes. Design changes to some components were necessary to achieve the package sizes presented in the case study. In every situation it is not possible or beneficial to reduce the size of components and therefore the relocations of components between modules were important also in package size optimization. With optimized package sizes it was possible to create efficient loading models that can improve case company's deliveries. The modeling process was guided by the unloading order of the installation and efficient space usage in the transportation. Loading models present an example of what case company's elevator deliveries could look like with logistical packaging.

Loading meters define the costs in road transportation and therefore it is important to compare created loading models with current deliveries. In the current deliveries it is challenging to define the actual length required by each delivery. Transportation planning has estimations that have been forming over time for each type of delivery. This means that there will always be around one meter of extra space. (Case study (19): Rinne) With loading models that have only few packages with variable lengths, the transportation planning team will have a better insight of the required loading meters. Table 16 shows a comparison of required loading meters between the created loading models and estimations of current deliveries.

Table 16. *Required loading meters.*

Product A			
Loading model	Number of elevators	Required loading meters (m)	Reduction in loading meters (m)
Current	1	7	0,4 - 1,2
Created	1	5,8 – 6,6	
Product B			
Loading model	Number of elevators	Required loading meters (m)	Reduction in loading meters (m)
Current	1	9 - 10	0,3 - 1,9
Created	1	7,1 - 8,7	1,3 - 2,9

In Product A loading meters in a single elevator delivery are a sum of the package lengths of modules 4 and 9. In product B's case it is a combination of the package lengths of modules 6, 4 and 1. There is variation in required loading meters because of the varying package lengths of modules 4, 6 and 9. Minimum and maximum are calculated with currently used package lengths. With loading models, it is possible to calculate required loading meters because it is known which packages define maximum length. Loading with additional packages will change loading models and therefore it takes time to understand how these packages are loaded and what kind of effect there is to the required loading meters. It is possible to define where a new handling unit can be loaded by inspecting the loading models. This way a quick calculation of the required loading meters can be made. To improve the transportation planning, a tool should be created that can receive the loading meter information from the loading models.

Multiple elevators are seldom loaded together and transported with costs by the used loading meters. With more than one elevator, transportation calculations are made in full trucks. With Product A, the average number of elevators that can be loaded into a trailer in the current situation is 2,4. There is variation from 2 to 3 depending on the number of packages. With Product B, the number of elevators is 2. (Case study (20): Zanini) Table 17 presents the number of elevators in created loading models that can be loaded into different transportation and a container.

Table 17. *Number of elevators in different transportation.*

Elevator product	Transportation	Number of elevators
Product A	Trailer / site truck	1
	Trailer / site truck	2
	Trailer	3 / 4*
	40’ Sea crate	2
Product B	Trailer / site truck	1
	Trailer / site truck	2*
	Trailer	3**
	40’ Sea crate	1
* Requires more rigid packaging ** Requires more rigid packaging and small end elevator		

Numbers presented in Table 17 are for full elevator deliveries. With Product A it is possible to have 3-4 elevators in a trailer. With Product B it is possible to have 2-3. Loading models offer same or greater loading efficiency than the current solutions and enable usage of site delivery trucks for two elevators. Additional benefits are that all elevator packages are in the same trailer and support the preferred order by the installation team. Logistic package measurements defined in this thesis provide improved situation even if elevators’ packages would be divided into multiple trailers. Modular package sizes ensure an efficient fill ratio when the same size packages are loaded together. Therefore deliveries from manufacturing sites to DCs also benefit from logistical package sizes. Transporting elevator packages in multiple trailers might cause more sorting in the receiving end.

All the models for road deliveries, except for the Product B’s single elevator delivery model, are based on the idea that packages are loaded from one side and unloaded from the opposite side. Loading models offer harmonized delivery, ensuring that installation workers receive deliveries always the same way which makes it easy to plan the unloading and storage on site. Unloading can be done in a way that packages can be easily stored on site according to the installation order. This reduces the installation time and increases process harmonization. When a delivery arrives at the site, there should be no confusion as to where to start the unloading. In current deliveries, it is not possible to ensure the correct unloading order.

The created loading models are examples and suitable for certain kind of deliveries. With the large variety in elevator products and components, there are factors that cannot be completely taken into account. Therefore it is reasonable to create loading models for the standard deliveries that have the largest volumes. By having only few varying measurements, the loading structure can be controlled. Models and solutions created in this case study are proposals and all of them are not directly suitable for implementation because they require product design updates, changes to supplier operations, packaging design, packaging tests and packing instructions to achieve a working supply chain.

Changes in the module structure and loading structure enable to reduce the number of damaged components during the installation process. This affects the number of claims and additional spare part shipments. Process harmonization can also be increased. Therefore cost savings can be achieved in the supply chain operations and in delivery efficiency. Operational costs are related to the pricing of the elevator products. Benefits achieved in the supply chain can result in more competitive pricing and competence in the elevator markets.

9.3 Other findings

With product specific loading models it is possible to define which packages are to be loaded on top of each other. This information can be used in packaging design to ensure stacking with certain type of packages. In the packaging design process, stackability must be validated to ensure safe and cost-efficient solutions. Current stacking rule allows only packages with the same size to be loaded on top of each other. With loading models this rule can be partly ignored which offers wider possibilities for stacking between different types of packages.

In the beginning of this thesis it was assumed that a guiderail package with the length of 2400 mm would be the most efficient. The reason for this was that it could be loaded sideways in a truck and therefore greatly improve the fill ratio of the whole delivery. During the modeling process it was discovered that there were no major benefits by having guiderails packed in logistical length. By comparing a model with short guiderails and the created loading models, the reduction of loading meters from a shorter guiderail package was around 1 meter. Small benefits gained in the loading efficiency and possible claim reduction would not compensate the costs from increased installation time. There are benefits in smaller guiderail lengths but it would require a different type of installation method for maintaining the same installation time.

10. CONCLUSIONS

Logistic efficiency and the fast installation process are key elements in the supply operations. By improving these processes, it is possible to reduce the supply chain costs and achieve competitive advantage in the elevator market. Packaging has an important part in these processes and therefore should be focused on. The case company's organization is not completely aware how packaging affects the whole supply chain and what kind of benefits could be achieved by having logistical packaging. With case company's current development structure and product design principles, it is extremely challenging to achieve large scale improvement with packaging solutions. Therefore the case company is not utilizing all the methods for improving logistic efficiency. Packaging based design should be one of the top priorities when minimizing costs from the supply chain.

The Design for packaging -concept created in this thesis aims to improve the supply chain process. This study supports researches of Twede (1992) and Olander-Roese & Nilsson (2009) showing that it is necessary for the packaging development team, product designers and development process owners to contribute in order to achieve optimized packaging solutions. The Design for packaging -concept provides information for these members about the concept's goal and why and how they should support the packaging development team. This helps to prevent change resistance which can occur if the concept is not completely understood.

The different types of features and functions required from an elevator packaging were documented. The effects of component features on packaging were also documented. From this information the Design for packaging guidelines were developed for the product design organization. The guidelines aim for logistical packaging solutions in the following ways:

- Present optimal component dimensions that should be followed.
- Inform about component features that cause challenges in different phases of the supply chain. The Design for packaging guidelines are to be used with other Design for X guidelines.

The optimal component measurements ensure the usage of logistical package sizes. Measurements are based on the package sizes optimized for used transportation. Other instructions ensure packability, the handling of components, the reduction of packaging waste, product modularity inside packages and improved quality and safety.

Process improvements were created during this thesis to ensure that the packaging development team can co-operate with product designers. This can be considered the most important outcome of this study because in this way packaging aspects can become a part of the product design. Change ensures that major packaging development opportunities are not missed. Concept development projects offer a much more suitable environment for development tasks because in concept development phases it is possible to influence the product design. The updated development process would change the operations of the packaging development team. In the current situation development is conducted during the packaging design tasks. Development is done by implementing the best practice findings into new designs. Process change is more clearly dividing the operation of the packaging development team into development and packaging design tasks.

By implementing the Design for packaging guidelines, it was possible to create more harmonized loading structure for current products. Harmonization improves handling processes but the benefits are more challenging to measure. Improved loading efficiency is easier to calculate. As a continuance from this thesis there should be a business case study done to an existing product in order to research what kind of cost savings could be achieved by utilizing logistical packaging. This information could then be used as a concrete reference by the packaging development team to promote the concept of logistical packaging internally to other projects and higher management.

Packaging size optimization is also necessary due to environmental restrictions. In the future, the amount of packaging waste must be greatly reduced or prevented completely. Therefore environmental friendly solutions, such as returnable packaging should be focused on. If package size harmonization and standardization are not done, returnable package solutions must be company specific. Solution like this would be expensive. Great savings could be made in the transition, if component sizes are suitable for packaging solutions that are used commonly. EUR-pallet for example is a widely used solution with large number of items in the rotation. Package size consideration should begin early so that when the usage of returnable packaging becomes mandatory, there would be solutions ready for implementation. The Design for packaging -concept provides tools that can be used to achieve this goal.

In further development it is necessary to create more specific process steps for the packaging development team and project managers in the concept development projects. Before implementing the Design for packaging -concept, training material needs to be created. This way there will be sufficient amount of information so that the concept can be well instructed and implemented. If the concept is implemented only with the Design for packaging guidelines, it is challenging to understand why the concept should be implemented and followed. Benefits and cost savings should be able to be presented so that the value of the concept is acknowledged and implemented.

In order to benefit from the updated development process, it is important to ensure that the packaging development team has adequate resources to support the concept development projects. If the product design organization does not receive required support, the whole Design for packaging -concept starts to lose its importance. (Laajaniemi & Vesola)

As the packaging development team is the one driving this change in the organization, they need to make sure that the implementation plan is followed.

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