



# UNIVERSITY OF TWENTE.

## Cargo Layout Design for the Stackability of Boxes in ULDs for the Inbound Products of Company X

### ANONYMOUS VERSION

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# MANAGEMENT SUMMARY

This thesis is the closing element of my Bachelor Industrial Engineering and Management at the University of Twente in Enschede. It is performed at company X in the south of the Netherlands. The target is to describe, analyze and improve a specific part of the company X logistics system, i.e., **airfreight of inbound logistics**.

Company X is a car manufacturer with its assembly plants all around the world. Car parts are produced in supplier plants all over the world and are shipped to these plants for final car assembly. This process is called “inbound logistics”.

The critical element in Company X’s car manufacturing process is continuity. Assembly line stoppages are very expensive and must be avoided at all times. 2018 will be a critical year for Company X, as it must reach mass production volumes, fulfill the financial market expectations and stay ahead of competition. Therefore, all efforts are focused on timely delivery of parts to the assembly lines.

Inbound logistics overseas can be done by boat, in containers or by plane, in ULDs. ULD is short for Unit Loading Device. A ULD is an aluminum container used to store boxes/pallets during flight. These ULDs have an efficient fit in the aircraft and allow for easy handling. Obviously, container shipments are cheaper, but also slower, requiring longer term planning. For short term needs or unforeseen events, car parts are flown in, using boxes that are packed in ULDs. In order to minimize the high airfreight cost, this study focuses on improving the use of ULDs by designing a more efficient stacking pattern of standard boxes, the so-called IMCs.



To improve the load efficiency of the ULDs a cargo layout model has been designed. This model calculates an efficient filling method on the basis of the size of ULD and IMCs used. This limits the cost per volume shipped. The model can be used by the handlers when loading the ULDs or by the freight forwarders in order to create pre-stacked pallets ready for ULD loading.

The benefits of pre-stacking pallets for maximum ULD efficiency are less handling, more load stability and therefore less risk for transport damages and unforeseen delays. The benefit for the freight handlers is a higher ULD filling grade, thus decreasing freight cost per m<sup>3</sup>.

In conclusion: using the Cargo Layout Model improves the reliability, predictability and efficiency of the inbound logistics process for Company X, decreasing the risk of faulty deliveries and ultimately line stoppages.

It is recommended that the model is implemented as a base for the forwarders and freight handlers used by company X for its products.

# PREFACE

Before you lies the thesis “Cargo Layout Design for the Stackability of Boxes in ULDs for the Inbound Products of Company X”. This thesis is written as a final stage of my Bachelor Industrial Engineering & Management at the University of Twente. I conducted the research as an intern at Company X in the south of the Netherlands. The main research question is formulated together with my University of Twente supervisor, Dr. P.C. Schuur.

During this period as an intern at Company X, I have learned a lot about the company, their way of management and the ‘hands-on mentality’. In addition, it has been a very fun time thanks to the friendly and open environment and all colleagues.

Writing the thesis and designing the Cargo Layout Model have been challenging and educational at the same time. Fortunately, my supervisors have been available throughout this period to answer all my questions and help improving the research.

I would like to express my sincere gratitude to company supervisor Mr. X, for giving me the opportunity to conduct my research at Company X, guiding me throughout the entire internship and making the four months at Company X great for me.

In addition, I would like to thank my University of Twente first supervisor Dr. P.C. Schuur for helping me take this thesis to a higher level, providing me with new insights to design the model and improving the thesis. Furthermore, I would like thank Ir. H. Kroon for his insights and support as my University of Twente second supervisor.

Last but not least, I would like to thank my family, and especially my father for correcting and improving my thesis, Nathalie and my friends for helping and supporting me throughout my internship.

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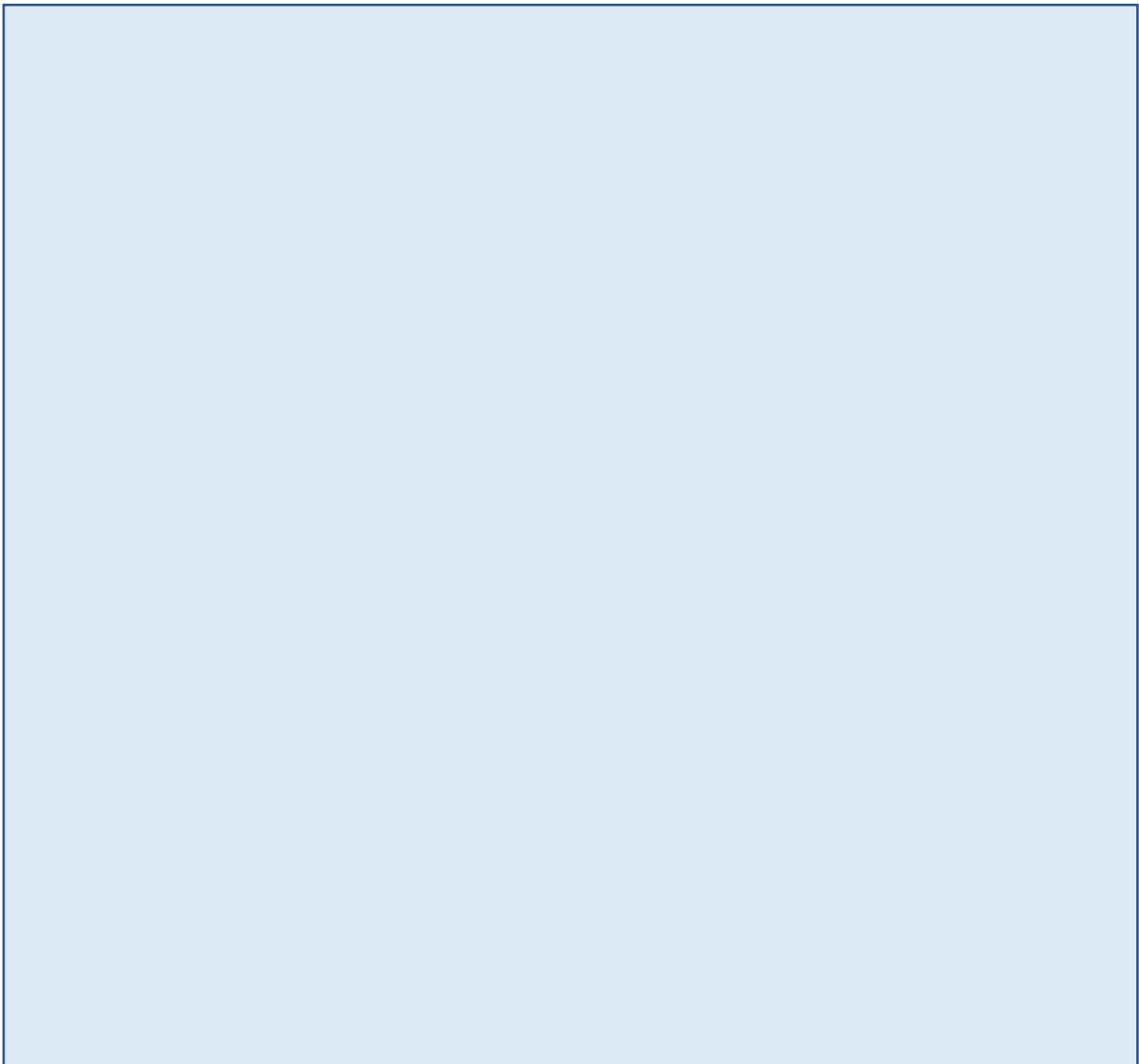
# 1. INTRODUCTION

In the framework of completing my Bachelor Industrial Engineering & Management at the University of Twente, this thesis is written. I performed research at the Automotive Manufacturer Company X in the south of the Netherlands. The thesis focuses on designing a Cargo Layout Model that calculates an efficient cargo layout for Company X's inbound EMEA boxes in airfreight.

This chapter contains an introduction to Company X and its inbound logistic process in section 1.1. In section 1.2 the research problem is described followed by the research design in section 1.3.

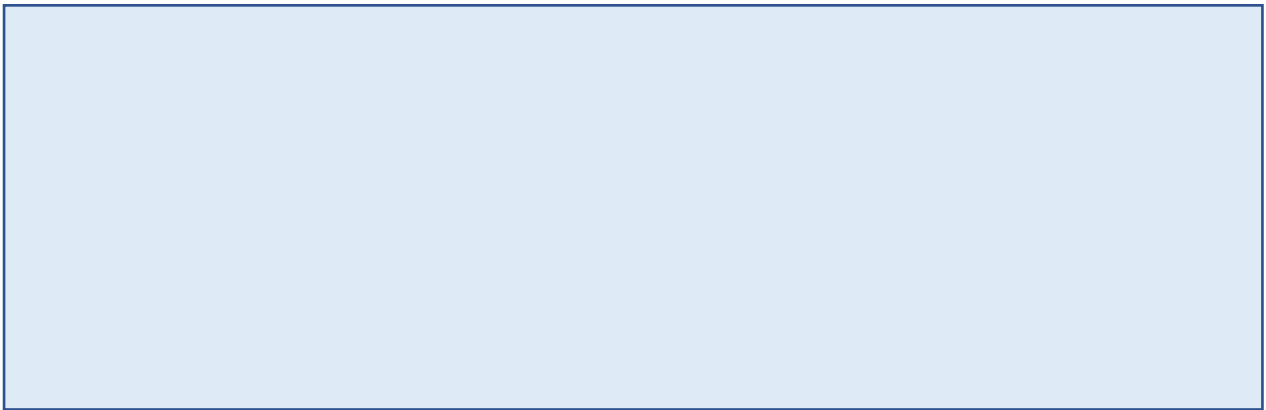
## 1.1 INTRODUCTION TO COMPANY X

### 1.1.1 COMPANY BACKGROUND

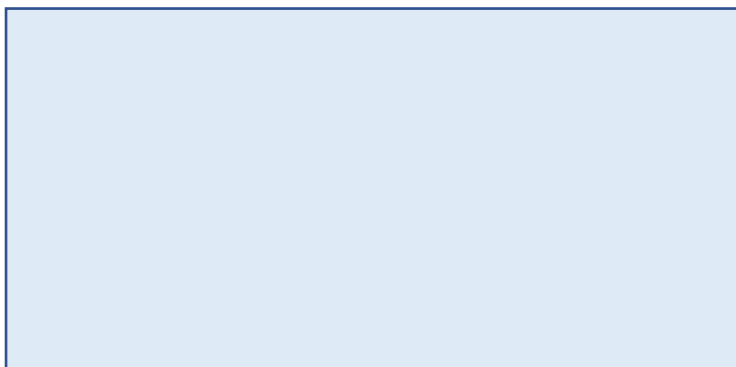


Since Company X is a relatively new and very innovative company, the focus is on global hierarchy. This means that Company X aims for minimal regional divisions and tries to keep the entire organization centralized. Decisions are made by the central management. Since Company X is a multinational, having regional divisions is unavoidable and necessary in order to implement market specific strategies and marketing campaigns. The advantage of having a global centralization is effective global control in all markets. This allows Company X to quickly implement new strategies and tactics.

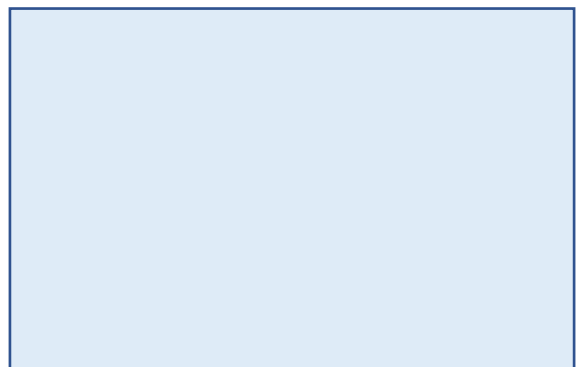
A downside of a global hierarchy is that, if Company X needs to respond in a specific market, there is no local management. This can only be solved by giving local offices more autonomy but this 'decentralization' is something Company X is trying to avoid. Company X keeps this global hierarchy in order to continuously adapt to new market expectations and being more innovative. Below, Company X' chain of command is shown in figure 1-2. Figure 1-3 shows Company X its factory and figure 1-4 shows the outline and layout of Company X's factory.



*Figure 1-1: Company X' Chain of Command*



*Figure 1-3: Company X Factory*



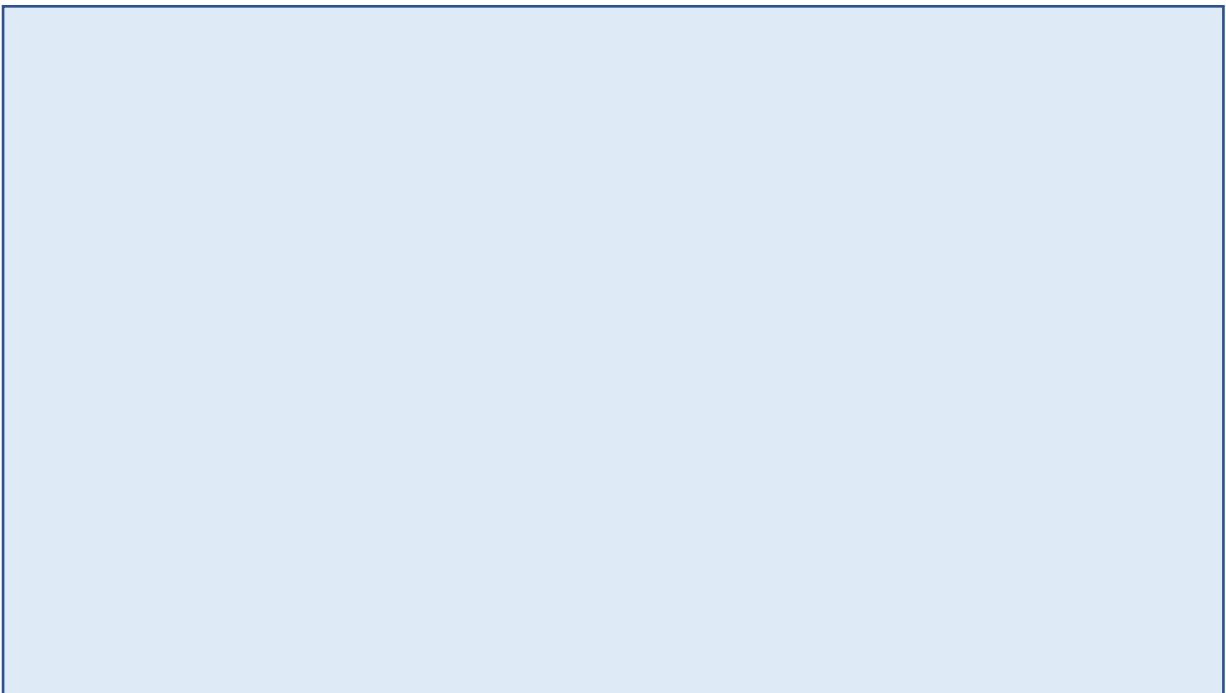
*Figure 1-4: Company X Factory Layout*



### 1.1.2 LOGISTICAL ELEMENTS EXPLAINED

#### Inbound logistics for Company X EMEA

This research focusses on the inbound logistics of Company X EMEA. EMEA stands for Europe, Middle-East and Africa. “Inbound logistics refers to the transport, storage and delivery of goods coming into a business. (Outbound Vs. Inbound Logistics, 2017)” In the case of this research thesis, the inbound logistics of Company X refer to the products transported from and within EMEA. This means that the transport of products from EMEA to the factories in the USA is also arranged by the Logistics team EMEA & India. In figure 1-5 below, a map is shown with all suppliers that are handled by the logistics team EMEA.



*Figure 1-5: EMEA Inbound Suppliers Company X*

In order to keep all factories running, it is of great importance that the parts get delivered to all factories in time. Since the downtime of factory is extremely expensive, Company X tries to make sure this never happens. It often occurs that a container shipment will not arrive in time and then Company X chooses to use airfreight in order to make sure the products do arrive in time. The sudden transition from container shipments to airfreight requires suppliers to change the designed cargo layout. Since pallets are mostly already build, the logistical carrier has to make sure the cargo layout for airfreight is efficiently designed.

Air freight is the most expensive method of transportation in the cargo business and used mainly for urgent and high-value items. There are restrictions on the weight and size of the goods that can be carried, as well as more banned items. Packaging is very important since size affects price. (Air Freight Guide, 2017). Since airfreight has far more transportation restrictions than container shipment, it is harder to respond to last minute changes and still arrange efficient transportation. One of the major restrictions for Company X is the height in the planes. As for different aircrafts, Company X uses three options.

- *Freighter Aircrafts*
- *Wide-body Aircrafts*
- *Narrow-body Aircrafts*

More details of these planes can be found in appendix 2.

Due to size restrictions and availability, almost all airfreight of Company X is done using wide-body aircrafts.

### Unit Load Device (ULD)

To make sure cargo is being loaded and carried in an efficient way, large aircrafts use specific pallets and containers known as Unit Load Devices (ULD). "A Unit Load Device is either an aircraft pallet and pallet net combination, or an aircraft container (Unit Load Devices (ULD), 2017)." The ULDs are mostly handled by freight handlers and are therefore not filled by forwarders. (Unit Load Devices (ULD), 2017).

Since most of the airplanes used by Company X are Boeings, an article will be used of Boeing as a reference for ULDs. Boeing has a total of thirty different ULDs used in their aircrafts, each with their own specifications and 'common designation'. In total, there are about 900,000 aircraft ULDs in circulation with a total value of over USD \$1 Billion (Unit Load Devices (ULD), 2017). Since they require correct handling, the International Air Transport Association (IATA) started an ULD safety campaign with five key points regarding the use and handling of ULDs.

There are four types of ULDs that fit in a wide-body aircraft. There are rectangular ULDs and ULDs with (a) sloped side(s). A ULD consists of aluminum, aluminum with canvas, or an aluminum basis that is then wrapped and netted. The ULDs shown in figure 1-6 fit in the lower hold of a wide-body aircraft.

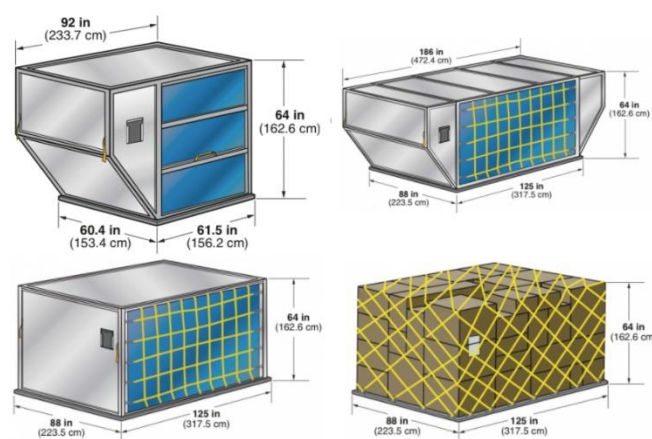


Figure 1-6: ULD types

The thirty different kinds of ULDs with their corresponding specifications and restrictions are shown in appendix 3. Since only wide-body aircrafts are the focus of this research thesis, a total of 18 ULDs will be implemented in the designed tool. Below in figure 1-7, the common path of an ULD is shown. Boxes are delivered at an airfreight handler warehouse where ULDs are ‘build’. Several legal/documental steps are performed so that the products are approved for transport. The handler moves the ULDs to the designated flight and the products are then transported. On arrival the ULDs are ‘broken down’, picked up by a freight forwarder and moved to the final destination.

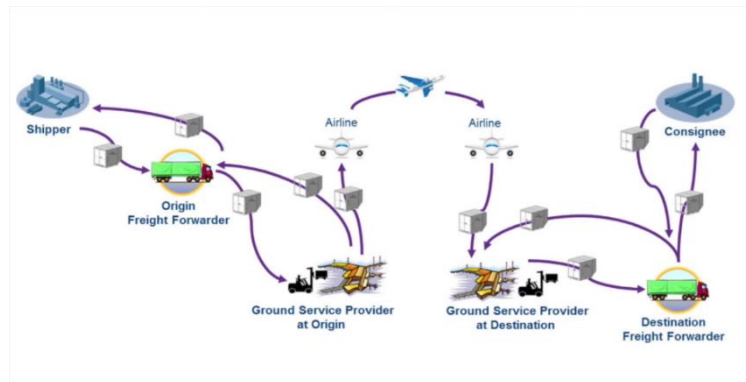


Figure 1-7: ULD Path

### ISO-Modular Carton (IMC) Program

In order to make sure that the inbound products of Company X get transported correctly by their suppliers, Company X offers standard packaging options from where suppliers choose a certain packaging option called the ISO-Modular Carton (IMC) program. This IMC program is an industry standard for ocean freight. The IMC program was created by FORD in order to arrange a standardized packaging system for their suppliers (Iso Modular Carton, 2017). This program is optimized for transportation and Company X made their own IMC program for their products.

Depending on the size of the part needed to be transported, an IMC-option gets picked. These options vary, depending on continent of import and overseas. The two groups consist of the ‘North & South America IMC Carton Sizes and Performance Specifications’ and the ‘European & Asia Specific Carton Sizes and Performance Specifications’. Since every part has a unique dimension, the IMC program offers standardized options such that not every product needs a unique package.

Company X has tens of IMC options for North- and South-America, and several tens of options for Europe and Asia. Each IMC option has its own restrictions and dimensions. These are shown in appendix 2.

### Container Shipment vs. Airfreight

In this chapter, container shipment is compared to airfreight. In figure 1-8, five aspects of transport are mentioned. The left side means it is better for container shipment, the right side means it performs better in airfreight (International Air Freight Explained: Calculating Costs and Price Trends, 2017). Subsequently, each aspect and their position will be explained.

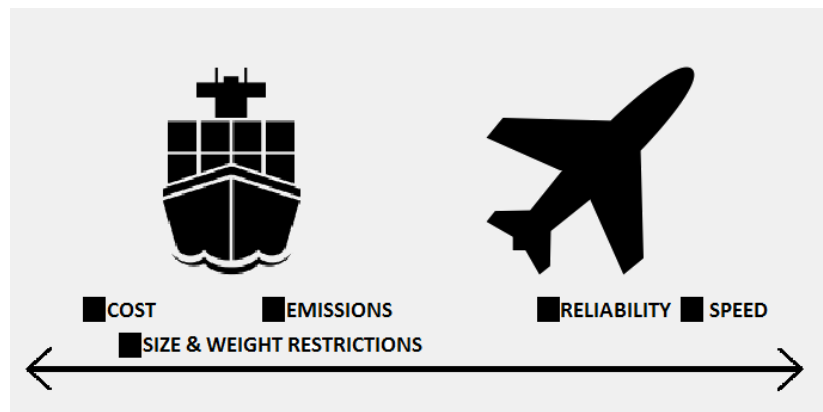


Figure 1-8: Container Shipment vs. Airfreight

### Speed

In general, airfreight is approximately 25 times faster than container shipment. The average speed of a wide-body aircraft ranges up to about 900 km/h while a container ship travels at about 35 km/h. High-priority items that need to arrive at a certain location with a strict deadline thus often are being transported using airfreight. Standardized items, ordered weeks before demand, are often being transported using shipment since time is of no relevance.

### Reliability

As a whole, air freight is a more reliable transportation method compared to shipment. There are several reasons for that statement. First of all, shipments tend to be more sensitive to delays due to poor weather conditions or other influential factors. Furthermore, shipments via ocean lines mostly run on weakly schedule compared to daily schedules regarding air freight. Most delays can thus be avoided with airfreight since several flights per day travel in between major cities which is far more often compared to ocean lines.

### Cost

Cost is an important aspect for every company. For that reason, airfreight is often avoided since it is far more expensive compared to shipments. Airlines charge their cargo customers according to chargeable weight.

Chargeable weight is mostly described as:

*“The Chargeable Weight is the Actual Gross Weight or the Volumetric Weight of the shipment – whichever is the greater. Typically, large items with a light overall weight take up more space on an aircraft than a small, heavy item. That’s why the Airlines charge according to Chargeable Weight (Chargeable Weights, 2017).”*

The price difference between airfreight and container shipment is substantial. Due to cost of transportation, companies tend to move their products for the lowest price while maintaining reliability (International Air Freight Explained: Calculating Costs and Price Trends, 2017). Airfreight is often used for last-minute high priority products or other high value items.

Since cost is such an important factor, it will be broken down for the airfreight sector. In general, airlines have three cost components (Modes of transportation and their performance characteristics, 2013).

- The first one is fixed cost of infrastructure and equipment.
- The second component is cost of labor and fuel, independent of passengers or cargo, but fixed for every flight.
- Third and final, a variable cost that depends on the passengers or cargo carried. Due to the fact that most of the costs are already incurred when the aircraft departs, it is of great importance for the airline to maximize the revenue generated per flight and thus arrange efficient cargo layout. Due to these three cost components and the fact that most of the costs are predetermined before takeoff, airfreight is far more expensive compared to container shipments.

### **CO<sub>2</sub> Emissions**

The reduction of CO<sub>2</sub> emissions has become extremely important since the issues of global warming started to become more apparent and the consequences of using fossil fuels started to arise. Comparing airfreight to container shipment, the conclusion is that boats are far more carbon-efficient than airfreight. As stated in an article about the comparison of emissions:

*“A big ship will emit about 0.4 ounces of carbon dioxide to transport 2 tons of cargo 1 mile. That’s nearly a fiftieth of what an airplane would emit to accomplish the same task (Berg, 2016).”*

This big difference can be a decisive factor for companies reducing their carbon footprint. The downside of the speed of container shipments imply last-minute high-priority items can’t be transported using airfreight.

### **Size Restrictions and Weight Restrictions**

As explained above, airlines nowadays use ULDs in order to safely and efficiently transport goods via airfreight. These ULDs are designed to fit in certain aircrafts, either freighter aircrafts, wide-body aircrafts or narrow-body aircrafts. The ULDs all have their own weight and size restrictions depending on the kind of airplane used, or the size of the container. The International Air Transport Association designed strict regulations to ensure flight safety is the number one priority. Since the variety in transportation options is so large, the different options and their corresponding restrictions will be shown in appendix 3. The regulations and restrictions of airfreight is stricter than container shipment since far more can go wrong. The limitations of container shipment are bounded by the maximum sizes of containers and weight plays a minor role since containerships can bear a lot of weight.

## 1.2 RESEARCH PROBLEM

This section describes the main problem of this thesis. In section 1.2.1 the context of this thesis is explained, followed by a description of current logistics in 1.2.2. In section 1.2.3 the desired logistical situation is described. Subsequently, in section 1.2.4, the discrepancy between those two situations is mentioned. Then in section 1.2.5 the problem owners are outlined followed by the actual problem definition in section 1.2.6.

### 1.2.1 CONTEXT

The context for this research consists of two parts.

- First of all, the logistics team EMEA of Company X wants more insight in packaging of inbound suppliers. This is needed for the major goal of automating the lines and factories of Company X's models. Since many suppliers are non-compliant regarding packaging and labeling, complaints arise at the factories. This is something that needs to be researched and changed. The EMEA team started with a chargeback protocol since the start of the research in combination with the Supplier Operations Support (SOS) team. Since this is a new protocol, the boundaries must be set and this is done during this research thesis.
- Secondly, the company lacks process optimization. As Company X focusses on rapid growth, the company doesn't optimize the current processes. The optimization of airfreight cargo layout has not been focused on before and thus this will be a major component of this research thesis.

The problem cluster in figure 1-9 shows the relationship between the problems that lead to the current situation.

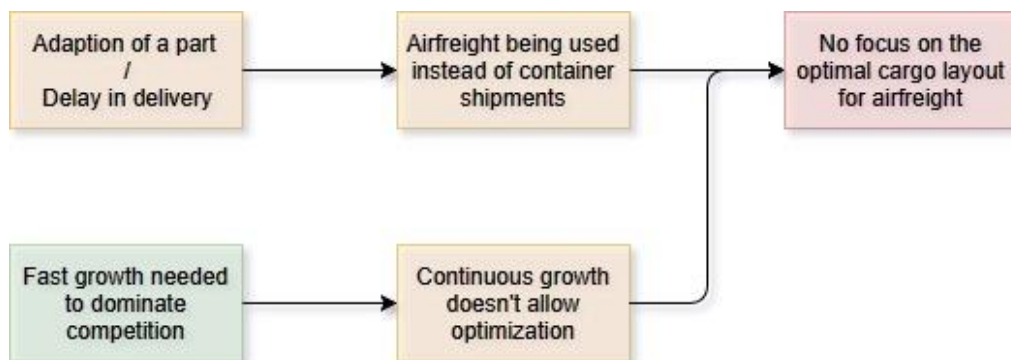


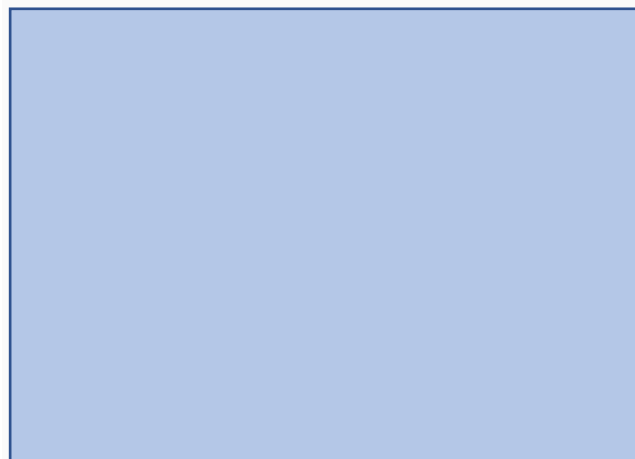
Figure 1-9: Problem Cluster

- ❖ 'Change in part': This is caused by the continuous improvement of Company X's vehicles. Unlike many other car manufacturers, Company X continuously improves the parts used in their cars. This continuous process means that Company X does not wait with changing a part until a new model is introduced, but a part can be changed from one day to the next. This means that the suppliers of these parts suddenly have to deliver a different part compared to what has been transported previously and thus, the current stock of these parts are not used anymore and thus these new parts need to be delivered as soon as possible.

- ❖ 'Delay in delivery': A delay in delivery is something that can always happen due to several circumstances. A supplier can have production issues, accidents or strikes can cause parts to not be transported in time, etc. A delay in delivery can cause a problem with container shipment since this takes a total of two to five weeks for a shipment to arrive depending on port routes.

The two issues above combined lead to a delay in the part delivery and thus to airfreight instead of container shipment. Airfreight is much faster which is needed to guarantee timely arrival. The downside is that airfreight is much more expensive.

- ❖ Company X's rapid growth: Company X is dominating the current market and known as the pioneer of driving. In order to stay ahead of competition, Company X is continuously growing as fast as they can, improving their products and designing new products. If Company X would stop doing this and focus on making optimization of their transportation and production, competitors would have more time to take part in the market as well which leads to more competitors in the market. Another aspect is the value of Company X compared to other automotive companies. Earlier this year, Company X became more valuable than Company Y.



*Figure 1-10: The Market Numbers*

Figure 1-10 shows the comparison between the car companies.

### 1.2.2 CURRENT SITUATION OF LOGISTICS INBOUND EMEA

In order to meet expected demand, Company X is making its logistical process more efficient. Complaints arrive via the different factories or logistical carriers of wrong packaging and/or labeling. These errors cause different problems, for instance a production line has to be stopped. Since it is not exactly clear what goes wrong and who causes these problems, the logistical department aims to map the current situation and start solving the problems.

### Packaging:

We obtained this knowledge by visiting carrier warehouses and check inbound packaging of all inbound suppliers. As expected, a lot of things go wrong. Company X uses a standardized IMC packaging program to ensure all suppliers use the same boxes and to facilitate automation. Not all suppliers use these IMCs but use their own boxes.

### Labelling:

To ensure automation, labeling needs to be correct. Each box should contain a content label on the long side of the box in the right below corner with a QR-code of 4.2" inches. This is demanded by Company X to make sure machines can scan each box itself to speed up the production process. Most of its suppliers are not compliant regarding this subject. Besides a content label, a receiving label is required on the middle of each side of a pallet with a QR-code of 4.2" inches as well. Each of these labels also mention all other information regarding the package. The majority of suppliers currently fail to comply with the demands of Company X. In order to keep the factories running and avoid downtime, packages are never stopped at warehouses if suppliers are non-compliant. This results in non-compliant parts with non-compliant packaging or labeling entering the production line, which causes problems regarding automation since the scanning and/or unpacking machines fail to function correctly. In those cases, the boxes have to be handled manually to prevent downtime but this slows down the process. One could think it would then be better to stop any non-compliant products at the warehouses to prevent manual labor and thus delay in production but this is never done since it is more important for Company X to have the parts at the desired location than having compliant packaging and labeling.

### Pallet layout:

Most suppliers fail to optimize pallet lay out. The layout of a pallet can vary depending of the type of box transported and depending on if it is a homogenous pallet or a mixed pallet. A homogenous pallet is a pallet with just one sort of (IMC) box on it. The labels corresponding with such a pallet are called 6J labels. A 5J pallet is a pallet that has mixed boxes, so at least two different sorts of boxes.

As we saw during an inspection of one of Company X's carriers' warehouses, many of the pallets are 6J pallets but not filled entirely. This causes two problems:

- Stackability: Company X's IMC program demands all IMC Unit Loads must be designed for double stacking of the same weight for overseas shipments and triple stacking for warehouse purpose. This cannot be done if pallets are not filled completely since the top layer will not be flat at thus stacking will be impossible. This causes problems regarding efficient container shipping.
- Last moment change of plan: Not all shipments go according to plan which can lead to a shortage of parts at the factories. To avoid downtime in these factories, high-priority items are then transported using airfreight instead of container shipment. Airfreight is much faster but more expensive. The cargo space of most aircrafts is much smaller than standard ocean containers. Therefore, standard pallets do not always fit.



### 1.2.3 DESIRED SITUATION

With the launch of the new model, Company X plans to make hundreds of thousands of cars in 2018. To achieve this, a multibillion dollar factory is built in the Location A, where specific parts will be made. The processes will be as automated as possible in order to reach the production target goal. It is thus of great importance to continuously track all inbound parts and make sure they arrive in time. The unboxing and unloading of the inbound parts will become fully automated. The top of a box will be sawed off automatically and a machine will unload and unbox all parts. In order to make this work, all boxes and labels need to meet Company X demand which is only possible if suppliers follow these demands.

**Therefore, supplier compliance is crucial in order to reach the target production.**

Ideally suppliers are fully compliant and this is monitored by Company X's carriers in their warehouse. Company X monitors the non-compliance itself by visiting warehouses. This responsibility should shift to the carriers in the future. If packaging is non-compliant, this is monitored and the information is sent to Company X, so a chargeback procedure can be started. By penalizing suppliers for incorrect packaging and labeling, supplier compliance will improve.

Next requirement is optimization of airfreight. A cargo layout model is created to design the efficient packaging layout for IMCs in a ULD. Efficient cargo layout will decrease the average transport cost per part. The efficient cargo layout model will be offered to Company X's forwarders to increase efficiency and decrease cost.

### 1.2.4 DISCREPANCY BETWEEN CURRENT AND DESIRED SITUATION

- The first discrepancy is the availability of information. Supplier compliance is being checked as soon as the parts arrive at the factories. Since this is already too late, this slows down the entire process and thus results in additional costs for Company X. The non-compliance of suppliers needs to be checked in the warehouses before the parts are being transported to the designated factories. A checklist needs to be designed by Company X in order to let carriers check the packaging and labeling before transport in the warehouses. This proactive information is needed to prevent non-compliance in the future.
- Airfreight is a last-minute, high-priority subject without focus on efficient cargo layout for the IMC packaging program. Company X has always focused on production and now, with high production level demand for the new model, the transportation of airfreight needs to be optimized as well. Instead of the desired situation where cargo layout is efficient, currently all IMC options are being loaded on their pallets instead of checked if more boxes fit on this pallet, or the layout of the pallet needs to be changed since this is not taken into account. This is solved using the Cargo Layout Model.

#### 1.2.5 PROBLEM OWNERS

There are two problem owners.

- The first problem owners are the suppliers of Company X. As explained in the previous sections, supplier compliance is needed to ensure automation and thus one of the major causes of logistical issues and holdups. Since it is hard to ensure supplier compliance, the design of a chargeback procedure needs to solve this matter. Non-compliance of suppliers is now tracked at the factories when it's already too late. The chargeback procedure is a retrospective procedure that can only be a temporary solution to lead towards the final goal of fixing the problem at the source instead of the final destination, the factory.
- The second problem owner is Company X itself. Designing a more efficient cargo layout is something that has not been looked at and the reason for this research thesis. For that reason, suppliers or carriers cannot be held accountable since Company X has not demanded it yet so there is no non-compliance. With the introduction of the new model, Company X targets to produce a total of hundreds of thousands of cars a year by the end of 2018. In order to reach this target, Company X aims to fully automate delivery of parts in order to continuously maintain stock. If parts still need to be transported via airfreight, an efficient cargo layout is crucial to lower costs and transport maximum number of parts.

#### 1.2.6 RESEARCH GOAL

The goal of this research is to provide Company X with a tool to improve the cargo layout for airfreight.

A Virtual Basic for Application (VBA) tool is designed that provides its user with a layer by layer layout for different packages (IMC units) in different containers (ULDs). The tool will optimize the filling of ULDs and could provide insights on the possible need to design a new box for products. By checking left over space, the conclusion can be drawn that it might be beneficial to design a new box that will allow an extra layer in the X, Y or Z axis to be added.

#### 1.2.7 RESEARCH QUESTION AND DESIGN

In order to achieve the goal of this research, the following main research question is formulated:

***To what extent can the stacking efficiency be improved - compared to the manual handling in the current situation - by pre-determining the cargo layout for Company X's airfreight?***

In order to answer this main research question, several other questions have to be answered first that will provide the answers needed for the main research question. For each sub-question, a description is given of why the sub-question is needed, where the methodology will be described and where the answer will be given.

In the first sub-question, a description will be given of the current situation regarding the cargo layout for airfreight. This description will provide a better insight in the overall handling of airfreight cargo and determining a cargo layout. This information is needed to design the cargo layout tool. The current system is needed to understand how the basics of airfreight packaging works and to find parts that can be improved. Furthermore, this information is needed as a comparison for the designed tool and to check if the designed layout is realistic. The methodology regarding this sub-question is given in chapter 4 and sub-question 1 is answered in chapter 2.

***Sub-question 1: How is the cargo layout determined in the current situation?***

The second sub-question is needed to make a comparison between the designed tool and the current situation. This question is focused on quantifying the current situation by looking at the different components that determine cost and the logistical numbers regarding the airfreight usage of Company X. The used methodology will be explained in chapter 4. The sub-question itself will be answered in chapter 2.

***Sub-question 2: To what extent is it possible to quantify the current airfreight use regarding Company X's EMEA inbound logistics?***

***Sub-question 2.1: How efficient is the current ULD filling method?***

***Sub-question 2.2: How much does airfreight cost Company X Annually?***

***Sub-question 2.3: How many boxes (IMC units) are transported via airfreight annually?***

***Sub-question 2.4: How many cubic meters are used for Company X's airfreight annually?***

The third sub-question describes the general methods of airfreight pricing. The answer of this sub-question is needed to gain a better understanding in airfreight but especially how the prices are determined. This sub-question is also answered in chapter 2, while the methodology is explained in chapter 4.

***Sub-question 3: How is the pricing for airfreight determined?***

The fourth sub-question focusses on checking if it is mandatory to deliver the IMC units on a pallet or not. This is a very interesting subject since it can restrict the different cargo layout options. The usage of a pallet affects the height restrictions as well. This information is thus needed for the designed model. The methodology is explained in chapter 4. Next, the answer to the question is given in chapter 2.

***Sub-question 4: To what extent is it possible to transport IMC units via airfreight without the use of a pallet?***

In addition to the mapping of the current situation, an extra subject arises. The stacking of different IMC units may have consequences for the condition of those units. It is thus needed to find out if and how the condition of IMC units is affected by stacking them. The applied methodology is explained in chapter 4 while the answer to this sub-question is given in chapter 2.

***Sub-question 5:** To what extent does the stacking of IMC units affect the condition of these units in airfreight?*

## 1.3 RESEARCH DESIGN

### 1.3.1 SCOPE

Since the research time is limited to ten weeks, the scope of the research is important to provide a manageable and achievable goal. After a few interviews with the company supervisor, the following scope was designed:

- Map the current logistical situation regarding Company X EMEA inbound suppliers. This part consists of conducting interviews with Tilburg's Logistical department, having a weekly packaging meeting with the US, visiting carrier warehouses to check suppliers' compliance and conducting research to draw conclusions and start chargebacks to help Company X solve this matter.
- Conducting research to inspect the current logistical airfreight situation. As mentioned before, this consists of several part. The first part is to research the logistical cargo options Company X uses and their sizes and restrictions. Using this information, a tool is designed to design an efficient Cargo layout using the current IMC program of Company X and how these would efficiently fit in the ULD options of (mainly) wide-body aircraft. This will then result in an efficient layout. The tool will only focus on one specific part per pallet/ULD since this is mostly the case.
- The designed excel tool only focusses on wide-body aircraft ULD options since freighter-aircrafts and narrow-body aircrafts are rarely used. Checking freighter-aircrafts and narrow-body aircrafts would exceed the scope of this research thesis.

### 1.3.2 DELIVERABLES

During this thesis, a model is created to calculate the efficient cargo layout for airfreight. The following deliverables are presented to Company X:

- A working model that designs an efficient cargo layout by selecting a specific ULD and IMC. The exact input variables are shown in section 5.3.1. The model can be skilled up to be able to calculate the cargo layout when combining several IMC types. This is explained in section 6.2.
- A manual is made to instruct its user. The model is easy to use but instructions are needed to fully understand the designed cargo layout model. This will be provided to Company X. The manual is seen in appendix 7.

### 1.3.3 LIMITATIONS

The major limitation of the research is time. The research will be conducted in a total of 13 weeks of which 3 weeks consist of writing a proposal. This results in 10 weeks of thesis research. Since this time frame is very short, it will not be possible to perform an in depth research for all components. Therefore, during the thesis research, new subjects can be found that Company X want to have researched. This is not always possible since there is no time to address all issues. This can thus result in unaddressed issues and possibly a lack of information for the recommendations.

Another limitation is the fact that this thesis will only provide Company X with recommendations in the form of a tool. The company has to implement and use the findings itself. The findings of this research thesis will be focused on the carriers assigned by Company X. This thesis will present its findings to Company X, and Company X will oblige these carriers to implement the findings to make transportation more efficient. The problem that arises is Company X's carriers may not fully implement the new tool as meant or may come with issues that they think are not fixable.

Due to the complexity in cargo layout, the designed tool focusses on a specific IMC packaging option at first and shows the possibilities for filling the remaining gaps. Inbound suppliers mostly fill a pallet with one part number instead of mixing up the pallet which could improve efficient layout. The designed tool does the same by mainly focusing on a specific part number and later on look at leftover space.

Furthermore, an option could be to check if the IMC program designed for Company X is actually suitable for the specific EMEA suppliers. Given the time constraint, this will not be a part of this thesis.

### 1.3.4 THESIS STRUCTURE

The thesis structure for the following chapters is as follows.

- Chapter 2 describes the current airfreight practice at Company X.
- In chapter 3, the theoretical framework is explained. This framework is used to substantiate this research thesis and the recommendations.
- Next, in chapter 4, the methodology of this thesis is described.
- Chapter 5 focusses on the explanation of the designed cargo layout conversion model.
- Finally in chapter 6, the conclusions and recommendations are described and explained.



## 2. CURRENT AIRFREIGHT PRACTICE AT COMPANY X

This chapter answers the five sub questions described in Chapter 1 and therefore the current airfreight practice at Company X.

### 2.1 THE CURRENT PROCESS

An order is placed at one of Company X's suppliers. Depending on the location of the company and the stock of the needed parts, a logistical plan is made. If container shipment will result in the parts not arriving in time, airfreight is chosen as the transportation method. Company X communicates this with their logistical carrier and arrange a pick-up for the parts. The movement of cargo within Europe is generally done via truck, since the distance to the closest airport is quite small. Therefore, a pick up via truck is the fastest affordable option. After the cargo is picked up by Company X's carrier, it is then moved to either a port for ocean transport or to an airport for transport via air. As mentioned above, this decision is based on the urgency of the part. The general path from supplier to destination is shown in appendix figure 5

This research focusses on airfreight. Once the cargo arrives at the airport handlers' warehouse, the cargo is loaded into/onto a ULD or deconstructed to allow for a better fit in an ULD. The carrier generally do not fill the ULDs themselves. Airfreight handlers fill ULDs manually since not only the dimensions of an IMC unit is important, but also the weight of an IMC unit. The weight determines what is put on the bottom of an ULD and what goes on top. This is done to prevent possible damage.

Once the cargo arrives at the designated airport, the ULDs are unloaded and the parts are picked up by Company Z. The parts are then moved to their final destination. The exact handling of airfreight is shown in figure 2-1 below. The three phases describe the handling of cargo in the handlers' warehouse, on the airport and once the cargo reaches its destination warehouse (Air Cargo - How It Works, 2011).

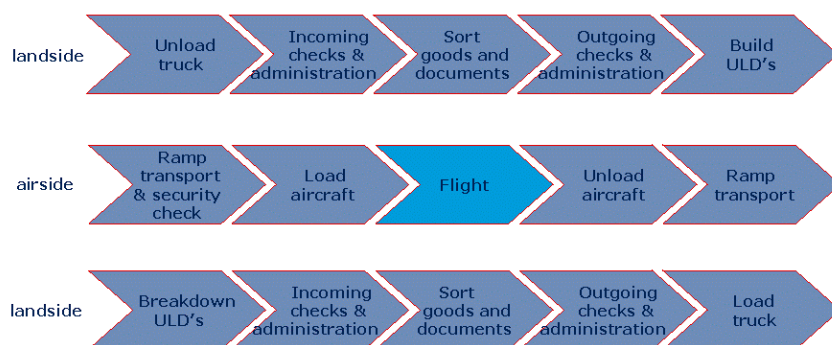


Figure 2-1: ULD Design Scheme

## 2.2 QUANTIFICATION OF THE CURRENT AIRFREIGHT USE BY COMPANY X

As mentioned in chapter 1, this sub-question is split in the following parts:

### 2.2.1 HOW EFFICIENT IS THE CURRENT ULD FILLING METHOD?

It is hard to determine how efficient the current ULD filling method is since ULDs are generally filled manually by the designated airport handler. ULDs can also be filled with loose boxes from other companies to utilize more of the ULDs' space. A ULD can be declared full for two different reasons, namely either dimensional restrictions or weight restrictions. Dimensional restriction mean that the ULD is filled due to the lack of free space. If a ULD is full regarding weight, it means no extra weight can be added to comply with aviation rules. Only a few suppliers have dense cargo that causes the weight limit to be reached first.

In the case of Company X, 95% of ULD's are declared full due to volumetric reasons.

### 2.2.2 HOW MUCH DOES AIRFREIGHT COST COMPANY X ANNUALLY?

A report of airfreight booked by Company Z for Company X is used as data to quantify the current airfreight usage. The data in the report starts on 01-01-2017 and ends on 19-12-2017. In total, Company X has issued almost a thousand airfreight orders within this time limit. The total actual revenue is several million euros with an average of several thousands per order. The designed tool creates the efficient cargo layout for a selected IMC and ULD. The amount of IMC units inside the ULD is determined by one of three options; the quantity entered as input, when a ULD is filled regarding dimensions or when the weight limit is reached. The designed cargo layout is compared with the actual used cargo layout.

Taking the abovementioned information into account, this means that the model can be used in 95% of the cases.

### 2.2.3 HOW MANY BOXES (IMC UNITS) ARE TRANSPORTED VIA AIRFREIGHT ANNUALLY?

The report states that thousands of units were transported via airfreight. This results in an average of 4.61 units per order. A unit is either a pallet or a IMC unit and the data is mixed. In section 2.2.5 the data is filtered for comparison. Since several orders can be issued in one day, the assumption is made that, when orders are transported on the same day, they are transported via the same airplane. Based on this assumption the average number of IMC units per flight is 14.66 units per order.

### 2.2.4 HOW MANY CUBIC METERS ARE USED FOR COMPANY X'S AIRFREIGHT ANNUALLY?

In total, several thousand cubic meters of airfreight where issued between 01-01-2017 and 19-12-2017 by Company X. This results in an average of 8,70 cubic meters per order. As explained above, several orders can be issued in one flight. An average of 27,6 cubic meters is transported per flight.



### 2.2.5 ESTIMATED EFFICIENCY OF CURRENT AIRFREIGHT USE

Based on the current shipping data available the exact efficiency of the current airfreight use is not known. The freight handlers are focusing on weight while loading the ULDs and our data show that Company X's airfreight efficiency is mainly determined by volume. As the loading of the ULDs is mainly done by hand without one single methodology for filling, the filling efficiency is largely individual people dependent. Also the current data mix up loose IMCs with pre-stacked pallets.

In short, the only way to validate the model and to prove that using the model will improve loading efficiency and therefore decrease cost per unit is to set up a trial program, comparing the current method with using the Cargo Layout Model.

Based on a review of the current methods by discussions with Company X- and freight handlers' employees, it is estimated that using the model could create an increase in loading efficiency of 5%-10%. Whether this efficiency increase will be translated directly into a cost decrease will depend on the appointments with the freight handlers.

A potential saving of 5% on 95% of the IMCs shipped would result in an annual saving of well over a hundred thousand. This potential justifies the initiation of a trial program to verify the effectiveness of the Cargo Layout Model.

## 2.3 THE PRICING OF AIRFREIGHTED GOODS

There are four aspects that determine the price of airfreight (Pricing - air freight charges, 2017). These are:

1. Gross weight
2. Dimensions and volume
3. Quality of the goods
4. Station of origin and the final destination

Volumetric weight is generally determined using a global rule of thumb for airfreight. First one finds the item's volume in cubic meters. This is done by multiplying the length, width and height of the cargo. Next, this number is multiplied by 167 (also known as the 1:6 volume ratio). A 'weight' is then determined for the size of the cargo. If the volumetric weight is heavier compared to the gross weight, this becomes the chargeable weight. If the gross weight exceeds the volumetric weight, this become the chargeable weight. The chargeable weight is generally used by logistical carriers to determine the price of transport.

Combined with the location of origin and the needed destination, and the quality of the goods, a price is determined. The location of origin and the final destination are needed to calculate the total distance the order needs to travel. This logically affects the price.

The quality of the goods is a vague term. This term focusses on the quality of what is in the packaging. It could be time- or temperature-sensitive, but also very easily damaged and thus needs to stand on its own or possible dangerous goods. This all effects the price of airfreight since there are strict rules of what can and what cannot be transported via air.

The Federal Aviation Administration forbids the transport of lithium ion and lithium metal batteries via airfreight. This is done due to hazard of abrupt ignition. This rule effects Company X as well, since Company X is not allowed to transport some of their parts via airfreight.

## 2.4 PALLET USAGE

The build-up of a ULD has several restrictions. In order to use all space, it is needed to know whether it is mandatory to transport goods on a pallet, or if the pallets are broken down and the ULD is build using individual IMC units. The following information was acquired by logistical carrier Company Z.

One can load lose carton on a ULD, but that might create problems for trucking regarding labeling. Each IMC unit on a pallet has a content label on it that can be scanned. This label belongs to a single IMC unit. In addition, each pallet has a total of four receiving labels. These labels are scanned to require the information about the entire pallet. If a pallet is deconstructed, this might create issues for further transport. If it is decided that the IMC units will be transported loose, each IMC unit can get its own receiving label as well. Is thus happens and is possible to load loose IMC units.

When transporting lose IMC units, damage during transport to and from the airport is more likely to occur. The individual boxes are more exposed since an additional action is needed. The contact at logistical carrier Company Z still ensured that the transport individual IMC units is of no problem.

## 2.5 THE CONDITION OF THE CARGO

Damage to boxes happens, but is rarely caused during air transport. During interviews with team lead airfreight of Company Z, the estimation is made that in maybe 1% of the cases damage occurs. The damage generally is not created during air transportation, but during pick up in the airport warehouses once boxes are removed from the ULD or when during delivery handling.

## 2.6 IMPROVEMENT OPTIONS

In this section, improvement options regarding the current, manual method of cargo filling are explained. Possible options for improvent are:

- Change in box orientation per layer (Airfreight Handler)
- Quick and easy overview of number of boxes per layer (Airfreight Handler)
- Possibility to prestack pallets according to a specific pallet layout to ensure easy handling and prevent damage (Company X's Forwarders)

In the next chapters we take on the challenge of realizing these improvement options.

### 3. THEORETICAL FRAMEWORK

In this chapter, the theoretical framework of this thesis is described. The theoretical framework is needed as a substructure to answer the main research questions and the sub-questions. In order to answer the main research question and the sub-questions, a theoretical framework is used to demarcate the issue and support the solution.

#### 3.1 BIN PACKING

A bin packing problem is best described as a “finite collection of objects with varying width that is packed into one or more bins or baskets” (Watson, 2007). The goal is to pack all objects such that the least amount of empty space remains. With the increase of the amount of different objects into a bin and the type of dimensions, the difficulty of the problem increases. A bin problem is described as an NP-hard problem. In order to explain what this is, the difference between P and NP problems needs to be explained first.

- P is a collection of all decision problems that can be solved in polynomial time. Polynomial time is the time required for a computer to solve a problem, where this time is a simple polynomial function of the size of the input. This thus means that the answer yes or no can be decided in polynomial time.
- NP is a complexity of all decision problems for which it is presumed that it is not solvable in polynomial time. An example is the Traveling Salesman Problem (TSP). With a TSP, the shortest route has to be created between cities while returning in the city of origin. It is possible to find an approximate solution but finding the real solution takes significantly longer as the size of the problem increases. Finding an optimal for a NP-problem is therefore not possible.

##### 3.1.1 ONE-DIMENSIONAL, TWO-DIMENSIONAL AND THREE-DIMENSIONAL

As stated above, the difficulty of solving a bin problem increases in the number of dimensions increases as well. The number of options regarding part box placement increases exponentially if dimensions are added (Sweep).

In a one-dimensional bin packing problem, each object has either a fixed height with a variable width or a fixed width with a variable height. As mentioned above, the goal is to pack all object such that the least amount of empty space is left. There are many different packing strategies, these are mentioned in section 3.1.2.

In a two-dimensional bin packing problem, the problem gets more difficult. Both the width and the length vary in the two-dimensional problem as seen in figure 3-1. A restriction that comes with two-dimensional problems is that all objects are orthogonal. This means that an object can be rotated.

In a three-dimensional bin packing problem, each object consists exists of all three dimensions as seen in figure 3-2. The goal remains the same. In Company X's case, each box has a certain bottom position and thus there are only two orientations. Since all dimensions are part of the bin problem, deciding the order in which objects are efficiently placed differs depending on a certain packing strategy. The main strategies is mentioned in the next section.

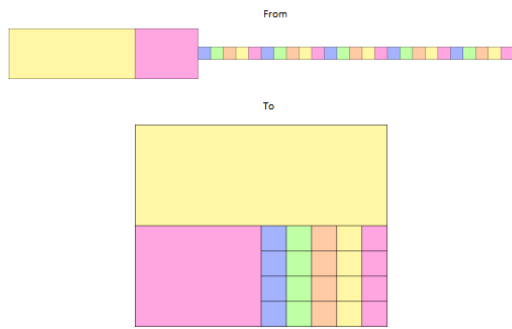


Figure 3-1: 2-dimensional Bin Packing

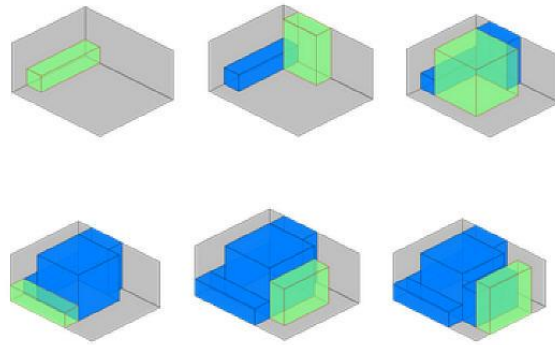


Figure 3-2: 3- dimensional Bin Packing Step By Step

### 3.1.2 BIN-PACKING HEURISTICS

As mentioned in the previous section, many different packing strategies exist. Some strategies are shortly explained below (Bin Packing, n.d.).

#### First fit

The first fit strategy is a very simple strategy that most certainly won't guarantee optimal layout. The first fit strategy placed the object is the closest point from the starting position that fits. If the object does not fit in the bin, it is put in a new bin or put aside depending on the amount of bins.

#### First fit decreasing

This strategy is the same as the first fit strategy, except for the fact that the object are first sorted on decreasing size. This means starting with the largest object continuously moving to smaller objects. If an object does not fit, it is also put aside or placed in the next bin.

#### Best fit

With the best fit strategy, an object is placed in the fullest bin that still has space left for the object. This way, most of the empty spaced is filled.

#### Worst fit

The worst fit strategy focusses on the opposite bin compared to the best fit, namely the emptiest bin. This is mostly no efficient packing strategy.

#### Almost worst fit

This strategy is proven to be the better than the above-mentioned strategy. The almost worst fit places the object in the second-emptiest bin.

### Largest Area Fit First (LAFF) minimizing height

This strategy focusses on the largest area per object and simultaneously minimizes height. This means that objects are placed on the x/y axis, and only if there is no more space the box is placed in the z axis. The different ULDs available all have very strict restrictions, but especially height has an important role. For this reason, the LAFF minimizing height strategy could be used in the thesis.

### Knapsack loading

With Knapsack loading, each object has a certain value depending on dimensions, weight, etc. The knapsack has a limited amount of space and thus, a decision needs to be made what object is taken/placed. With knapsack loading, the aim is to minimize leftover space. This is thus an interesting strategy to be used.

Figure 3-3 shows the starting position of a random set. Figure 3-4 shows the results after using certain bin-packing heuristics (Bin Packing, n.d.).

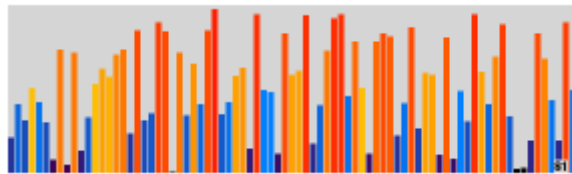


Figure 3-3: Random Set of Objects

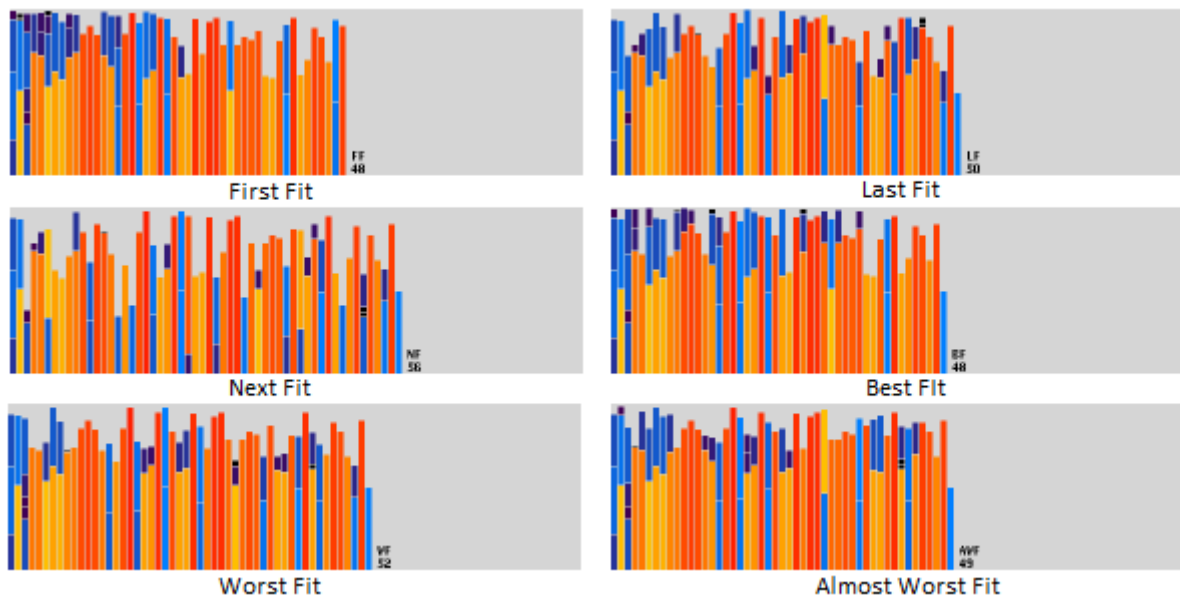


Figure 3-4: Bin Packing Heuristics

### 3.1.3 REAL-WORLD-LIKE PROBLEMS AND RESTRICTIONS

In this section, the connection with real-world-like issues and restrictions are made, since the calculated efficient layout is not always possible due to other restrictions. The major restrictions are mentioned below (Sweep).

#### **Gravity**

The restriction gravity is an important factor that needs to be taken into account when designing an efficient cargo layout. If this is not done correctly, there is the risk of a bin falling over or object within a bin getting damaged due to wrong stacking. This is there for an important factor to take into account. Furthermore, in order to withstand gravity, it is important for object and their bins to have a surface to rest on. In Company X's case this is a pallet.

#### **Weight**

The weight of an object is very important to take into account. First of all, each box has a maximum weight. Manhandled boxes have a maximum of 15 KG and in addition, boxes that are picked up via forklift have a unique weight restriction as well. As mentioned in section 1.1.2, container shipments have easier weight restriction compared to airfreight. Since this research thesis focusses on the efficient cargo layout of airfreight, it is important to take the maximum weight restriction per ULD into account. This is something that not all packing strategies implement, but something very important for in this research. In addition, the weight of each bin needs to be taken into account since it is not possible to put a very heavy bin on top of a weaker bin. This will cause an object to get damaged.

#### **Balance**

Gravity and weight combined cause for the next concern, namely balance. As mentioned above, gravity needs to be taken into account to decide if an object will fall or not. Besides the correct balance of objects in a bin, the balance of a container or ULD is very important as well. If this is not done correctly, a plane will have a wrong balance point or a cargo ship has the possibility to become unstable.

#### **Priority items**

Priority items are items that needs to be take into account when designing a cargo layout. It could be that certain objects have a high priority and need to be handles much quicker compared to other objects. For Company Xf, when airfreight is used, all items have a high-priority status and therefore there is no distinction specific a pallet.

## 4. METHODOLOGY

In this chapter, the methodology used is described. Section 4.1 describes the research methodology and different methods used. Next, in section 4.2, the applied methodology is described.

### 4.1 RESEARCH METHODOLOGY

This research thesis uses different data gathering methods needed that verify and validate the current situation and issues, needed for problem solving. Both quantitative research methods as qualitative research methods are used.

Quantitative research methods used in this thesis are historical company data regarding packaging non-compliance. Furthermore, warehouse checks are part of this research method. The carrier warehouse checks are needed to provide Company X with enough information and evidence to penalize suppliers for non-compliance and to start working towards solving the issue.

Qualitative research methods used in the thesis are mostly interviews and attending meetings. Since the logistics team of Company X EMEA is working together with other teams to improve supplier compliance, weekly meetings are held in order to keep track of current situation and any changes.

### 4.2 APPLIED METHODOLOGY

The applied methodology is described below. In order to answer the main research question, the sub-questions have to be answered first. This section will describe the applied methodology to answer all sub-questions. The answers to the questions themselves will be given in Chapter 5.

#### 4.2.1 DETERMINING THE CURRENT AIRFREIGHT SITUATION

In this subject, the first sub-question is covered. This subject focusses on finding out how the cargo layout is currently determined by Company X, its carrier or the airport handler. In order to answer this sub-question, qualitative methods are used. This is explained below:

- I. *Qualitative research: Interviews Logistics Manager Company X & Company Z Team Lead HAL AF ops*
- ❖ Mr. X (Logistics Manager Company X)  
Meetings have been conducted with company supervisor Mr. X. These meetings were used to gain knowledge about airfreight usage in general and how Company X arranges airfreight. In addition, Mr. X helped with designing additional questions that need answers to provide insights for this research thesis.

❖ Mr. Z (*Company Z Team Lead HAL AF ops*)

Mr. Z handles all of Company X's airfreight as team lead at logistical carrier Company Z. By interviewing him, details are acquired regarding airfreight with focus on how the airfreight for Company X is handled. Mr. Z furthermore provided percentages needed to check newly designed tool.

#### 4.2.2 THE QUANTIFICATION OF THE CURRENT AIRFREIGHT USE OF COMPANY X

In this section, the applied methodology techniques are described to answer the question regarding the quantification of current airfreight handling. The applied methodology consists of both qualitative as quantitative aspects, which are described below.

I. Qualitative research: Interview with *Company Z Team Lead HAL AF ops*

In order to quantify the current situation needed to make a comparison between the current situation and the designed tool, additional sub-questions mentioned in chapter 1 are answered by Mr. Z. Most of these answers consist of quantitative numbers, but are accompanied by qualitative explanations.

II. Quantitative research: Annual airfreight cost records

Annual airfreight cost reports are used to quantify the current airfreight usage of Company X. Furthermore, reports acquired via Company Z will be used to design an 'average' airfreight transport which is used to compare the designed tool.

#### 4.2.3 DETERMINING THE PRICING OF AIRFREIGHTED GOODS

This section focusses on methodology of the third sub-question. In order to answer this question, both qualitative as quantitative research is conducted regarding airfreight pricing. The two methods and its findings are described below:

I. Qualitative research: Interviews with Logistics Manager Company X

Meetings with company supervisor Mr. X were held to gain general insight in how airfreight pricing is determined.

II. Quantitative research: Price methods and comparison of logistical carriers

Several logistical carrier websites were contacted to see how they determine the price for airfreight. This was then compared with the report acquired from Company X's logistical carrier Company Z. Combined, a list of pricing points is determined.



#### 4.2.4 THE OBLIGATORY USAGE OF A PALLET

The pallet build-up in a ULD has several restrictions. In order to efficiently use all space, it is needed to know whether it is mandatory to transport goods on a pallet, or if the pallets are broken down and the ULD is build using individual IMC units. This subject is approached using a qualitative method

##### I. Qualitative Research: Interview with *Company Z Team Lead HAL AF ops*

Once again, Mr. Z from Company Z described the process and thus the use of a pallet whether after an interview and contact via mail. No quantitative methods are used to answer this sub-question.

#### 4.2.5 THE EFFECTS OF STACKING IMC UNITS

This subject aims at describing possible damage to IMC units when transported via airfreight. To make Company X's cargo damage more clear, a qualitative research was conducted.

##### I. Qualitative research: Interview with *Company Z Team Lead HAL AF ops*

This sub-question is also answered by conducting an interview with Mr. Z. Besides general information, an estimation is also given.



## 5. EFFICIENT CARGO LAYOUT TOOL

This chapter describes the tool that is designed for the recommendations regarding the efficient cargo layout. This model will be used by Company X's carriers to design the needed stacking pattern. In section 5.1, the concept of the tool is explained and what information is used. In section 5.2, the simplified problem and phased plan is explained. Next, in section 5.3 the design of the model is described.

### 5.1 CONCEPT

The concept of this model is explained in this section. The tool will be used by Company X's carriers to predetermine the shape of the pallet to make sure the cargo layout is efficiently designed. This will help Company X to transport more boxes via airfreight at a time and thus reduce costs per goods. The tool will allow its user to enter all necessary variables needed to calculate the cargo layout per layer. Restrictions regarding weight, size or quantity will be taken into account as well.

### 5.2 SIMPLIFIED PROBLEM AND PHASED PLAN

A simplified problem is introduced as a step-by-step visualization of how a ULD is filled with IMC units. In section 5.3.4 a toy problem shows the exact steps with the corresponding calculations per step.

#### 5.2.1 TWO-DIMENSIONAL APPROACH FOR RECTANGULAR CONTAINERS

As mentioned above, a toy problem is used to start solving Company X's cargo layout problem. The first toy problem only consists in a two-dimensional view for rectangular containers. This way, a basic tool can be designed that can be adapted if other elements are added.

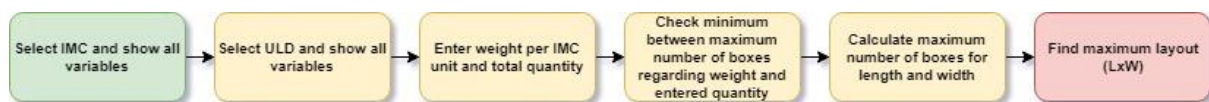


Figure 5-1: Flow Chart 2D Rectangular

To solve the toy problem, certain steps are taken. These steps are shown above in figure 5-1. First, the variables of the selected IMC unit are shown. Next, these dimensions are also shown for the selected ULD unit. Using the weight per IMC, the maximum number of IMC units are calculated based on the maximum weight the ULD can hold. This is then compared with the entered total quantity and the minimum is chosen. The maximum length and width is then calculated by dividing the length of the ULD by the Length of the IMC. This is similarly done for the width. It is checked whether the length x width exceeds the maximum number of boxes and if so, the minimum number is selected. This then results in finding the maximum layout based on the length and width.

Below, the step-by-step actions are visualized in figure 5-2.

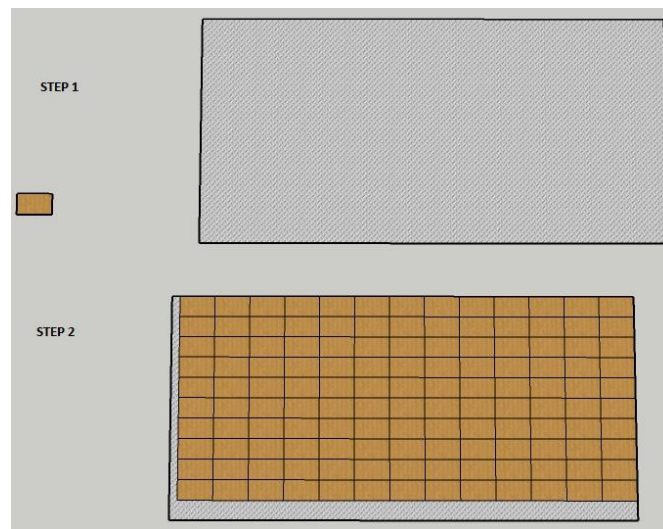


Figure 5-2: 2D Rectangular Container

### 5.2.2 THREE-DIMENSIONAL APPROACH FOR RECTANGULAR CONTAINERS

In this section, the toy problem of section 5.2.1 is extended. The height is taken into account as well which means it becomes a three-dimensional problem. Once again, this is only done for rectangular containers.

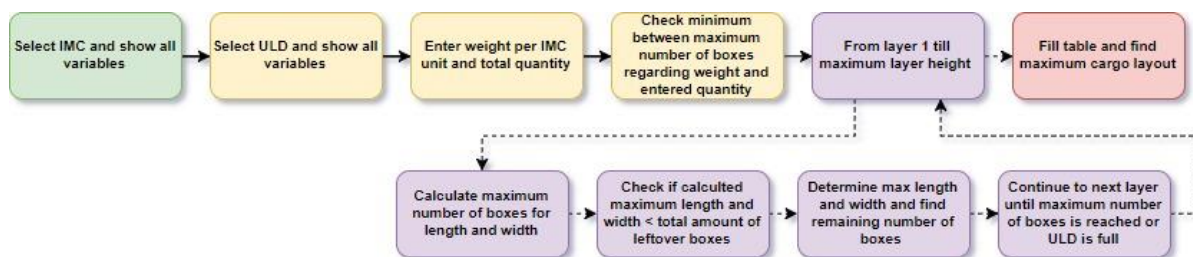
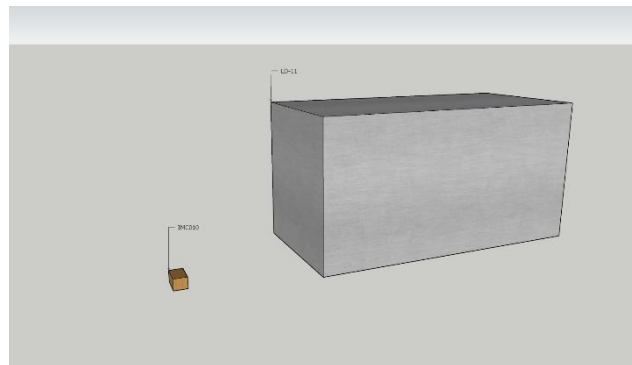


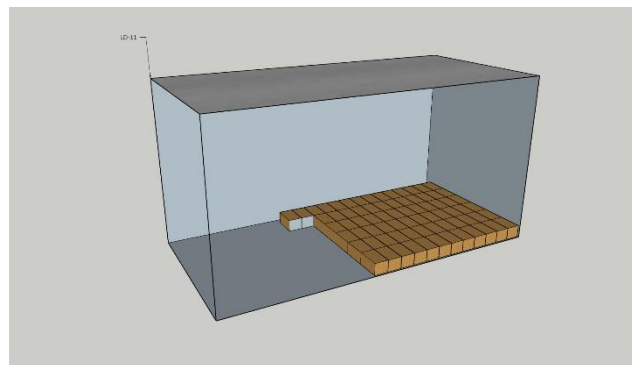
Figure 5-3: Flow Chart 3D Rectangular

In figure 5-3 the step-by-step path is shown. The first four steps are the same compared to the flow chart in section 5.2.1. In the fifth step, the tool starts at the bottom of the layer. It then calculates the maximum number of boxes that fit in the length and width using the same method as the previous section. If the total number of boxes remaining is larger than the calculated maximum length and width, this layout is taken. If it is smaller, the multiplication is found for which the designed cargo layout is equal to the total number of remaining IMC units. The calculated layout is found and the tool moves to the next layer. This is looped until the maximum number of IMC units is reached or if the ULD is full.

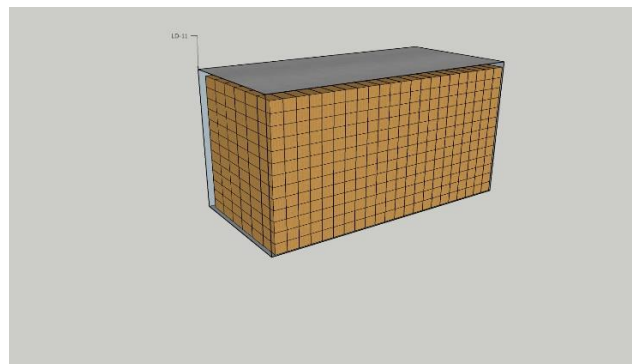
The step-by-step visualization is once again shown below in figure 5-4, 5-5 and 5-6.



*Figure 5-4: Step 1 3D Rectangular Container*



*Figure 5-5: Step 2 3D Rectangular Container*



*Figure 5-6: Step 3 3D Rectangular Container*

### 5.2.3 THREE-DIMENSIONAL APPROACH FOR CONTAINERS WITH A SLOPED SIDE

In this section, the toy problem is adjusted to be similar to the actual problem for Company X. Containers are added with sloped sides. This means that for each layer, the width has to be calculated for the top and bottom of the IMC unit. The path is shown below in figure 5-7

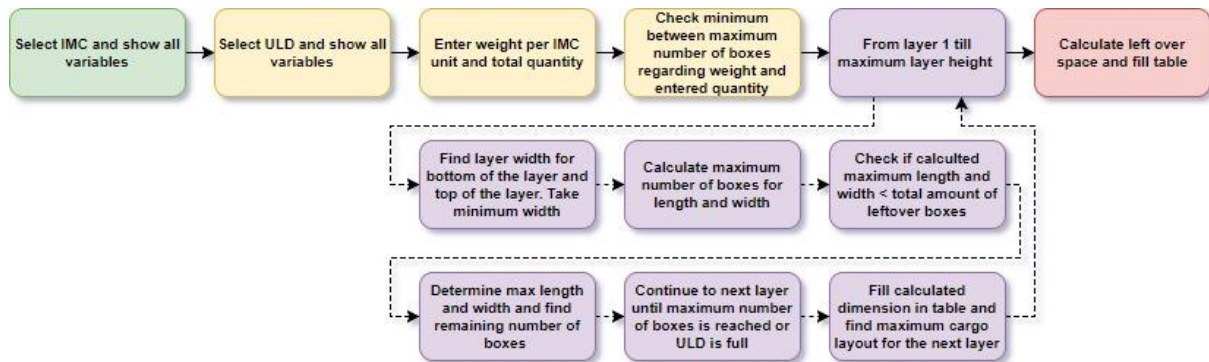


Figure 5-7: Flow Chart 3D Sloped Side

Once again, the first steps are similar to the flowcharts shown in the previous two sections. By adding ULDs with a sloped side, the toy problem becomes increasingly difficult. The amount of IMC units that fit in the length stay the same, whereas the amount of boxes that fit in the width can differ per layer. For that reason, the width of the layer is checked for both the top as the bottom of the layer current layer. The minimum width is taken and used to calculate the amount of boxes that fit in the width. The next steps are the same as mentioned in section 5.2.2 except in the end, the total left space in the length and width per layer is calculated.

The figures 5-8 till figure 5-14 show the step by step filling of a ULD for both orientations.

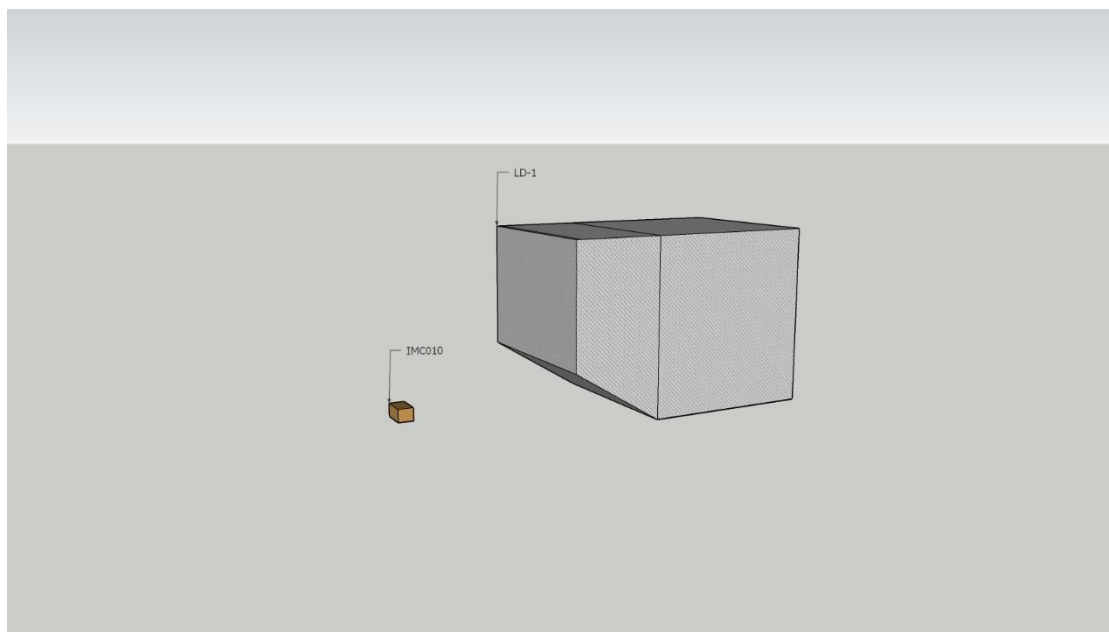
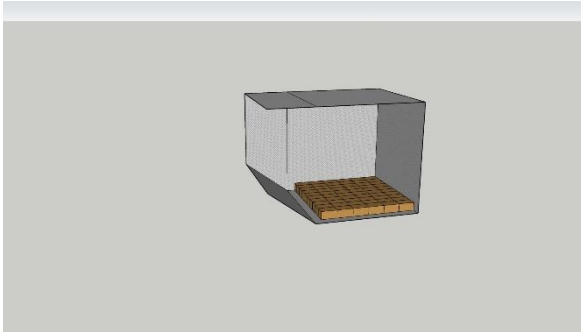
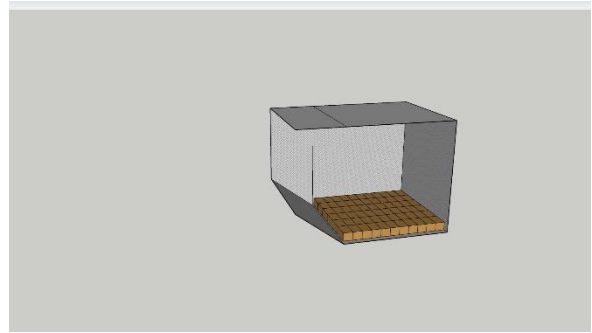


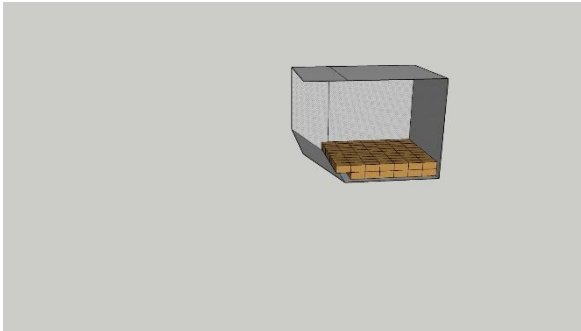
Figure 5-8: Step 1 3D Sloped Side



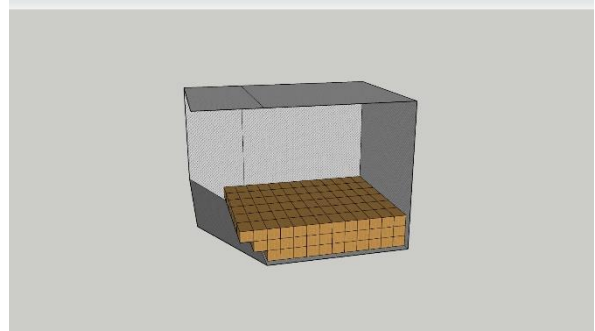
*Figure 5-9: Step 2 Sloped Side Original*



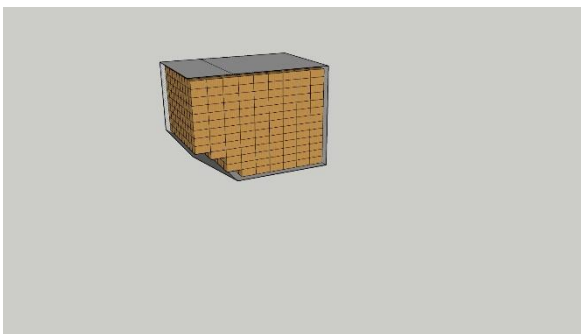
*Figure 5-10: Step 2 Sloped Side Flipped*



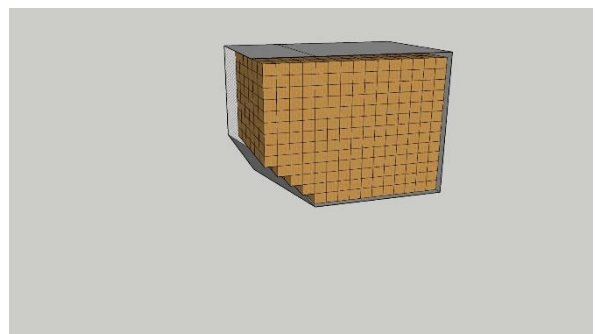
*Figure 5-11: Step 3 Sloped Side Original*



*Figure 5-12: Step 3 Sloped Side Flipped*



*Figure 5-13: Step 4 Sloped Side Original*



*Figure 5-14: Step 4 Sloped Side Flipped*

#### 5.2.4 ADDING A SECOND ORIENTATION

The fourth and final step is to adjust the toy problem to look at check both orientations. This means the ULD length and width always stay the same, but the IMC unit can be changed over the x-axis. This means the length and width of the IMC unit are swapped to calculate if more boxes fit in the 'Original' orientation or in the 'Flipped' orientation. This is explained in section 5.3.4. The orientation is checked per layer and the orientation that allows the most IMC units is chosen as seen in figure 5-15.

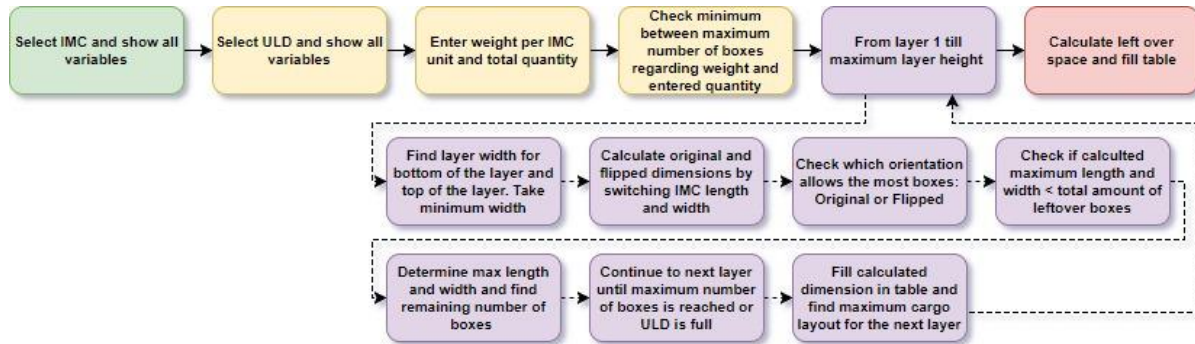


Figure 5-15: Flow Chart 3D Second Orientation

The step-by-step visualization is shown in the figure in section 5.2.3. Two orientations mean the box is flipped 90 degrees along the z-axis. This is shown in figure 5-16 below.

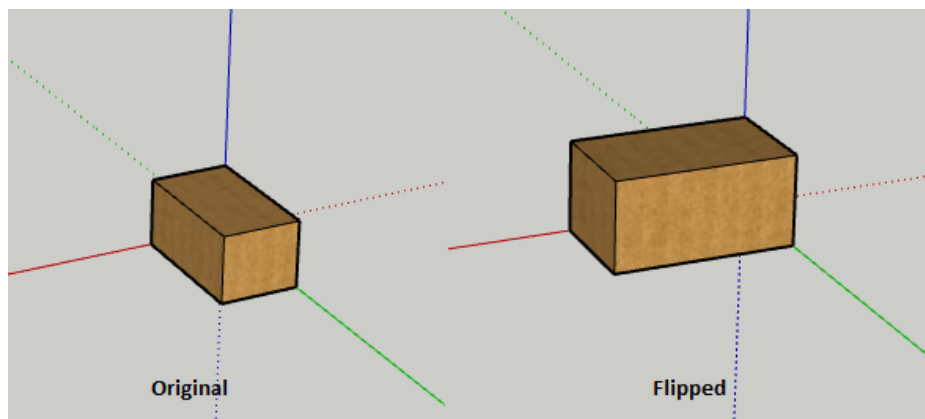


Figure 5-16: Original and Flipped Orientation



## 5.3 DESIGN

In this section, the tool design is explained. This consists of several parts. These parts discuss the features of the tool and the data they show. Next, the assumptions made in order to for the model to work will be described. Finally, the VBA code and tool design will be explained. In this part, the usage of the model will be explained as well.

### 5.3.1 INPUT

The designed tool allows its user to enter five different input variables. These variables are:

- IMC option (type of box)
- Quantity
- Weight per IMC
- ULD option
- Pallet (Y/N)

The IMC option cell gives its user the ability to pick one of the 43 IMC options Company X has for the European & Asia pacific. Each IMC option has its own restriction as shown in appendix 2. When the IMC option is selected, the user has to manually enter the total quantity of IMC options needed to be transported via airfreight. Furthermore, the weight per IMC has to be entered since this is important to make sure the weight restriction of an ULD is not exceeded.

The ULD option is a dropdown list of the ULD options used by Company X that fit in a wide-body aircraft. There are two types of ULD. The first type are rectangular ULDs. These are easier to fill since the space per layer always stays the same. The second ULD type are ULDs with a sloped side. This sloped side makes efficient cargo layout more difficult since rectangular IMC options will not fit without leaving a blank space. The tool needs to check the width of the container after each layer to see if an extra box can be added, a box has to be removed or the next layer has the same restrictions.

The pallet option is a checkbox function that is either checked or not. If the 'pallet' button is checked, a total of 12.3 cm is taken of the height of the selected ULD since this is the height dimensions of the standardized pallets Company X uses. This function immediately shows its user whether the usage of a pallet will affect the maximum amount of boxes that can be fit in a pallet.

### 5.3.2 ASSUMPTIONS

The tool is designed in such a way that certain assumptions are made that in a real-life situation would not always be valid. The assumptions made are stated below and explained why the assumption is made.

- The angle of sloped ULDs is always the same.

The main focus of this research is on wide-body aircrafts. The height restriction is always 162.6 cm for the ULDs. ULDs with a sloped side have a varying width and thus the number of boxes that fit differ per layer level. In order to calculate the width difference per height difference, an angle of 48.65 ° is taken. This angle is calculated from known ULD dimensions. Since the lower hold of a wide-body aircraft is similar, the rounding of the planes are similar as well. Since not all ULD dimensions are known, the assumption is made that all angles of the sloped sides of ULDs are 48.65 °

- The thickness of ULDs

ULDs are made from aluminum in order to be as light as possible since weight is a major restriction for airplanes. This means that the aluminum is as thin as possible. Since the thickness of the aluminum is rarely given on carrier website, the assumption is made that the outer layer dimensions are the same as the inner dimensions. These dimensions are taken from a carrier's website and validated by comparing them to several sources.

- Homogeneous ULDs

As explained above, a ULD is filled with IMCs. In a real-life situation, a supplier can choose to have a mixed pallet load. This means that the supplier has at least two sorts of IMCs on a pallet. During the demarcation of this research thesis, the conclusion was drawn that the amount of products transported result in several pallets at a time. For this reason, it is chosen to see all ULDs homogeneous ULDs, which means that the ULD is filled with only one sort of IMC.

- Stackability of an IMC option

It is taken into account that all similar IMC options are stackable. This means that it is expected that this is possible considering weight restrictions. As stated in the abovementioned assumption, only one sort of IMC is used per ULD. This means that the assumption is made that, if the size restrictions allow it, all IMCs inside the ULD are stackable.

- Leftover space per ULD

Each ULD is filled with a specific amount of IMCs. This amount is determined by the ULD or input restrictions and this is explained in section 5.3.3. Since the IMC layout will never fill the complete ULD, leftover space always occurs. Due to the scope of this research thesis, the effect of movement of boxes in the ULD is not integrated in the tool. This means that the tool will show leftover space, but the tool will assume that the IMC options won't move during flight. This can be solved by filling the leftover space with filling material or other boxes.

- Pallet dimensions only effect height.

As mentioned above, the checkbox function 'Pallet' is an input function of the tool. The height of the standardized pallets that Company X lets its suppliers use is 12.3 cm. The assumption is made that, when the 'Pallet' checkbox is checked, only the height of the pallet is taken into account as an extra height restriction. The length and the width of the pallet is not take into account. This is done since most ULDs are not able to fit two pallets side by side. Furthermore, the price of airfreight is determined by volume and weight, and thus only the height of the pallet will affect the amount of boxes that fit.

- Orientation per layer

Due to the scope of this thesis and for simplicity, the assumption is made that only one orientation is used per layer. Each layer thus either has an 'Original' or 'Flipped' orientation. There is no difference in orientation within a certain layer.

### 5.3.3 OUTPUT

The Excel/VBA tool has several different output variables in a total of seven different parts. The output of the tool is used as an instruction on how to efficiently pack the ULD, and show all restrictions. In order to fully explain what output variables the tool displays, the seven parts will be described one by one. These are explained below:

- IMC dimensions and restrictions

After selecting an IMC option as an input variable, the tool shows the dimensions of the IMC in the cells next to the IMC option. Furthermore, the max. weight restriction is shown. If the weight of the IMC entered as an input variable is larger than the max. IMC weight, a message box tells its user that the IMC option is too heavy.

- ULD dimensions and restrictions

The dimensions and restrictions of a ULD option are more extended compared to the IMC output. The ULD output variables have the length, height and max weight similar to the IMC part, but extra output variables are shown as well. Since not all ULDs are rectangular, there can be a difference regarding the base width and the top width. This means that more/less boxes fit in the base of the ULD compared to the top and thus the efficient cargo layout can change per layer. In order to calculate the cargo layout for ULDs with a sloped side, the 'height of the slope' and the 'Rate of change of width' is needed. The height of the slope tells the tool at what height the sloped side of the ULD starts.

The 'rate of change of width' is best described as the change in width per height change. For instance, the LD-29 has a 'Rate of change of width' of 1.76. This means that for each cm that the tool moves upwards in the ULD, the width changes with the changed height difference \* 1.76. This is done until the width of the sloped side is equal to the maximum/minimum width of the ULD, depending on the direction of the sloped side. This allows the tool to find the efficient cargo layout for both rectangular ULDs as ULDs with a sloped side.

- Max. Base layout per orientation

The max. base layout is an output list that consists of two groups, depending on the orientation of the boxes. The basic usage of the tool is that the tool gives the maximum length, width and height for the IMC option in the chosen ULD. The 'Max. per layer' is the multiplication of the length and width in that row. The boxes that are loaded into the chosen ULD have a fixed side that has to face upwards. This means that of the six orientations a box can be placed, only two are left. In the designed tool, these two orientations are called 'Original' and 'Flipped'.

The orientation 'Original' uses the corresponding directions as shown in the tool. This means that the number of parts that fit in the length of the ULD is determined by dividing the shown ULD length by the IMC length. This is also done to find the Max. base layout for the 'Original' width. This way, the dimensions calculated in this part follow the same orientation as the ULD.

The orientation 'Flipped' works the following way. The ULD dimensions stay the same as shown after the ULD option is chosen. To calculate the max. base layout for the 'Flipped' situation the ULD length is divided by the IMC width. This way, the maximum number of boxes that fit are determined for the 'Flipped' situation. The maximum number of boxes that fit in the width is then determined by dividing the ULD base width by the IMC length. This gives the 'Flipped' dimensions.

- Max. Boxes regarding weight

In this part, the max number of boxes regarding weight is determined. This is done by dividing the maximum weight of an ULD by the weight entered as an input variable.

- Layer layout

The design of the layer layout is the main goal of the tool. This part consists of several output variables. The tool finds how many boxes can be transported at once by finding the minimum between the input quantity, the maximum amount of boxes regarding weight and the total number of boxes that still have to be placed. It then searches for the max layout looking at the base dimensions and the orientation. When the length and the width are found, the multiplication of these numbers are shown in the column 'Formation Units'. Since not every number can be found by making a multiplication within the maximum base layout restrictions, the column 'Additional Units' is added. Together, the 'Formation Units' and 'Additional Units' add up to the column 'Total units'. This is done per layer. In section 5.3.5, the VBA code is explained to show how each number is calculated.

- Leftover space per layer

The final part of the tool is the 'Leftover space per layer' part. This part is designed as an extra request of Company X. In this part, the amount of leftover space in the length and width is shown per layer. This way, Company X can easily see whether an IMC option causes a lot of leftover space per layer in the ULD. As explained before, the IMC program is a standardized packing program and thus not every box is efficient for the parts that are in it. Via this part of the tool, Company X can choose to design a new box for certain parts if this means that an extra

layer can be added, or an extra row can be added regarding the length or the width of the cargo layout.

#### 5.3.4 TOY PROBLEM

A toy problem is introduced as a step-by-step explanation of how the cargo layout model functions. In every step, a visualization is shown.

In this toy problem, the ULD 'LD-1' is filled with the IMC type 'IMC040'. As seen below in figure 5-17, a total quantity of 5000 units is entered and a weight of 5kg per IMC. By manually entering the variables in the green cells, the yellow cells are automatically generated. In the current example, no pallet is is used.

IMC	Length	Width	Height	Max. Weight
IMC040	28	24	24	15

Quantity	5000
Weight	5

ULD	Length	Base Width	Top Width	Height	Max. Weight	Height of Slope	change of width
LD-1	153.4	156.2	233.7	162.6	1468	0	0.88

☒ Pallet

Figure 5-17: Input Variables Cargo Layout Model

The LD-1 and the IMC060 and their dimensions are shown in the figures 5-18 and 5-19 below.

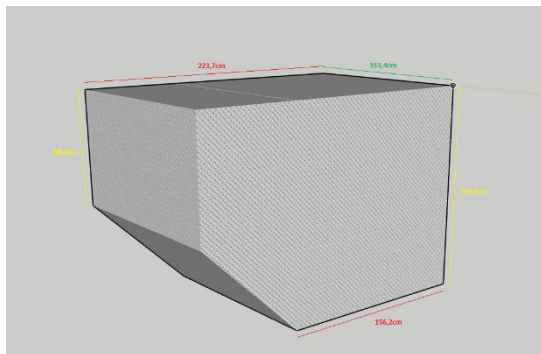


Figure 5-18: LD-1

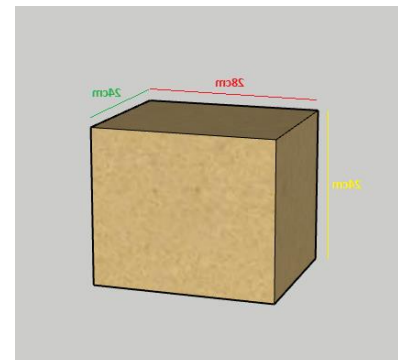


Figure 5-19: IMC040

Next, the model calculates the maximum base layout for the two existing orientations, either 'Original' or 'Flipped'. Whichever allows the most IMC units in that layer is chosen as orientation. For simplicity, we assume that only one orientation per layer is used.

	Length	Width	Height	Max per Layer
Max. Base Layout Original	5	6	6	30
Max. Base Layout Flipped	6	5	6	30

Max. Boxes regarding weight	293
-----------------------------	-----

Figure 5-20: Orientations Base Layout

The model starts at the 'Original' layout and since the maximum base layout in both orientations allows the same number of IMC units, the 'Original' orientation is chosen. The visualization of the starting position and the first layer is shown below in figure 5-21 and figure 5-22.

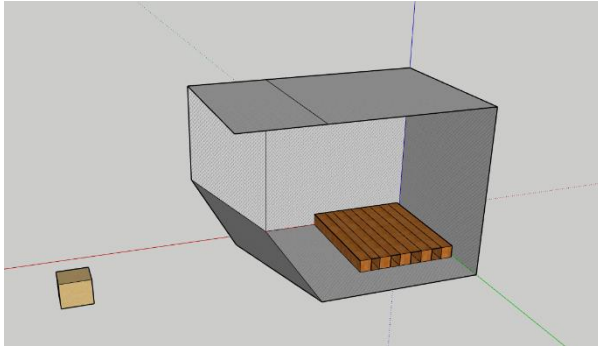


Figure 5-21: Starting Position

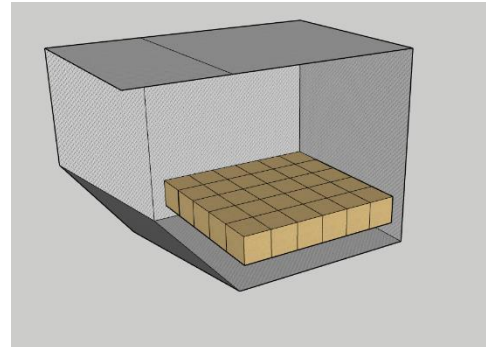


Figure 5-22: Layer 1 Original

The first layer is then filled in the cells and the model moves to the second layer. The width of the ULD is calculated for the second layer at both the top and the bottom of IMC unit, as seen in figure 5-23. The minimum width is chosen and once again the maximum layout for both orientations is calculated. The orientation that allows the maximum number of boxes is then selected. In the case of the current problem, the 'Flipped' orientation allows the maximum number of boxes. The result is seen in figure 5-24 below.

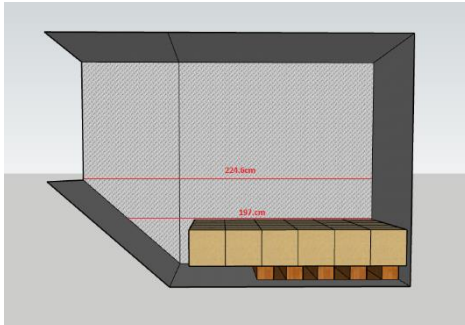


Figure 5-23: Starting Position

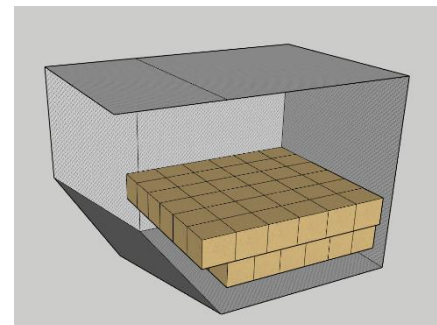
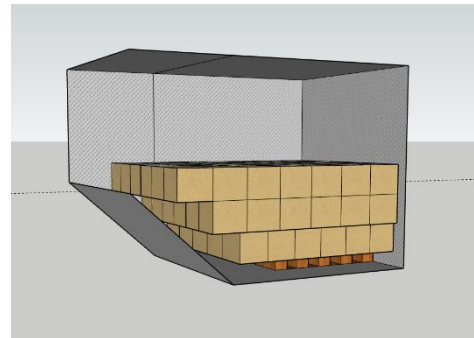


Figure 5-24: Layer 2 Flipped

The width of the LD-1 is then determined for the third layer and the most efficient lay orientation is calculated. This process is then repeated for each layer. After the third layer, the maximum width of the ULD is reached and for that reason the maximum layout per layer as well. The steps for each layer are shown in the figures below.



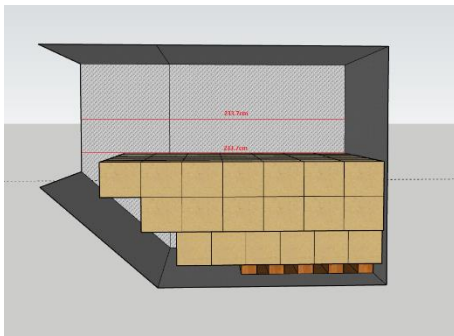


Figure 5-27: Determine Width Layer 4

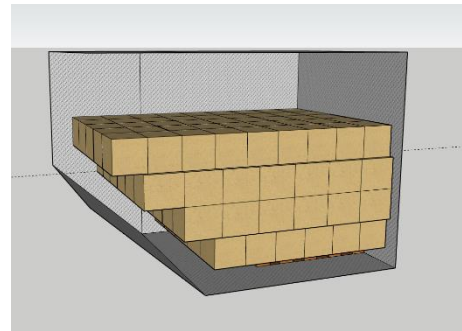


Figure 5-28: Layer 4 Original

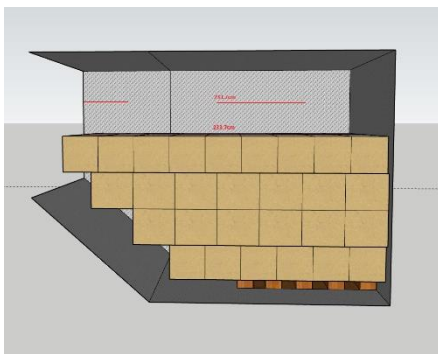


Figure 5-29: Determine Width Layer 5

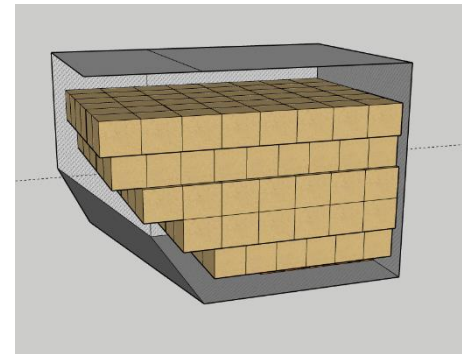


Figure 5-30: Layer 5 Flipped



Figure 5-31: Determine Width Layer 6

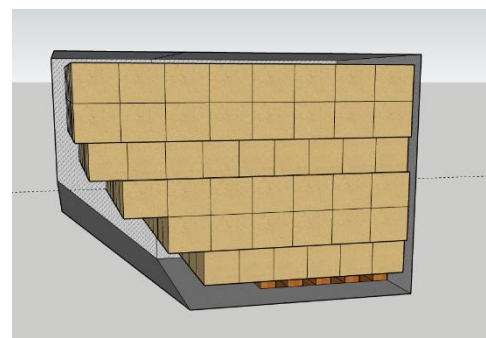


Figure 5-32: Layer 6 Flipped

After six layers, no extra layer layout can be added as seen in the previously shown figure 5-32. The ULD is then efficiently filled by the Cargo Layout model and the stacking pattern table is shown. The leftover space per layer is shown as well. The results of this designed cargo layout and the leftover space are shown in figures 5-33 and 5-34 below.

	Length	Width	Orientation	Formation Units	Additional Units	Total Units
Layer 1	5	6	Original	30	0	30
Layer 2	6	6	Flipped	36	0	36
Layer 3	6	7	Flipped	42	0	42
Layer 4	5	9	Original	45	0	45
Layer 5	6	8	Flipped	48	0	48
Layer 6	6	8	Flipped	48	0	48
Layer 7						
Layer 8						
Layer 9						
Layer 10						
Layer 11						
Layer 12						
Layer 13						
						+
						249

Figure 5-33: Calculated Cargo Layout

Leftover space per layer	Length (cm)	Width (cm)
Layer 1	13.4	12.2
Layer 2	9.4	9.32
Layer 3	9.4	2.44
Layer 4	13.4	3.56
Layer 5	9.4	9.7
Layer 6	9.4	9.7
Layer 7		
Layer 8		
Layer 9		
Layer 10		
Layer 11		
Layer 12		
Layer 13		

Figure 5-34: Leftover Space

### 5.3.5 TOOL DESIGN AND VBA MACROS

Most of the output of the tool is given due to the VBA macros that are designed. The VBA code consist of several elements, each responsible for a specific part of the tool. In order to fully explain the VBA code, the elements will be explained one by one.

The output dimensions of the different IMCs and ULDs are determined via the VLOOKUP function in excel. This function lets its user check for a specific term within a range and call the value of a chosen cell. This function is used to find the shown values of the IMCs and ULDs.

As explained above, the maximum base layout dimensions are determined by dividing the ULD dimensions with the IMC dimensions. If the orientation is flipped, the opposite IMC dimensions are chosen. This is explained above.

Now the VBA code will be explained by walking through the code. The total code is shown in the appendix 4.

In the first few rows of the code, all variables used to calculate the final dimensions are defined. The Dim ... as Double is used for real numbers with decimal points. The Dim ... as Integer is used for round numbers. The Dim ... as Long is used for Integer numbers.

Next, values are assigned to names. As seen in figure 9, IMC length = Range("IMC length"). IMC length should find the value of the length of the IMC. Since the value has decimal numbers, the IMC length is defined as double. The Range("IMC\_length") searches within the excel sheet for the name IMC length. The IMC length is then defined in excel using the Name Manager function.

Instead of directly typing in a 'cell code' like Range("O3"), the value of IMC length is assigned to cell 'O3' in the Name Manager. This is done to keep the VBA code more clear and to more easily design new functions and find errors. This is done for all the ULD and IMC dimensions. To make it more clear, a small part of the model is shown in the figure below.

A mentioned in the previous section, when a pallet is used, it only affects the height. This can be seen figure 5-35 below.



```

Dim IMC_length As Double
Dim IMC_width As Double
Dim IMC_height As Double
Dim IMC_quantity As Double
Dim IMC_weight As Double
Dim IMC_MaxWeight As Double

Dim pallet As Double
pallet = Range("pallet")

IMC_length = Range("IMC_length")
IMC_width = Range("IMC_width")
IMC_quantity = Range("IMC_quantity")
IMC_weight = Range("IMC_weight")
IMC_MaxWeight = Range("IMC_MaxWeight")

```

Figure 5-35: Part 1 Code

Next, the code checks whether the entered weight per box exceeds the weight limit of the actual box. If this is the case, an error pops up saying: "IMC weight exceeds weight limit". If this is not the case, the tool continues as seen in figure 5-36.

```

' Check if weight IMC unit does not exceed max IMC weight
If IMC_weight > IMC_MaxWeight Then
    MsgBox "IMC weight exceeds weight limit"

```

Figure 5-36: Exceeding Weight

Next, these dimensions are determined for the layers. This is done in the same method as shown above. A difference of the layer dimensions compared to the IMC/ULD dimensions is that the layer dimensions will be looped and will continuously change per layer. To fill the 'layer layout' as mentioned in section 5.2.3, the VBA code first clears out any previously determined numbers in this part. Subsequently the code starts in layer 1 and loops until the maximum height is reached, as shown below in figure 5-37. If a pallet is used, this will only effect the height of the lowest layer.

```

'clear old table
Range("D24:I36").ClearContents
Range("D40:I52").ClearContents

For layer = 1 To lay_height

If layer = 1 Then
IMC_height = Range("IMC_height") + pallet
Else
IMC_height = Range("IMC_height")
End If

'reset ULD dimensions for this layer and find the width at the bottom and top of the IMC unit
ULD_width = getUld_Width((layer - 1) * IMC_height, layer * IMC_height)
ULD_length = ULD_length

```

Figure 5-37: Part 2 Code

The ULD width is determined by calling the getUld\_Width function. This function has been predetermined. When the function is called, two height values will be determined for the bottom of the layer and the top of the layer as seen above. This will then transfer to the function shown below with the height of the bottom of the layer and the top of the layer, height1 and height2 respectively. Next, the width of the top of the selected ULD is checked compared to the width of the base of the ULD. This is needed to find out whether a ULD is rectangular or if the ULD has a sloped side.

```
Function getUld_Width(height1, height2)
heightOfSlope = Range("T11")
rateOfChange = Range("U11")
baseWidth = Range("ULD_baseWidth")
topWidth = Range("ULD_topWidth")
```

Figure 5-38: Part 3 Code

There are three possible options. The top width is larger than base width, the top width is smaller than the base width, or the top width and base width are equal. Each option calls for a specific part of the function. These three options are shown below in figure 5-39.

```
'if top width is larger than base width
If topWidth > baseWidth Then
    If height1 > heightOfSlope Then
        width1 = Application.WorksheetFunction.Min(topWidth, baseWidth + rateOfChange * height1)
    Else
        width1 = baseWidth
    End If

    If height2 > heightOfSlope Then
        width2 = Application.WorksheetFunction.Min(topWidth, baseWidth + rateOfChange * height2)
    Else
        width2 = baseWidth
    End If
```

Figure 5-39: Part 4 Code

If the top width is larger than the base width, this means that a ULD with a sloped side is picked and the width will increase from the when adding a layer. Height1 was predetermined as '(layer – 1) \* IMC height' and equal to the base of the layer. Height2 is 'layer \* IMC height' and thus equal to the top of the layer. The width of the base and top of the layer is then determined by finding the minimum width between the width of the top of the ULD and the 'basewidth \* RateOfChange \* height#'. As explained in the previous section, the rate of change is best described as the ratio of change in width compared to the change in height.

Subsequently, width1 and width2 are determined in figure 5-40. Width1 is equal to the width of the ULD at the base of the current layer. Width2 is equal to the width of the ULD at the top of the layer.

As seen in appendix figure 11, this is also done if the top width is smaller than the base width or if a rectangular ULD is used and thus the top width is equal to the base width.

```
getUld_Width = Application.WorksheetFunction.Min(width1, width2)

End Function
```

*Figure 5-40: Get ULD Minimum Layer Width*

Finally, depending on which of the three options is the current situation, the minimum width between the top and bottom of the layer is found. The code that moves back to the Sub AllULDs() with the minimum width for that layer. This way, if an extra layer is added, the code moves up one box per layer and checks the minimum height.

Since the width of an ULD is the only changing variable, the next step is to calculate the cargo layout for the current layer. The boxes used have a fixed side of the box that has to face upwards. This means that a box can only be put in two different orientations. These will later on be called 'Original' or 'Flipped'.

The macro first checks how many boxes would fit if the orientation of the IMC units in the ULD remain in the 'Original' position. This means that the ULD length is divided by the IMC length and the ULD width is divided by the IMC width. These are then called respectively lay\_lenght\_orig and lay\_width\_orig. The multiplication of these numbers will give the maximum number of boxes for that layer in the original orientation and is called 'orig\_product'.

Next, the macro checks this for the 'Flipped' orientation. In the 'Flipped' orientation, the ULD orientation stays the same, but the length and width of the IMC are swapped. This thus results in dividing the ULD length by the IMC width and dividing the ULD width by the IMC length. This way, the 'flip\_product' is found as shown in figure 5-41.

```
'calculate layout dimentions and orientation
lay_length_orig = Int(ULD_length / IMC_length)
lay_width_orig = Int(ULD_width / IMC_width)
orig_product = lay_length_orig * lay_width_orig

lay_length_flip = Int(ULD_length / IMC_width)
lay_width_flip = Int(ULD_width / IMC_length)
flip_product = lay_length_flip * lay_width_flip
```

*Figure 5-41: Determine Original and Flipped*

Now the product is known for both orientations, the code checks which of the two orientations allows the maximum number of boxes on that layer. This way, the lay\_length, lay\_width and lay\_orientation is found. Before filling the table, the remaining total number of boxes have to be checked compared to the maximum layer product. This is done to make sure that the ULD is not overfilled and can be seen in figure 5-42.

```
lay_maxPerLayer = Application.WorksheetFunction.Min(totalRemaining, lay_length * lay_width)
```

*Figure 5-42: Determine Max of Layer*

Once again, three situations can occur. The product of the lay\_length \* lay\_width can be greater larger than totalRemaining, the product can be smaller than the totalRemaining or the totalRemaining can be zero.

As seen in figure 5-43, if the lay\_maxPerLayer is equal to zero, the length and width of that layer will be zero as well since no more boxes should be added. Next, if the maximum product for the layer is smaller than the totalRemaining number of boxes, the maximum layout is picked. The third and last situation is the hardest situation. In that case, the total number of remaining boxes is larger than zero, but smaller than the maximum product for that layer found earlier. In this case, the code checks which dimension is the largest and starts subtracting 1 row. This is looped until the product of the lay\_length and lay\_width is smaller or equal to the totalRemaining. This way, the lay\_length and the lay\_width are found for the specific layer.

```
'Set to 0 if no units are left
If lay_maxPerLayer = 0 Then
    lay_length = 0
    lay_width = 0
End If

If lay_length * lay_width <= totalRemaining Then
    'normal
    lay_formationUnits = lay_length * lay_width
Else
    'decrement the greater of the lay_length and lay_width until their product is less than the total remaining
    While lay_length * lay_width > totalRemaining
        If lay_length >= lay_width Then
            lay_length = lay_length - 1
        Else
            lay_width = lay_width - 1
        End If
    Wend
End If
```

Figure 5-43: Part 5 Code

Since the numbers used to find the product are restricted by the maximum number of boxes that fit in the length and width of the current layer, it is not always possible to find a product between the lay\_length and lay\_width that is equal to the totalRemaining number of boxes for the final layer. For that reason, the product is defined as the lay\_formationUnits and a lay\_additional is defined for any leftover boxes that would fit in the layer.

```
'set the final values of the formation units and additional units
lay_formationUnits = lay_length * lay_width
lay_additional = lay_maxPerLayer - lay_formationUnits
```

Figure 5-44: Part 6 Code

The second last part of the VBA code is used to fill the actual layer table in excel. Since all dimensions are already defined by the previous parts of the code the only thing left is to give them a designated cell in the table. This is best shown by looking at the code in figure 5-45:

```
'fill data table
totalRemaining = totalRemaining - lay_maxPerLayer
Range("C23").Offset(layer, 1) = lay_length
Range("C23").Offset(layer, 2) = lay_width
Range("C23").Offset(layer, 3) = lay_orientation
Range("C23").Offset(layer, 4) = lay_formationUnits
Range("C23").Offset(layer, 5) = lay_additional
Range("C23").Offset(layer, 6) = lay_maxPerLayer
```

Figure 5-45: Fill Data Table

The final part of the code is designed since a request by Company X is to visualize the remaining free space in per layer in the ULD. As explained in the previous section, this can be used to investigate whether it is profitable to design a new IMC option that will allow an extra row to be added. The leftover space is determined by checking which layout orientation fits the most boxes per layer. The abovementioned designed layout dimensions are then used to find the leftover\_length by subtracting length of the total number of boxes from the ULD length. This is similarly done with the width of the ULD to find the leftover\_width. These dimensions are then designated to the correct dimension and layer cell in the table in excel. This is shown in figure 5-46.

```
' leftover space
If lay_orientation = "Original" Then
    leftover_length = ULD_length - (lay_length * IMC_length)
ElseIf lay_orientation = "Flipped" Then
    leftover_length = ULD_length - (lay_length * IMC_width)
End If

If lay_orientation = "Original" Then
    Leftover_width = ULD_width - (lay_width * IMC_width)
ElseIf lay_orientation = "Flipped" Then
    Leftover_width = ULD_width - (lay_width * IMC_length)
End If

Range("C39").Offset(layer, 1) = leftover_length
Range("C39").Offset(layer, 2) = Leftover_width
```

Figure 5-46: Leftover Space

The macro then walks through all layers until the maximum number of boxes is reached, the ULD is filled or the maximum number of boxes regarding weight is reached. The designed cargo layout can then be used to create the actual ULD or build a pallet in a specific stacking pattern. An example of the result of the cargo layout model is shown in appendix 6.

Summarized, the Cargo Layout model calculates an efficient fit. The code works in the following way: When the ULD and IMC are manually entered, the Cargo Layout model recognizes the code of the units and automatically generates the dimensions. These dimensions are then used to calculate the efficient orientation for the designated layer, starting at layer 1 and moving up one layer at a time until no more IMC units fit. The left over space per layer is also calculated which provides Company X with information regarding possible improvements. Due to the scope of this research, it is assumed that only one orientation is used per layer and that the leftover space in the ULD is filled with either filling material or other boxes.

The model improves the current filling process by removing as many manual processes as possible. As stated in chapter two, the current filling process is manual which leads to the possibility of human errors or lack of efficiency. Changing the orientation per layer as the width of an ULD increases may not always be as clear as expected since some differences are very small. Furthermore the insight for pre-determining the pallet layout for Company X's forwarder is very helpful. This will allow the forwarder to use a specific pallet stacking-pattern which will ensure an efficient fit and less individual handling, which results in a decrease of possible damage.

## 6. CONCLUSIONS AND RECOMMENDATIONS

### 6.1 CONCLUSIONS

Company X is currently not focusing on designing an efficient cargo layout for airfreight, but sees the need to do so given the large cost involved. This creates the need for a tool which is the cargo layout model. The designed model can be used by Company X's forwarders to predetermine pallet layout.

The main research question is: *To what extent can the stacking efficiency be improved - compared to the manual handling in the current situation - by pre-determining the cargo layout for Company X's airfreight?*

For this question to be answered, several sub-questions had to be answered. Summarized:

- Cargo layout is currently manually designed by airport handlers. The weight determines the stacking order of the boxes.
- The transport of IMCs is arranged by Company X's forwarders.
- Price is determined by four components:
  - o Gross weight
  - o Dimensions and volume
  - o Quality of the goods
  - o Station of origin and the final destination
- IMC units are mostly transported on a pallet instead of loose boxes. It is not mandatory to use a pallet.
- Damage to the cargo occurs in approximately 1% of the orders.
- In 95% of the orders of Company X's, volume is the restricting factor for airfreight.

The final bullet point is very important for the designed model, since this means it can be used in 95% of the orders.

To answer the main research question, the model provides Company X's forwarders with an exact cargo layout. This allows the forwarders to stack the pallet according to the calculated cargo layout. This will improve reliability, predictability and efficiency of the inbound logistics process for Company X. In addition, it will decrease the risk of faulty deliveries and ultimately line stoppages. Furthermore, by using a specific stacking pattern, less handling is needed which will decrease the chance of damage. The use of the Cargo Layout Model can therefore provide Company X with a tool to save cost and decrease risk for its EMEA inbound logistics system. In addition, when used by the airfreight handler, the Cargo Layout Model will provide insights in the possible change of orientation per layer. In the current manual situation, this might not be done efficiently.

Quantified, it is expected that the Cargo Layout model will be 5-10% more efficient compared to the current situation. A potential saving of 5% on 95% of the IMCs shipped would result in an annual saving of €142,500. This potential justifies the initiation of a trial program to verify the effectiveness of the Cargo Layout Model.

## 6.2 RECOMMENDATIONS

The first recommendation focuses on the designed model. The model only allows one IMC type to be entered to calculate the cargo layout. The expansion of the model to allow two or more IMC types to be used will generate a more useful and realistic cargo layout. Furthermore, this will allow its user to even add IMC units from other companies in such a way that the model will become useful not only for the products of Company X, but for other companies as well. This way, a ULD can be mixed with boxes from more than one company.

After implementation of the above, Company X can redesign their logistical routes to have an efficient fit in the ULDs. Mostly when a large IMC type is used, the leftover space is large enough to fit a smaller IMC type. By combining different IMC units from different suppliers, a mixed pallet can be made that would eliminate most of the leftover space. This would result in a better filling rate of a pallet or ULD and thus reduce the average cost per unit.

Additionally, Company X could choose to redesign or add IMC types. There are 43 different IMC types in total. For smaller parts, there are many different IMC types in which the part can fit. For larger parts, only a few IMC types remain. By looking at the leftover space after using the model, the decision can be made to try and design a new IMC type for some parts that allows an extra layer to be added. This would therefore reduce the average cost per unit as well.

In order to check whether the expected increase in layout efficiency will actually be applicable, Company X needs to start with a trial period. During this period, the results of the current manual method can be compared to the cargo layout model to validate its expected results.



## 7. DISCUSSION

The designed Cargo Layout Model generates an efficient cargo layout for the selected IMC unit in the ULD. It is nevertheless, not always a realistic comparison with a real-life situation. The designed tool calculates the efficient cargo layout provided that only one IMC option is used. This assumption is made due to interviews in the beginning of this research thesis and the designed scope. It does occur that more than one IMC option is used so the model might not always realistically calculate the best cargo layout. The model can therefore only be used if an ULD is completely filled with one sort of IMC option or if only one type of IMC option needs to be transported.

Another subject for discussion is the use of a pallet and the extra restrictions it brings. In the current model, the use of a pallet only restricts the height dimensions with an extra 12.3 cm. This is done for the usability of the model. The use of a pallet also affects the length and width of an ULD since a pallet generally has no good fit within an ULD. Since the height is the most critical dimension for airfreight, the decision is made to let a pallet only affect the height.

Airfreight might not be used as much in the future compared to the current use. Company X aims for reaching steady production levels for all models. With the current growth, the production levels can differ per week. Furthermore, the line of the new model does not run as expected. When the targeted production levels are reached, the forecasting of demand can be far more standardized. The expectation is that in the future, when suppliers are fully compliant and production levels are stable, most of Company X stock can automatically be reordered and thus the use of airfreight will only be needed in exceptional situations. The designed model might therefore generate less benefits once in the future.

Furthermore, the quantification of the current manual filling technique is a point of discussion. The data provided by Company Z is not useful since several transport units are mixed. The number of units are either pallets or boxes and therefore calculating average airfreight cost per box is not possible. In the future, keeping track of exact shipments may be useful to check the efficiency of the used methods/models.

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## Appendix 1 - Aircraft types

### Freighter Aircrafts

Freighter aircraft is the largest type of aircraft available for transportation. It is an aircraft specifically designed for transportation of goods and not of people. There are many different kinds of planes and the restrictions for transportation regarding weight and size are the lowest. Freighter aircraft can be used in two different ways; consolidated freight or fill a scheduled plane (Air Freight Guide, 2017).

- The first option, consolidated freight, is a method whereby shipments from different suppliers get combined by a freight forwarder in order to create a more cost-effective load and to ensure better rates from the airline due to an economy of scale.
- The second option, a scheduled plane, is a plane specifically deployed by a company for the transportation of only their goods.

The downside of freighter aircraft is that there is a limited amount of planes that fly on a limited time schedule. For that reason, most of the transportation done via air freight is done in a Wide-body aircraft or Narrow body aircraft. These planes are used as people carriers as well.

### Wide-body Aircrafts

A Wide-body Aircraft transports, next to possible cargo, passengers as well. The International Civil Aviation Organization (ICAO) defined wide-body and narrow-body aircrafts as:

*“A combination aircraft (often referred to as combi aircraft in the airline industry) is a transport aircraft capable of carrying both passengers and cargo on the main deck, often in varied configurations (Manual on the Regulation of International Air Transport, 2004).”*

Since a combination aircraft is not specialized in solely cargo, the size and weight restrictions are limited compared to the freighter aircrafts mentioned above. The ICAO definition for wide Wide-body aircrafts is:

*“A large transport aircraft with internal cabin width sufficient for normal passenger seating to be divided into three axial groups by two aisles (in practice this means not less than 4.72 meters (15.6 feet). (Manual on the Regulation of International Air Transport, 2004)”*

Most of the airfreight transported for Company X is done in a wide-body aircraft. These planes are more common, have acceptable size and weight restrictions and fly very often. For that reason, wide-body aircrafts are mostly used if Company X chooses to use airfreight instead of sea freight. The different wide-body aircraft models used by Company X are:

- Boeing 787
- Boeing 747
- Boeing 777
- Boeing 767
- Airbus A330

- *Airbus A340*

These planes all have their own weight and size restrictions due to different sizes of doors. The type of airplane is chosen depending on restrictions and availability. This means that there is no standard plane that is always used and for that reason, efficient packaging/transportation options differ per transport. Company X mostly uses Boeing for airfreight and therefore these planes will be the most important guideline regarding measurements. The dimensions and restrictions are shown below.

As the name says, narrow-body aircrafts are smaller than wide-body aircrafts and freighter aircrafts. The definition by the ICAO is:

“A narrow-body aircraft is an aircraft having only one aisle in the cabin with passenger seating divided into two axial groups (Manual on the Regulation of International Air Transport, 2004).”

There are several narrow-body aircrafts that could be used by Company X:

- *Boeing 757*
- *Boeing 737*
- *Boeing Super 80*
- *Airbus A321*
- *Airbus A320*
- *Airbus A319*

Types	Forward Door		Aft Door		Bulk Door		Maximum Pallet Height (CM)	Maximum Bulk Piece Weight (KG)	Maximum Single Piece Weight (KG)
	Height (cm)	Width (cm)	Height (cm)	Width (cm)	Height (cm)	Width (cm)			
Boeing 787	162	269	162	269	101	114	162	2735 containers - 158 bulk loaded	158
Boeing 777-300ER	162	269	162	269	114	91	162	4535 containers - 158 bulk loaded	158
Boeing 777-200ER	162	269	162	177	121	96	162	4535 containers - 158 bulk loaded	158
Boeing 767-300ER	162	340	162	177	121	96	162	4535 containers - 158 bulk loaded	158
Airbus 330	162	269	162	269	60	93		4535 containers - 158 bulk loaded	
Boeing 747-									
Airbus 340	169.799	270.1036	168.1988	272.1102	95.0976	61.8744	157.48		

Figure A-0-1: Wide-body Aircrafts dimensions

Types	Forward Door		Aft Door		Bulk Door		Maximum Pallet Height (CM)	Maximum Bulk Piece Weight (KG)	Maximum Single Piece Weight (KG)
	Height (cm)	Width (cm)	Height (cm)	Width (cm)	Height (cm)	Width (cm)			
Boeing 757-200	101	139	101	139			101	158	
Boeing 737	71	114	71	114				158	
Airbus 321	116	180	116	180				158	
Airbus 320	116	180	116	180				158	
Airbus 319	116	180	116	180				158	
Boeing Super 80	71	132	71	132				158	

Figure A-0-2: Narrow-body Aircrafts Dimensions

Types	External (m)			Internal (m)			Door Height (m)	Door Width (m)	Cubic Capacity	Max Gross Weight	Tare Weight
	Length	Width	Height	Length	Width	Height					
40ft HC container	12.2	2.44	2.9	12.04	2.35	2.69	2.58	2.34	76.4	30480	3660
40ft GP container	12.2	2.44	2.6	12.03	2.35	2.39	2.28	2.34	67.6	30480	3470
20ft HC container	6.06	2.44	2.9	5.96	2.35	2.69	2.58	2.34	37.4	30480	2100
20ft GP container	6.06	2.44	2.6	5.9	2.35	2.39	2.28	2.34	15.95	30480	2000

Figure A-0-3: Container Dimensions

## Appendix 2 - IMCs

IMC Carton Number	EXTERIOR DIMENSIONS (mm)			TARE WEIGHT kg.	BURST STRENGTH (lbs)	FLUTE SIZE	BOX DESIGN	MAX WEIGHT PER BOX kg.
	L	W	H	KG	LBS			KG
IMC010	140	240	120	0,1	275 #	C	RSC	15
IMC020	140	240	240	0,2	275 #	C	RSC	15
IMC030	280	240	120	0,2	275 #	C	RSC	15
IMC040	280	240	240	0,3	275 #	C	RSC	15
IMC050	280	480	120	0,4	275 #	C	RSC	15
IMC060	280	480	240	0,7	275 #	C	RSC	15
IMC070	560	240	120	0,3	275 #	C	RSC	15
IMC080	560	240	240	0,8	275 #	C	RSC	15
IMC090	560	480	120	1,3	275 #	C	RSC or FTD	15
IMC100	560	480	240	2,1	400 #	CB	RSC	15
IMC110	560	480	480	2,8	400 #	CB	RSC	15
IMC120	560	960	120	2,3	275 #	C	RSC or FTD	The carton weight capacity varies depending on the pack design. For the smaller hand held cartons the maximum weight is defined by the ergonomic weight limit (15kg)
IMC130	560	960	240	3,9	500 #	CB	RSC	
IMC140	560	960	480	5,1	500 #	CB	RSC	
IMC150	1120	480	120	1,7	275 #	C	RSC or FTD	
IMC160	1120	480	240	3,7	500 #	CB	RSC	
IMC170	1120	480	480	4,9	500 #	CB	RSC	
IMC180	1120	960	240	8,2	500 #	CB	RSC	
IMC190	1120	960	480	9,6	500 #	CB	RSC or HSC & LID	
IMC193	1120	960	480	12,7	1100 #	CAA	RSC or HSC & LID	
IMC197	1120	960	600	10,2	500 #	CB	RSC or HSC & LID	
IMC200	1120	960	960	12,3	450 #	CB	RSC or HSC & LID	
IMC203	1120	960	960	17,0	1100 #	CAA	RSC or HSC & LID	
IMC400	1300	1120	960	21,4	1100 #	CAA	HSC & LID	
IMC410	1300	1120	480	16,4	1100 #	CAA	HSC & LID	
IMC420	1450	1120	960	17,4	1100 #	CAA	HSC & LID	
IMC430	1450	1120	480	17,4	1100 #	CAA	HSC & LID	
IMC440	1680	1120	960	24,8	1100 #	CAA	HSC & LID	
IMC450	1680	1120	480	18,0	1100 #	CAA	HSC & LID	
IMC460	1960	1120	960	27,0	1100 #	CAA	HSC & LID	
IMC470	1960	1120	480	20,9	1100 #	CAA	HSC & LID	
IMC480	2260	960	960	25,9	1100 #	CAA	RSC or HSC & LID	
IMC490	2260	960	480	19,3	1100 #	CAA	RSC or HSC & LID	

Figure A-4: IMC Dimensions North & South

IMC Carton Number	EXTERIOR DIMENSIONS (mm)			TARE WEIGHT	BCT	BURST STRENGTH	PUNCTURE RESIST	MAX WEIGHT PER BOX
	L	W	H	KG	KG	LBS		KG
IMC010	140	240	120	0.1	208	1320	6	15
IMC011	240	140	120	0.3	208	1320	6	15
IMC020	240	140	240	0.2	208	1320	6	15
IMC030	280	240	120	0.2	243	1320	6	15
IMC031	280	240	120	0.4	243	1320	6	15
IMC040	280	240	240	0.3	243	1320	6	15
IMC050	280	480	120	0.4	294	1320	6	15
IMC060	280	480	240	0.8	294	1320	6	15
IMC070	560	240	120	0.4	301	1320	6	15
IMC080	560	240	240	0.5	301	1320	6	15
IMC090	560	480	120	1.1	692	2180	12.8	15
IMC100	560	480	240	1.3	692	2180	6	30
IMC110	560	480	480	1.8	692	2180	6	60
IMC120	560	960	120	1.9	737	2470	13.8	30
IMC130	560	960	240	2.7	1179	2800	15.2	60
IMC133	560	960	280	2.8	1179	2800	15.2	60
IMC136	560	960	360	3	1179	2800	15.2	60
IMC140	560	960	480	3.3	1074	2500	14.2	60
IMC142	560	960	600	3.4	1074	2500	14.2	60
IMC144	730	560	480	3.2	1074	2500	14.2	60
IMC147	800	960	320	3.4	1074	2500	14.2	60
IMC150	1120	480	120	1.7	952	2470	13.8	30
IMC160	1120	480	240	2.4	1102	2500	14.2	60
IMC170	1120	480	480	3.3	1102	2500	20.2	60
IMC180	1120	960	240	7.8	1950	3524	20.2	60
IMC186	1120	960	360	8.6	1950	3524	20.2	60
IMC190	1120	960	480	9.4	1950	3524	20.2	210
IMC193	1120	960	560	9.9	1950	3524	20.2	250
IMC197	1120	960	600	10.2	1950	3524	20.2	420
IMC198	1120	960	730	11	1950	3524	20.2	420
IMC200	1120	960	960	12.5	1950	3524	20.2	500
IMC210	1240	480	480	5.2	1990	3524	20.2	250
IMC220	1460	1120	840	15.8	2430	3524	20.2	500
IMC230	1470	560	120	4.3	2160	3524	20.2	120
IMC240	1470	560	240	5.1	2160	3524	20.2	250
IMC250	1470	560	360	5.8	2160	3524	20.2	250
IMC260	1470	1120	240	11	2430	3524	20.2	500
IMC270	1470	1120	480	13	2430	3524	20.2	500
IMC280	1660	800	300	8.5	2380	3524	20.2	500
IMC290	1740	1120	240	12.2	2560	3524	20.2	350
IMC300	1740	1120	480	14.3	2560	3524	20.2	500
IMC310	2240	1120	480	16.8	2780	3524	20.2	500
IMC320	2240	560	480	9.1	2530	3524	20.2	350

Figure A-5: IMC Dimensions Europe & Asia

## Appendix 3 - ULDs

Types	Dimensions (cm)			Rate Class	Maximum Gross weight	Tare Weight	Volume		Suitable for	
	L	Top	W				H	m <sup>3</sup>		
	Bottom	Top				KG		AS	Boeing	
DEMI	223.5	223.5	157.5	200.7	Type 7	3016	80	5.3	5.3	727F, 737F, 757F main deck, 747F, 767F, 777F, DC-10F, MD-11F main deck
IRMA Stull	317.5	317.5	223.5	162.6	Type 2	3500	1310	18.4	18.4	main deck 747F, 767F, 777F, DC-10F, MD-11F
1D-1	156.2	233.7	153.4	162.6	Type 8	1588	70 - 170	5	5	747, 767, 777, 787, MD-11 lower hold
1D-11	317.5	317.5	153.4	162.6	Type 6	3176	185	7.4	7.2	747, 777, 787, DC-10, MD-11 lower hold
1D-2	119.4	156.2	153.4	162.6	Type 8D	1225	92	3.5	3.5	747, 767, 777, 787 lower hold
1D-2A	317.5	406.4	223.5	162.6	Type 5	6033	250	13.3	13.3	747, 777, 787, DC-10, MD-11 lower hold
1D-2B	317.5	472.4	223.5	162.6	Type 5	6033	265	14.4	14.4	747 lower hold
1D-2B Reeler	317.5	472.4	223.5	162.6	Type 5	6033	450	11.1	11.1	747 lower hold
1D-3	156.2	200.7	153.4	162.6	Type 8	1588	82	4.5	4.5	A300, A310, A330, A340, 747, 767, 777, DC-10, MD-11, L-1011
1D-3 Reeler	156.2	200.7	153.4	162.6	Type 8	1588	210	4.5	4.5	747, 767, 777, 787, DC-10, MD-11 lower hold
1D-3S	317.5	472.4	243.8	162.6	Type 2BG	5035	290	15.9	15.9	747 lower hold
1D-4	243.8	243.8	153.4	162.6	Type 8	2449	120	5.7	5.5	767, 777, 787 lower hold
1D-4	317.5	406.4	153.4	162.6	Type 6W	3175	230	9.1	8.9	747, 777, 787, DC-10, MD-11 lower hold
1D-7	317.5	317.5	223.5	162.6	Type 5	4626	105	10.5	10.7	Wide-body: All aircrafts lower holds and main decks
1D-7 With Angled Wings	317.5	398.8	223.5	162.6	Type 5	5000	170	14	14	747, 777, 787, DC-10, MD-11 lower hold
1D-7 With Folding Wings	317.5	398.8	223.5	162.6	Type 5	5000	152	14	14	747, 777, 787, DC-10, MD-11 lower hold
1D-8	243.5	317.5	153.4	162.6	Type 6A	2450	127	7.1	6.9	767, 787 lower hold
1D-9	317.5	317.5	223.5	162.6	Type 5	Lower hold: 4624 Main deck: 6000	Canvas: 215 Solid: 270	10.8	10.8	747, 767, 777, 787, DC-10, MD-11 lower hold
1D-9 Reeler	317.5	317.5	223.5	162.6	Type 5	Lower hold: 4624 Main deck: 6000	400	9.6	9.6	747, 767, 777, 787, DC-10, MD-11 lower hold
M-1	317.5	317.5	243.8	243.8	Type 2	6804	350	17.6	17.6	747F, 747 Combi, 777F center load only
M-1H	317.5	317.5	243.8	299.7	Type 2H	6800	370	21.2	21.2	747F, 747 Combi, 777F center load only
M-2	605.8	605.8	243.8	243.8	Type 1	11340	1000	33.7	33.7	747F, 747 Combi, 777F center load only
M-6	605.8	605.8	243.8	243.8	Type 1	11340	500	33.7	33.7	747F, 747 combi, 777F
M-6 (111"H)	605.8	605.8	243.5	299.7	Type 1	11340	500	39.6	39.6	747 combi, 777F, 747F cargo door only
M-6 Twin Car Rack					Type 1P	8900	400			747F, 747 Combi, 777F
MDP	497.8	497.8	243.8	243.8	Type 1P	11300	410	27.6	27.6	747F, 747 Combi, 777F
PLA Half Pallet	317.5	317.5	153.4	162.6	Type 6	3175	91	7.1	7.1	747, 777, 787 lower hold, 707F, 727F, 737F main deck with countered load
PBC/P&P Pallet	317.5	317.5	243.8	162.6 - 299.7	Type 2GB		120			747, 767, 777, 787, DC-10, MD-11
PNA Half Pallet	243.8	243.8	162.6	162.6	Type 8	2449	83	5.5	5.5	767, 787 lower hold
Type A Pen	317.5	317.5	223.5	243.5	Type 3		610	15.9	15.9	main deck 747F, 767F, 777F, DC-10F, MD-11F

Figure A-6: ULD Dimensions

## Appendix 4 - Model Code

```
Sub AllULDs ()

Dim IMC_length As Double
Dim IMC_width As Double
Dim IMC_height As Double
Dim IMC_quantity As Double
Dim IMC_weight As Double
Dim IMC_MaxWeight As Double

Dim pallet As Double
pallet = Range("pallet")

IMC_length = Range("IMC_length")
IMC_width = Range("IMC_width")
IMC_quantity = Range("IMC_quantity")
IMC_weight = Range("IMC_weight")
IMC_MaxWeight = Range("IMC_MaxWeight")

Dim ULD_length As Double
Dim ULD_width As Double
Dim ULD_height As Double
Dim ULD_MaxWeight As Double

ULD_length = Range("ULD_length")
ULD_width = Range("ULD_baseWidth")
ULD_height = Range("ULD_height")
ULD_MaxWeight = Range("ULD_maxWeight")

Dim lay_height As Integer
Dim lay_length As Integer
Dim lay_width As Integer
Dim lay_maxPerLayer As Long
Dim leftover_length As Double
Dim Leftover_width As Double

' Check if weight IMC unit does not exceed max IMC weight
If IMC_weight > IMC_MaxWeight Then
    MsgBox "IMC weight exceeds weight limit"
Else

    'Continu if IMC weight does not exceed IMC unit limit

    lay_height = Range("lay_height")
    lay_length = 0
    lay_width = 0
    lay_maxPerLayer = 0

    Dim totalRemaining As Integer
    totalRemaining = Range("maxCapacity")

    'clear old table
    Range("D24:I36").ClearContents
    Range("D40:I52").ClearContents
```

Figure A-7: VBA Macro part 1



```

For layer = 1 To lay_height

If layer = 1 Then
IMC_height = Range("IMC_height") + pallet
Else
IMC_height = Range("IMC_height")
End If

'reset ULD dimensions for this layer and find the width at the bottom and top of the IMC unit
ULD_width = getUld_Width((layer - 1) * IMC_height, layer * IMC_height)
ULD_length = ULD_length

'calculate layout dimentions and orientation
lay_length_orig = Int(ULD_length / IMC_length)
lay_width_orig = Int(ULD_width / IMC_width)
orig_product = lay_length_orig * lay_width_orig

lay_length_flip = Int(ULD_length / IMC_width)
lay_width_flip = Int(ULD_width / IMC_length)
flip_product = lay_length_flip * lay_width_flip

If orig_product >= flip_product Then
    lay_length = lay_length_orig
    lay_width = lay_width_orig
    lay_orientation = "Original"
Else
    lay_length = lay_length_flip
    lay_width = lay_width_flip
    lay_orientation = "Flipped"
End If

lay_maxPerLayer = Application.WorksheetFunction.Min(totalRemaining, lay_length * lay_width)

'Set to 0 if no units are left
If lay_maxPerLayer = 0 Then
    lay_length = 0
    lay_width = 0
End If

If lay_length * lay_width <= totalRemaining Then
    'normal
    lay_formationUnits = lay_length * lay_width
Else
    'Subtrect 1 row of the largest lay_length or lay_width until their product is less than the total remaining
    While lay_length * lay_width > totalRemaining
        If lay_length >= lay_width Then
            lay_length = lay_length - 1
        Else
            lay_width = lay_width - 1
        End If
    Wend
End If

'set the final values of the formation units and additional units
lay_formationUnits = lay_length * lay_width
lay_additional = lay_maxPerLayer - lay_formationUnits

```

Figure A-8: VBA Macro part 2

```

'fill data table
totalRemaining = totalRemaining - lay_maxPerLayer
Range("C23").Offset(layer, 1) = lay_length
Range("C23").Offset(layer, 2) = lay_width
Range("C23").Offset(layer, 3) = lay_orientation
Range("C23").Offset(layer, 4) = lay_formationUnits
Range("C23").Offset(layer, 5) = lay_additional
Range("C23").Offset(layer, 6) = lay_maxPerLayer

' leftover space
If lay_orientation = "Original" Then
    leftover_length = ULD_length - (lay_length * IMC_length)
ElseIf lay_orientation = "Flipped" Then
    leftover_length = ULD_length - (lay_length * IMC_width)
End If

    If lay_orientation = "Original" Then
        leftover_width = ULD_width - (lay_width * IMC_width)
    ElseIf lay_orientation = "Flipped" Then
        leftover_width = ULD_width - (lay_width * IMC_length)
    End If

Range("C39").Offset(layer, 1) = leftover_length
Range("C39").Offset(layer, 2) = leftover_width

Next layer

End If

End Sub

```

Figure A-9: Code Part 3

```

Function getUld_Width(height1, height2)
heightOfSlope = Range("HeightOfSlope")
rateOfChange = Range("RateOfChangeOfWidth")
baseWidth = Range("ULD_baseWidth")
topWidth = Range("ULD_topWidth")

'if top width is larger than base width
If topWidth > baseWidth Then
    If height1 > heightOfSlope Then
        width1 = Application.WorksheetFunction.Min(topWidth, baseWidth + rateOfChange * height1)
    Else
        width1 = baseWidth
    End If

    If height2 > heightOfSlope Then
        width2 = Application.WorksheetFunction.Min(topWidth, baseWidth + rateOfChange * height2)
    Else
        width2 = baseWidth
    End If

'if top width is smaller than base width
ElseIf topWidth < baseWidth Then
    If height1 > heightOfSlope Then
        width1 = Application.WorksheetFunction.Max(topWidth, baseWidth + rateOfChange * height1)
    Else
        width1 = baseWidth
    End If

    If height2 > heightOfSlope Then
        width2 = Application.WorksheetFunction.Max(topWidth, baseWidth + rateOfChange * height2)
    Else
        width2 = baseWidth
    End If

'if top width is equal to base width
Else
    width1 = baseWidth
    width2 = baseWidth
End If

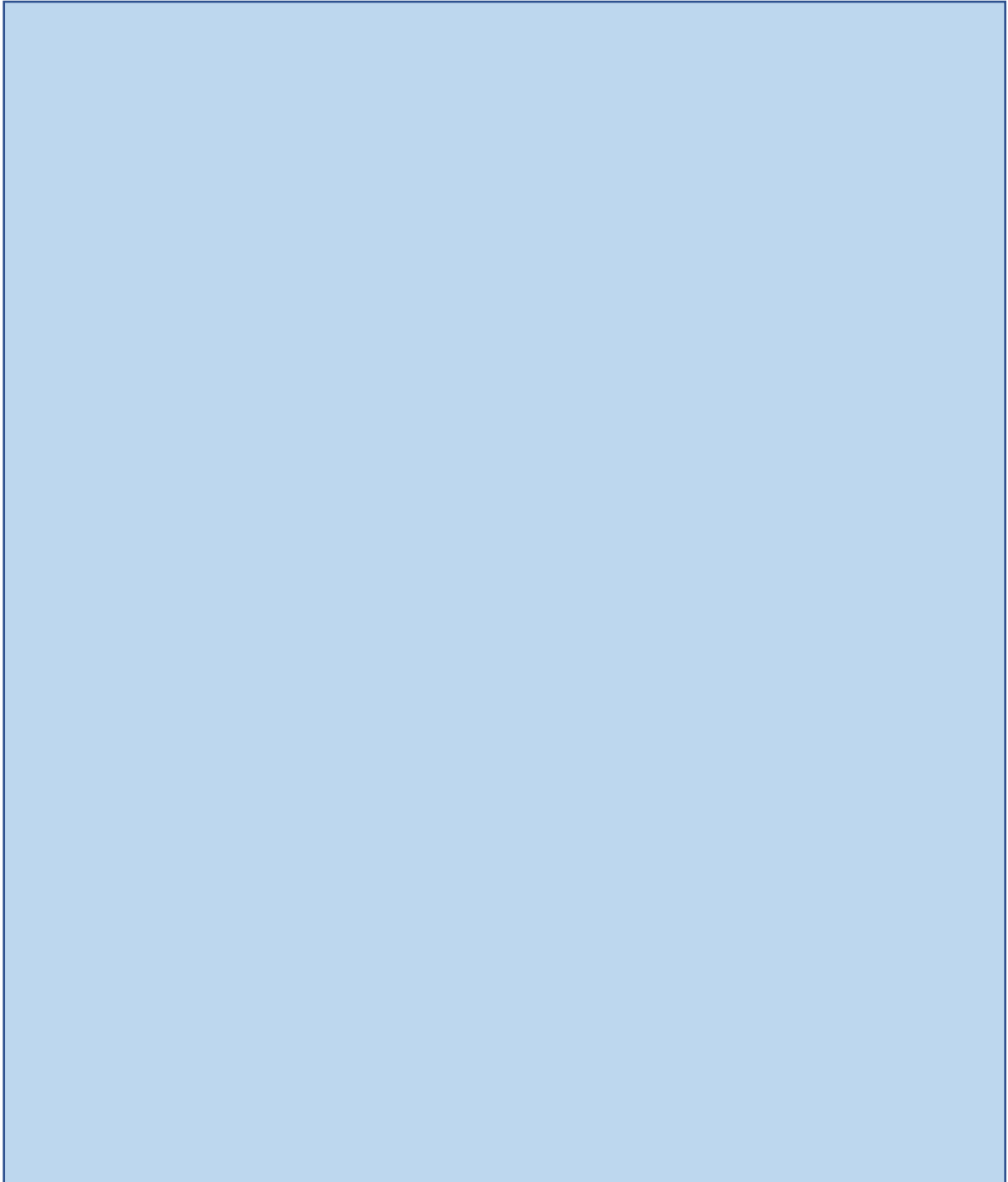
getUld_Width = Application.WorksheetFunction.Min(width1, width2)

End Function

```

Figure A-10: Get Width ULD

## Appendix 5 - Logistics Flowchart



*Figure A-11: Flow Chart Logistics*

## Appendix 6 – Example Cargo Layout Model

Quantity	5000
Weight	1

ULD	Length	Base Width	Top Width	Height	Max. Weight	Height of Slope	change of width
LD-1	153.4	156.2	233.7	162.6	1468	0	0.88

  
☐ Pallet
 

	Length	Width	Height	Max per Layer
Max. Base Layout Original	2	6	13	12
Max. Base Layout Flipped	6	2	13	12

Max. Boxes regarding weight	1468
-----------------------------	------

	Length	Width	Orientation	Formation Units	Additional Units	Total Units
Layer 1	2	6	Original	12	0	12
Layer 2	2	6	Original	12	0	12
Layer 3	6	3	Flipped	18	0	18
Layer 4	6	3	Flipped	18	0	18
Layer 5	6	3	Flipped	18	0	18
Layer 6	6	3	Flipped	18	0	18
Layer 7	2	9	Original	18	0	18
Layer 8	6	4	Flipped	24	0	24
Layer 9	6	4	Flipped	24	0	24
Layer 10	6	4	Flipped	24	0	24
Layer 11	6	4	Flipped	24	0	24
Layer 12	6	4	Flipped	24	0	24
Layer 13	6	4	Flipped	24	0	24
						258

Leftover space per layer	Length (cm)	Width (cm)
Layer 1	41.4	12.2
Layer 2	41.4	22.76
Layer 3	9.4	9.32
Layer 4	9.4	19.88
Layer 5	9.4	30.44
Layer 6	9.4	41
Layer 7	41.4	3.56
Layer 8	9.4	6.12
Layer 9	9.4	9.7
Layer 10	9.4	9.7
Layer 11	9.4	9.7
Layer 12	9.4	9.7
Layer 13	9.4	9.7

Figure A-12: Example Outcome Model

## Appendix 7 – Manual for using the Cargo Layout Model

Below, you will find a step-by-step approach on how to use the Cargo Layout model. Pictures have been added per step to make it clearer.

**Step 1.** *Open the Cargo Layout model*

**Step 2.** *Choose the IMC unit and enter the quantity and weight*

IMC	Length	Width	Height	Max. Weight
#N/A	#N/A	#N/A	#N/A	#N/A

Quantity	
Weight	

**Step 3.** *Choose the ULD unit that is going to be used*

ULD	Length	Base Width	Top Width	Height	Max. Weight	Height of Slope	change of width
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

**Step 4.** *Check dimensions step 2 and step 3 to see if everything is correct (example with*

IMC	Length	Width	Height	Max. Weight
IMC010	14	24	12	15

Quantity	2000
Weight	1

ULD	Length	Base Width	Top Width	Height	Max. Weight	Height of Slope	change of width
LD-1	153.4	156.2	233.7	162.6	1468	0	0.88

**Step 5.** *Check the 'Pallet' box if needed*

☐ Pallet

**Step 6.** *Make sure the table is clear by clicking the button 'Clear Content'*

Clear Content

**Step 7.** *Press the button 'Calculate Layout' to get the efficient Cargo Layout*

Calculate Layout

**Step 8.** *Use the calculated layout per layer to 'build-up' the pallet*

	Length	Width	Orientation	Formation Units	Additional Units	Total Units
Layer 1	6	11	Flipped	66	0	66
Layer 2	6	11	Flipped	66	0	66
Layer 3	6	12	Flipped	72	0	72
Layer 4	6	13	Flipped	78	0	78
Layer 5	6	14	Flipped	84	0	84
Layer 6	6	14	Flipped	84	0	84
Layer 7	10	9	Original	90	0	90
Layer 8	6	16	Flipped	96	0	96
Layer 9	6	16	Flipped	96	0	96
Layer 10	6	16	Flipped	96	0	96
Layer 11	6	16	Flipped	96	0	96
Layer 12	6	16	Flipped	96	0	96
Layer 13	6	16	Flipped	96	0	96
						1116