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# Decreasing the exposure of temperature-sensitive cargo to ambient temperature on the tarmac at KLM Cargo

G. Epe

# Decreasing the exposure of temperature-sensitive cargo to ambient temperature on the tarmac at KLM Cargo

by

G. Epe

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# Preface

This report was written as the final stage in the process of obtaining my degree as Master of Science in the field of Transport Engineering and Logistics at the faculty of Mechanical, Maritime and Materials Engineering at the Delft University of Technology. This graduation project is conducted at KLM Cargo, at their hub at Amsterdam Airport Schiphol.

First, I would like to thank my daily supervisor at KLM, Paul Crombach, for the support that he provided to me over the past seven months. He was there to provide knowledge about the air cargo industry, preferable taught by drawings. I would like to thank Juliette Aloserij and Marja van Cleef, for they are part of the cool chain program as well and kept me sharp by asking the right questions.

I would like to thank my professor, Mark Duinkerken, for supervising me. I tend to start slow and I was struggling with my structure for a long while, but he kept patient with me and guided me well throughout the thesis. My first run in Congo will be for you.

Finally, I want to thank my friends inside and outside KLM for providing continuous support to me for the past months, especially when progress was slow.

*G. Epe*
*Amsterdam, August 2019*

# Abstract

Air cargo connects the world, playing a crucial role in the air transport chain. Without air shipments, global supply chains would be unable to function and it would limit the availability of certain products. Time- and temperature-sensitive goods, such as flowers, food and pharmaceuticals, require quick transport that can be achieved by air transport.

This research addresses the temperature-sensitive goods at KLM Cargo, where currently is a lack of performance measurements regarding the temperature excursions. This research aims to determine how the performance of transport on the tarmac can be quantified, analysed and be improved regarding the transport time and ambient temperature.

The temperature-sensitive cargo that is processed at KLM Cargo grounds can be defined as perishable (*fresh*) or pharmaceutical (*pharma*) goods. These goods are shipped under temperature controlled circumstances and the goods can differ in temperature requirements. Special handling codes, as determined by IATA, indicate the temperature range that a good should be present in during transport; COL *(2-8 degrees Celsius)*; CRT *(15-25 degrees Celsius)*; ERT *(2-25 degrees Celsius)*.

The most important influence for preserving the quality of temperature-sensitive cargo is the ambient temperature. Distributing goods around the world exposes loads to extreme temperatures, and the combination of time and temperature determine the gravity of damage to the products. The exposure to ambient temperature is depending on seasonality, this research focuses on three adjusted definitions of seasons; cold *(below 10 degrees Celsius)*; medium *(from 10 to 20 degrees Celsius)* and warm months *(above 20 degrees Celsius)*. These will function as the input scenarios for a model to analyse the current and possible future state.

For KLM specific, there are several processes that are conducted on Schiphol Airport. These processes can be seen as subsystems, multiple subsystems in subsequent order form an operational path. Together a total of 9 operational paths are conducted over the tarmac, which is the asphalt ground between the unloading area of the aircraft and the warehouse where the cargo is stored. One of the paths is listed as *other*, having over thirty shattered destinations and concerning only a small percentage of all operations. A modal split indicates in what percentage each operation occurs, where a cargo split is applied to take into account the occurrence of different types of cargo.

The performance of the tarmac operations within the cool chain have not been analysed before and therefore this research can be used as benchmark. It shows the exposure of each type of cargo during different seasons and subsystems, quantified in Degree-Hours. The accumulation of the mean values delivered an performance per process step in general, valued as exposure in Degree-Hours. The accumulation of different process steps form the operational paths, using the mean values of each step to create a mean performance per path.

Each scenario is run by one of the ten model configurations, indicating a protection improvement by using animal dollies, thermal blankets, cool dollies or a cool reefer. The final six configurations are regarding ground handling improvements, by decreasing the queue time of the ULD's at the ramp or at the warehouse, with 10, 25 and 50 %. The four protection configurations have a insulation value K that is determined with support of the insulation value R of the corresponding material. The K-values for an animal dolly, thermal blanket and the cool dolly plus cool reefer are respectively 0.7, 0.3, 0 and 0.

The costs that are linked to each configuration are determined with help of literature and expert calls. The cost for the dollies require a large investment and offer a lifespan of 15 years, where the cost for a thermal blanket depends on one-use only. Investing in protective dolly also requires further study into the storage of the dollies at KLM grounds. Costs to decrease the queue times are linked to the deployment of one, two or three extra employees per shift.

The exposure to ambient temperature can be decreased by improving ground handling manoeuvres or by applying protection methods to the transportation of ULD's. The results with the cost-performance overview show that on the short term, the animal dolly is a feasible solution to validate the assumed insulation factor and requires a relative low investment, where the cool dolly shows more potential for the long-term period.

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# List of definitions

**AFKL** Air France KLM
**AMT** Arithmetic Mean Temperature
**AWB** AirWay Bill
**BPI** Business and Process Improvement
**COL** Cooled storage
**CRT** Controlled Room Temperature
**DH** Degree Hours
**DSA** Delft Systems Approach
**ERT** Extended Room Temperature
**GDP** Good Distribution Practices
**IATA** International Air Transport Association
**ICH** International Council of Harmonisation of Technical Requirements for Pharmaceuticals for Human Use
**KC01** Koelcel 01
**KLM** Koninklijke Luchtvaart Maatschappij
**KN** Kuehne+Nagel
**KNMI** Koninkljke Nederlands Meteorologisch Instituut
**KPI** Key Performance Indicator
**MKT** Mean Kinetic Temperature
**PCHS** Pallet and Container Handling System
**PM** Performance Management
**SHC** Special Handling Code
**ToR** Time out of Refrigeration
**ULD** Unit Load Device
**VG6** Vrachtgebouw 6, Freight building 6
**WHO** World Health Organisation

# 1

# Introduction

This chapter introduces this research, conducted for KLM Cargo. It describes the field of research, research problem, research objective and the research design method. Next, it introduces the main research question, supported by corresponding sub-research questions.

## 1.1. Research context

Air cargo connects the world. It plays a crucial role in the air transport chain and in the globalised economy. Without air shipments, global supply chains would be unable to function and it would limit the availability of certain products. Time- and temperature-sensitive products, such as flowers, food and pharmaceuticals require quick transport that can be achieved by air transport.

During the past three decades, air cargo has gained importance for airlines, forwarders, shippers, airports and the economy in general. In 2017, airlines transported 53.9 million metric tons of goods, representing about 35 percent of global trade by value, according to the International Air Transport Association [9]. This is equivalent to 5.6 trillion dollars worth of goods annually, or 15.3 billion dollars worth of goods daily. At Air France-KLM-Martinair Cargo, 29 percent of the tons moved were temperature sensitive in 2017, accounting for 514 million euros in revenues [20]. The generation of such revenues, plus the importance of transferring certain goods result in air cargo to be considered as imperative to many facets of the twenty-first century.

The transport of perishable goods from one side of the world to the other would not be possible without transportation through air. The same counts for the pharmaceutical industry, which relies on air transport for its speed and efficiency in the transportation of medicines. These medicines, particularly vaccines, are regarded as high-value, time- and temperature-sensitive cargo and thus require good care during transport. Pharmaceutical cargo requires that every step in both the storage as in the transport chain is strictly regulated and controlled in terms of process and temperature control. This requirement is stated by regulations that are determined by the European Commission, also known as *Good Distribution Practices* (GDP) [5].

The transport of temperature-sensitive cargo is an exercise that requires dedication of airlines. They have to invest in large refrigerators or cooled areas in every mode of transport that is active in the cool chain in order to protect the cargo from the ambient temperature. Even after certain investments, there are still sections in the supply chain where the cargo is not protected against ambient temperature. This research will focus on actions that can be taken to fill these voids and protect the cargo.

## 1.2. Research field

This research is conducted for the company Air France-KLM-Martinair Cargo, from now on called KLM Cargo. To define the scope for this report, it is necessary to define the position of KLM Cargo within the Air France-KLM (AFKL) group: AFKL is a joint venture between Air France and KLM. This merger resulted in AFKL being one of the biggest airlines in the world.

The company's core business is to transport passengers and cargo through the air to destinations around the globe. Its cargo business department is Air France-KLM-Martinair Cargo (AFKLMP Cargo), which consists of the cargo divisions of Air France, KLM, and the former cargo business of Martinair. Besides cooperating as a group, both Air France and KLM still operate as individual airlines. Within KLM, the airline operates in three main divisions: Cargo, Engineering & Maintenance and Passenger Operations. Figure 1.1 provides an overview of the company structure and the position of both AFKLMP Cargo and KLM Cargo in it.

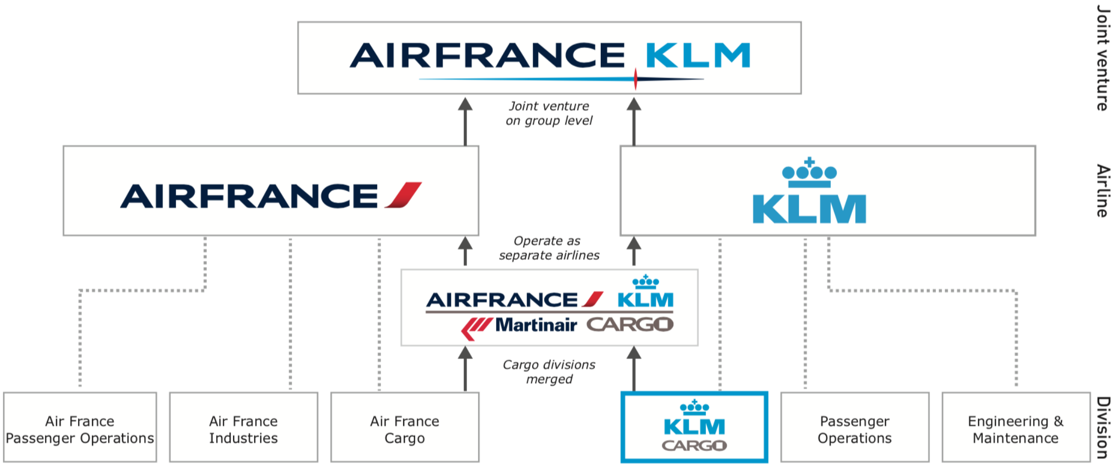


Figure 1.1: Company structure Air France - KLM [2]

KLM Cargo's main customers are the owners of the cargo (*shippers*), agents handling the transport for those shippers (*forwarders*) and recipients of the cargo (*consignees*). These actors together create the cargo supply chain. Transporting cargo from the cargo's origin airport to its destination airport is the main activity that KLM conducts for these customers. The company does this by using cargo capacity in the cargo hold of a passenger aircraft or by employing a dedicated freighter aircraft.

Within KLM Cargo, there are several divisions with divergent purposes. This research is executed for the department Business and Process Improvement (BPI), which fixates on improving current transportation processes. One of the active programs at BPI is the Cool Chain Program. This program focuses on improving the transport of cargo that has to be moved and stored under certain climate circumstances. The transportation of this cargo is executed at the tarmac, which is the asphalt ground between the unloading area of the aircraft, called apron, and the warehouse where the cargo is stored.

## 1.3. Problem definition and research scope

This research focuses on controlling and managing the cool chain of KLM Cargo, zooming in on the tarmac process. The tarmac process covers the cargo that is unloaded outside an aircraft until it is stored in the Pallet and Container Handling System (PCHS), an area in the outer edge of the warehouse. This is the starting point of the warehouse processes that lie outside the scope of this research. Some cargo contain solely cooled goods and they skip the PCHS but go straight into a cool room called KC01. These operations together belong to the inbound process, the outbound process has the same working principle: transporting the cargo from the PCHS to outside an aircraft, ready to be loaded inside the unit. Figure 1.2 gives an impression of the operations on the tarmac.

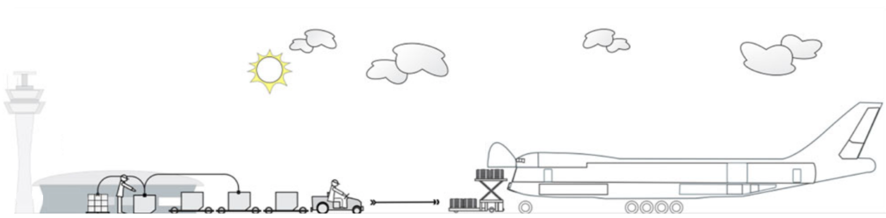

Figure 1.2: Tarmac operations [13]

KLM Cargo handles different types of cargo under various climate circumstances. The main types of cargo can be categorised as General, Fresh and Pharma. The general cargo is not temperature-sensitive and will be left outside the scope of this research. Fresh cargo can be distinguished as perishable goods, such as flowers, vegetables, fruits, seafood and meat [14]. The second type of cargo is called Pharma and comprehends all the pharmaceutic goods. Pharmaceutic companies often demand transparency of airlines regarding the cargo temperature, this is because the products are sensitive to temperature variations [15]. If the temperature of a medicine drops below zero, the composition of the compound could be disrupted and the product could change from live-saving to a life-threatening medicine.

Because pharmaceutics ought to be transparent to their customers regarding the temperature of the cargo, all relevant data of their cargo is recorded by data loggers during the transport process. Figure 1.3 shows the temperature versus the time of a data logger that is applied at a cooled cargo Unit Load Device (ULD). The data logger starts at the unloading point, where it was in the correct temperature. It shows that in the warehouse the cargo is also in a sufficient range of temperature. However, the peak in the temperature of the cargo is seen during the tarmac process, which indicates that in this step of the chain the cargo is not under the climate circumstances that it should be.

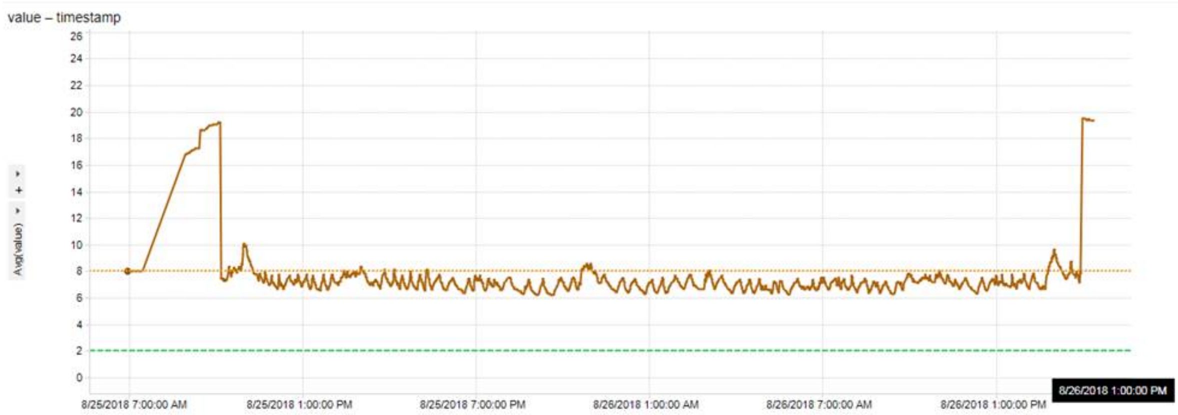


Figure 1.3: Data logger cool chain cargo [13]

The Fresh cargo also encounters these temperature fluctuations. After the consignees receive the cargo, a surveyor can be used to determine the quality of the cargo. The surveyor is able to conclude that the cargo has decreased in quality, this quality being defined as deterioration as a result of exposure to ambient temperature.

The scope of this research is to gain insight in the tarmac process regarding handling time and the effect of ambient temperatures i.e. the exposure time. This tarmac process is part of the supply chain that handles temperature-sensitive goods, which at KLM Cargo is defined as the cool chain. This research will create a model to analyse the performance of the current tarmac process. With help of this model, possible alternations will be simulated to show possible improvements can increase the protection of the cargo against ambient temperature exposure.

## 1.4. Research objective

This research will focus on the development of a model to analyse the current tarmac process within the cool chain. Data provided by KLM Cargo will be used to run and test this model. Based on the research problem and scope, the research objective is defined as follows:

*Design a model to analyse the tarmac process of the cool chain, with as significant parameters the process times and temperature difference between ambient and cargo. With this model, the effect of design alternatives will show if the system performance can be improved.*

## 1.5. Research questions

Based on the research objective, as defined and clarified in section 1.4, a research question is formulated:

*How can the performance of the tarmac process within the cool chain be analysed and how can this performance be improved?*

This main research question is supported by multiple sub-research questions. The sub-research questions are based on the methodology and literature research and are formulated as follows:

1. What characteristics can be identified that relate to the transport of temperature-sensitive cargo?
2. What operations are present in the transportation of temperature-sensitive cargo and how can the performance of these processes be measured?
3. What are the current processes at the tarmac within the cool chain at KLM Cargo?
4. Which operations at KLM Cargo show room for improvement and how can this improvement be realised?
5. How can a model be used to analyse the performance of the tarmac process within the cool chain?
6. What is the performance of the current system and which processes can be improved?
7. How can an experimental design be used to quantify the performance improvement?

## 1.6. Research methodology

Starting a research, one determines an methodology on how to conduct the research. A methodology offers an systematic, theoretical analysis of methods that can be applied to a field of study. This section will explain the deeper approach that is used to analyse the system.

### 1.6.1. Delft Systems Approach

The methodology that is applied for this research is called the Delft Systems Approach (DSA), an approach by Veeke et al. [32]. The objective of this approach is to fulfil certain functions in its environment. The approach is used to describe and analyse the input/output system.

It is used to describe the transportation system of the ULD's, by creating smaller subsystems and connecting these with one another. DSA is used because it follows a blackbox approach and it lies a suitable basis for simulations. By transforming input into output, requirements are being fulfilled to some extent, which is expressed by the performance. The requirements and performance are related to the objective of the function. The blackbox approach is shown in figure 1.4.

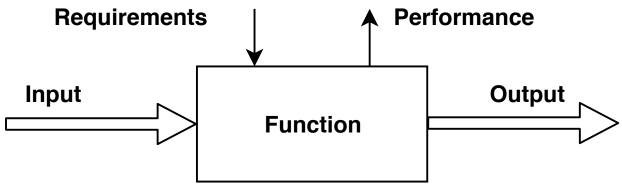


Figure 1.4: Blackbox approach, adapted by Veeke et al. [32]

### 1.6.2. Discrete event analytical model

To study the effects of the different handling strategies regarding temperature-sensitive cargo, the system itself needs to be studied as well. Figure 1.5 shows a road map that functions as decision-support whether a simulation or analytical model should be created to form the research [17].

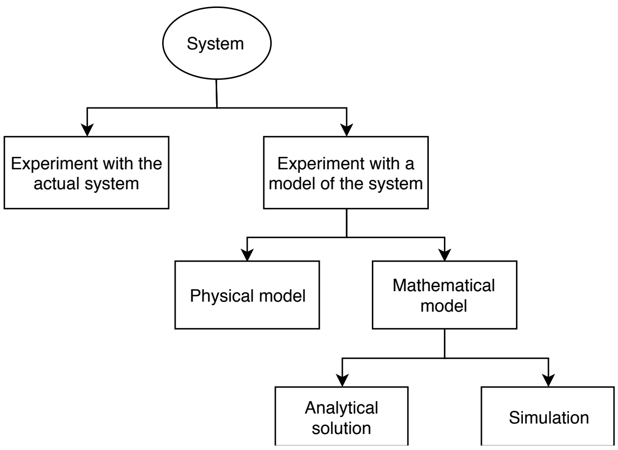


Figure 1.5: Ways to study a system, adapted by Law and Kelton [17]

A system may be studied in various ways, the first decision that has to be made is; can an experiment be done with the actual system or with a model of the system. Experimenting with the actual system comes with high costs and complexity, therefore a model of the system is used to experiment. To create a physical model would be be too complex and it would be not feasible to imitate all entities that are involved, therefore a mathematical model is chosen to pursue.

Finally, the model will describe discrete events that find place on the tarmac. Certain assumptions will be made that will ensure that the main focus of this research lies on the decrease of exposure of temperature-sensitive cargo. As a result of the assumptions, the mathematical model shows a level of simplicity that it can be resolved via an analytical solution and that a simulation is not necessary.

### 1.6.3. Data analysis software

The programming tools that were used for the construction of the models are Microsoft Excel and MATLAB. Excel is user-friendly and can be reviewed systematically, however it has less capability regarding large computations. The benefits of MATLAB are its easy implementation of probabilistic calculations and solid structure. Another reason to use MATLAB is the capacity to solve a large amount of mathematical problems. Excel is used to organise and order the big data set into smaller data sets, one for each subsystem. Matlab is used for the overall model in which the performance is calculated.

### 1.6.4. Research approach

This research commences with chapter 2: a literature study, to define the research context and to generate a framework that supports the research. The literature review answers the first and second sub-question, showing all the characteristics that are engaged within the selected case and define the operations that correspond to the tarmac process. It also shows existing methods to improve parts of the operations. Chapter 3 presents the current processes that are conducted at KLM Cargo. Next, a system analysis elaborates on the data that is linked to the current processes. The fifth chapter presents the model that is used to quantify the performance of the system. Chapter 6 consists of the data analysis that represents the performance of each subsystem and of the whole system. It includes an amount of subsequent operations that are conducted often to create a weight factor for each sequence. Chapter 7 forms an experimental design to show the performance improvement when looking at not a single shipment but during a single day with multiple shipments. Different scenario's will be run through multiple configurations, resulting in a complete overview of the system performance under various circumstances. Chapter 8 will evaluate the results, where chapter 9 concludes and presents recommendations. Table 1.1 summarises the outline of the research.

Table 1.1: Research outline

| Chapter | | Goal | Sub question |
|---|---|---|---|
| 1 | Introduction | Problem scope and research methodology | |
| 2 | Literature study | General operations description | 1, 2 |
| 3 | Current processes at KLM Cargo | Operations at KM Cargo | 3 |
| 4 | System analysis | Available information about current processes | 4 |
| 5 | Model design | Tool description for data analysis | 5 |
| 6 | Data analysis | Measuring performance with model | 6 |
| 7 | Experimental design | Setup of model scenario's and configurations | 7 |
| 8 | Results and evaluation | Comparison of results with data analysis | |
| 9 | Conclusion and recommendations | Conclude and recommend for future research | |

# 2
# Literature study

This research focuses on the transport process on the tarmac, transporting temperature-sensitive cargo whilst being exposed to ambient temperature and corresponding climate factors. This chapter will present a literature study on the topic to gain more insight in separate elements. Previous researches conducted by graduate students from the TU Delft will be taken into account. The general processes at an air cargo supply chain will be discussed, followed by relevant theories to measure system performances. This will include the characteristics of the processed cargo, as the climate elements that it is exposed to.

The following sub-research questions will be answered in this chapter:

1. What characteristics can be identified that relate to the transport of temperature-sensitive cargo?
2. What operations are present in the transportation of temperature-sensitive cargo and how can the performance of these processes be measured?

## 2.1. Previous research

Several researches have been conducted at KLM Cargo. Previous research regarding the cool supply chain is conducted by S. Vunderink (2019), B. Verhees (2018) and F.C.T. van der Voort (2016). S. Vunderink focused designing the optimal airside for temperature sensitive cargo on Schiphol, which is in line with this research [36]. The research comprehended a more global view on the case with as objective to look into the exposure times of temperature sensitive shipments. The research analysed the feasibility of limiting this exposure time to a maximum of thirty minutes. In order to achieve this, the research focused on which factors determine the exposure of temperature sensitive shipments and which cost-efficient measures were possible in order to reduce this exposure time.

B. Verhees focused on the design of the future state of the cool chain. This meant mainly to design a vision for the floriculture supply chain and to create a 'Time for Quality' concept for the cool chain [33]. The useful part of the research regards the boundary objects of three quality indicators: degree hours, exposure time and vase-life of flowers. These indicators are used to stimulate the discussion regarding the quality and the objective of the cool chain. Exposure time, ambient temperature and time spend in the temperature fitted best in the research conducted by Verhees and these indicators will return in this research.

F. van der Voort focused on the redesign of the cool chain for air transport of perishable goods [35]. Perishable goods being roses, in this research. Where Vunderink focuses on the time perspective of each step and where Verhees focuses on trends within the industry that resulted in a future design, van der Voort applied a more theoretical approach to analyse the current processes and how to improve this. The research contains overlapping performance indicators with former studies which can be of use within this research.

Previous researches were all focused on a wider scope, relating to the chain as a whole. Former studies did not distinguish the differences of various transport components on the tarmac, but regarded it as once piece of the chain. The main gap in the literature that this research will fill is concerning the transport processes that has to regard both the ambient temperature as the temperature of the cargo. Along with the time that the cargo it is exposed to the ambient temperature makes it a case with more than two variables and therefore challenging.

Table 2.1: Relevant literature on temperature sensitive supply chain

| References | Description |
|---|---|
| Sykes [29] | Supply chain challenges and solutions of time- and temperature-controlled transport |
| Verhees [33] | Design the future supply chain for floriculture, creating a 'time for quality' concept |
| Voort [35] | How to qualify the performance of the perishable supply chain |
| Vunderink [36] | Optimisation of the airside for temperature sensitive cargo |
| Ziehr [37] | WHO Guidance for storage and transport of time- and temperature-sensitive pharmaceutical products |
| Ostace et al. [25] | Heat transfer at cargo |

## 2.2. Cargo characteristics

The nature of cargo can differ per shipment, and for these different nature there are different handling procedures that need to be applied. Besides general cargo, this type of cargo is distinguished as special cargo by the International Air Transport Association (IATA) [10]. The various natures of special cargo can be categorised as follows:

- Dangerous goods
- Live animals
- Perishables
- Time and temperature sensitive healthcare
- Human remains
- Valuable cargo
- Outside and heavy cargo
- Fragile cargo

This research will solely focus on the cargo that is listed as perishables and time and temperature sensitive healthcare. The time and temperature sensitive healthcare cargo can also be called pharmaceuticals and this is how it will be called further in this report.

The transport of pharmaceuticals and perishables continues to increase globally on a yearly basis in line with a consumer demand that is growing. This growth is a result of the demand for healthy, fresh and medicinal produce all year round, irrespective of seasonality [8]. The most important aspect of air transportation of these goods are time and temperature management. This management needs to be supported by appropriate handling process and packaging methods to ensure food safety, health restrictions and other requirements. This section will describe the aspects that come into play for the general shipment of these temperature-sensitive goods.

### Parmaceuticals

Many pharmaceutical products are stored and shipped at improper temperatures, or the goods are delayed for such a duration that they reach their destinations past their shelf lives [29]. These kind of events can result in drugs not only being ineffective, but harmful and in some cases even life-threatening for people that are in need. These events are not conducted by pharmaceutical companies on purpose; even if they maintain good distribution practices, the goods can be affected. This is a result of the supply chain's complexity of environments, from manufacturer to hospital. Different modes of transport and multiple handling moments leave room for human error that is hard to exclude. Pharmaceutical products can be divided into different categories:

- Drug products
- Biological products
- Medical devices
- Homeopathic remedies
- Herbal products

### Perishables

In a cool chain, the shelf life, quality and safety of perishable foods through the chain is mainly affected by environmental influences. The main factor is ambient temperature, if the temperature of a perishable good exceeds a certain limit, this can lead to a decrease of quality [1].

The transportation of perishables differs per commodity that is shipped. Temperature is the characteristic of the post-harvest environment that has the most impact on the shelf-life of fruits and vegetables. Proper temperature management is required to delay the deterioration of the products. If perishable products are stored in a low temperature, the shelf life is longer but for some produce, from tropical origins especially, too low temperatures can result in chilling injuries. Perishable cargo can be defined as follows:

- Fruits and vegetables
- Fresh vegetables, cut fruits and herbs
- Plants and (tropical) flowers
- Meat and meat products
- Seafood
- Dairy products
- Baked goods
- Frozen food

Table 2.2: Relevant literature on cargo and ground operations at airport

| **References** | **Description** |
| --- | --- |
| IATA [8] | Ground operations manual |
| IATA Perishable Cargo Regulations [10] | General procedures for perishables cargo |
| IATA Temperature Control Regulations [11] | General procedures for pharmaceutical cargo |

### 2.2.1. ULD characteristics

Cargo can be shipped in any way and the volume or dimensions of the shipped goods are barely restricted. Most of the cargo is shipped on a ULD, being a container or a pallet. The dimensions of cargo is also dependent on the sort of product that is shipped. Loose cargo can be shipped separately from other goods, and live animals require to be shipped with a certain amount of space and breathable air in contrast to e.g. computer parts.

The type of ULD that is used will affect the level of temperature control achievable. Pallets or containers with transparent protection should not be used at any time. The greenhouse effect that is encountered with these types will jeopardise perishable loads in a matter of hours. In the case of regular aluminium ULD's, the lack of protection against outside temperatures makes them poor as well. Research has stated that when the outside temperature is 30 °C, the walls of an aluminium container will reach the same temperature in a few minutes. Most containers offer a decent physical protection to the load. Temperature-sensitive cargo packagings in most circumstances are stack-able types; used for fruits, or a box type. The box type can have ventilation openings, these are often used for flowers or fish [10].

Different types of ULD's are used in general air cargo transport. From a regular one, that consists of a flat panel with a smooth aluminium core surface, to an insulated ULD. These are made of insulating materials, with a tendency to thermally protect a load from changing temperature during distribution. Pallets with insulated blankets are also regarded within this category. The passive container type has as goal to keep the temperature of the shipment within a required temperature range. Besides that, there are a few active containers that are capable of keeping the inside at a set temperature, which is a highly recommended way of transported temperature-sensitive goods.

To categorise the standard types of cargo that are loaded on a flight, the following three can be distinguished: lower, main and upper deck cargo. The use of one type depends on the type of aircraft and the amount of cargo that is taken aboard. A lower deck often has diagonal sides, so it can be placed on the outer sides of the cargo belly.

### 2.2.2. Temperature control

Temperature requirements on the AirWay Bill (AWB), a document that is used to communicate the characteristics of the shipment from origin to destination, are an indication for the carrier that a shipment is sensitive to temperature and should be processed with care. This is not a guarantee that the carrier will maintain this temperature through the whole chain, whereas some steps in the chain are limited in temperature control.

During the flight, the temperature of cargo holds can be maintained at a certain level, however, this will vary between different types of aircrafts. There are a few specific characteristics that define the transport requirements for temperature-sensitive goods. In general, there are four common temperature ranges available for booking, as stated in table 2.3. The left column will indicate the Special Handling Code (SHC) as determined by IATA, where the right column will show the temperature range the shipment is required to abide by. Airlines are able to offer different processes in order to support the temperature ranges, this can depend on local infrastructure and capabilities.

Table 2.3: Special Handling Codes by IATA

| **Existing IATA Special Handling Codes** | **Related Temperature Ranges** |
|---|---|
| Cooled storage: COL | 2 °C to 8 °C |
| Extended Room Temperature: ERT | 2 °C to 25 °C |
| Controlled Room Temperature: CRT | 15 °C to 15 °C |
| Frozen storage: FRO | Keep frozen |

## 2.3. Climate characteristics

External climatic conditions have a decisive impact upon the climatic conditions of the ULD and inside the containers. These conditions are determined by the transport route, season and time of the day and the current weather (rain, sunlight, cloudiness). Due to the diversity of these factors, the prediction of the climate change inside the ULD is complex. This section will discuss the general influence of the climate that affects the quality of temperature-sensitive cargo. A closer look will be given of the ambient temperature. Next, weather elements like solar radiation and wind speed will be discussed as factors that the cargo is exposed to.

### 2.3.1. Weather

The weather has a significant effect on temperature changes inside a load, perishable or pharmaceutical. Solar radiation can have a major impact on the loads, just as the wind speed and cloudiness. Even when containers are exposed in the ambient temperature during a cloudy day, the solar radiation still exchanges heat by solar radiation. For this reason, ULD's should be protected from the sun as much as possible.

When waiting on the tarmac to be loaded on aircraft or into the warehouse, ULD's are exposed to prevailing environmental conditions. The ULD's become sensitive to heat gain or loss due to this exposure. Villeneuve of the Air Cargo Transportation Research Group has studied temperature evolution in closed ULD's during airport operations [34]. Within this research, he has taken into account all elements that are of influence in the heat gain and loss of a ULD. Elements that are of influence are:

- Solar radiation
  - Beam and diffuse radiation
  - Geographical latitude and longitude
  - Solar hour angle
  - Solar declination
  - Sky point of cloudiness
- Exposure time
- Outside temperature
- Wall orientation
- Optical and thermal properties of ULD material
- Wind speed and direction

### 2.3.2. Ambient temperature

The most important factor for preserving the quality of pharmaceuticals and perishables. Distributing goods around the world exposes goods to extreme temperatures. The combination of time and temperature will determine the gravity of the damage to the products.

For many perishables, low temperature causes most damages. Many products cannot recover once exposed to negative temperatures. The time of being frozen is not the main thing that matter, but moreover the affection by frost bite or being completely frozen. The influence of cold can originate from several external sources but from only a few as a result of climate characteristics. Prior or after the flight, cold can come from the exposure to the environment (wind and cold temperature). During the flight, the temperature can vary depending of the type of aircraft heating and cooling systems, as the location in the cargo nearby the door can also be a source of cold by the low temperature up in the sky.

Extreme heat can cause damage as well. In this case, time of exposure to high temperature is of greater importance than the temperature itself. The consequences of exposure to extreme temperatures can cause loss of quality in the form of firmness, loss in weight or even turn a life-saving medicines into a threat for human life. Products as fresh fruits and vegetables produce heat naturally during their post-harvest lives. Other type of perishables, like flowers, only warm up during transportation as a result of exposure to external heat sources. This is the reason that often a coolant is added inside the package, to intercept heat that passes through it. Like cold; heat can originate from external sources outside the flight, such as: field heat, non-refrigerated truck or airport facility and exposure to the environment. During flight, the temperature is dependant of the presence of an air-conditioning in the aircraft before the engine is running. Here also, the temperature can be dependant on the location in the cargo hold [8].

If the transit area for ULD's is not fully temperature controlled, it should as a minimum provide the load with a proper protection against ambient weather conditions. Well-packed loads, mostly from pharmaceuticals, are less likely to deteriorate rapidly when in a controlled environment. The most critical path is between the transit area and the aircraft, where exposure to weather conditions can expedite the deterioration of the goods.

The exposure to ambient temperature takes a different value depending on the season. Taking the meteorological season definitions, table 2.4 will show the season, the corresponding months and average temperature from 2018 based on historical data [16]. It also shows the median, minimum and maximum values during the month, showing outliers that affect the cargo extremely, for example the minus 8 degrees that definitely devalues pharmaceutical cargo. Figure 2.1 presents the COL and CRT temperature ranges in the temperature data of 2018, showing when possible excursions are occurring [7]. The ERT shipments share the lower and upper bound of the COL and CRT shipments, experiencing significantly less exposure.

Table 2.4: Meteorological seasons in degrees Celsius [16]

| Season | Months | Average | Median | Minimum | Maximum |
|---|---|---|---|---|---|
| Winter | December | 6.7 | 7 | -1 | 14 |
| | January | 5.6 | 6 | -1 | 14 |
| | February | 1.1 | 1 | -8 | 10 |
| Spring | March | 4.7 | 5 | -8 | 15 |
| | April | 12 | 11 | 1 | 27 |
| | May | 16.4 | 17 | 4 | 29 |
| Summer | June | 17.2 | 17 | 9 | 28 |
| | July | 20.6 | 21 | 10 | 35 |
| | August | 18.7 | 18 | 8 | 33 |
| Fall | September | 15.2 | 16 | 4 | 24 |
| | October | 12.5 | 13 | 3 | 26 |
| | November | 7 | 7 | 0 | 19 |

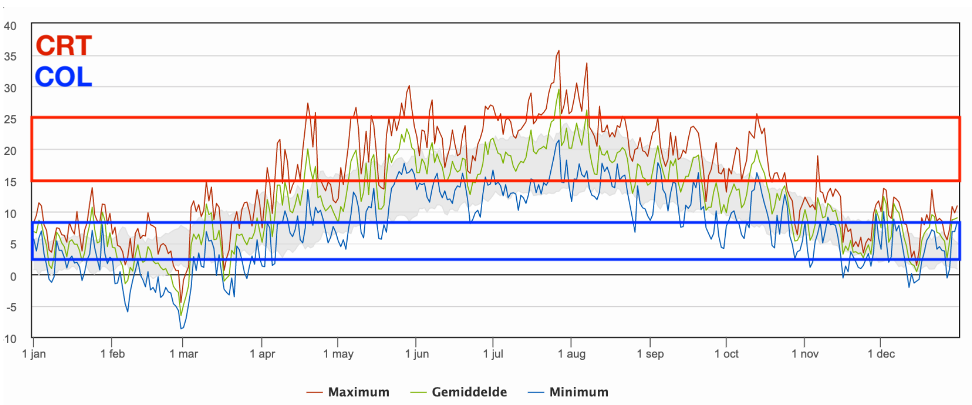


Figure 2.1: Ambient temperature in 2018 [7]

## 2.4. Cargo and ground operations

Carriers, airport operators and air cargo terminals alike deal with a variety of arrival and departure schedules, irregular volumes of cargo, different cargo service classes. In addition, many different types of handling units are active in the operational work that is conducted. The freight itself may be containerised or loose. These factors create important planning challenges for the scheduling and processing of freight handling employees at air cargo terminals [8].

Perishables are expected to be delivered to the cargo terminal during the time frame that is agreed upfront in order to allow sufficient time for acceptance (which can include passing a security scan), the build-up of a ULD, load planning and aircraft weight and balancing activities. These activities all take place prior to the flight. Due to the importance of environmental conditions on the quality of the perishables, handling techniques at airports have to be well planned. A proper flow of the goods is required within every load and unload cycle, being well coordinated and executed.

Air cargo transport involves a series of services from origins to destination, accumulating to serve the goal of moving cargo. Chapter one mentioned the stakeholders that are active within the cargo supply chain, these are represented in figure 2.3. The shipper is in need of the commodity to be sent anywhere at a low cost and at the required service level. The forwarder acts between the shipper and the airlines. The road transporter provides the ground transportation services prior and after air transport. The airline receives, stores, transfers, tracks, loads and unloads the cargo. These actions take place on the ramp, on the air side lanes outside the warehouse and inside the warehouse. The airline also assigns and manages the capacity of both the aircrafts as the ground control and the warehouses. The consignee receives the shipment. The following subsections will comprehend the whole transportation chain from aircraft until warehouse and vice versa.


Figure 2.2: Stakeholders cargo supply chain [33]

### 2.4.1. Inbound processes

At first, the general processes will be described that are executed by inbound cargo. Figure 2.2 shows a design of the process in the form of a Swimlane diagram. All boxes that are present in the diagram can be seen as black boxes with the input and output being a ULD. These processes don't comprehend queuing steps, for there is no regulation but that it has to be transported as quick as possible or be stored into a temperature controlled area.

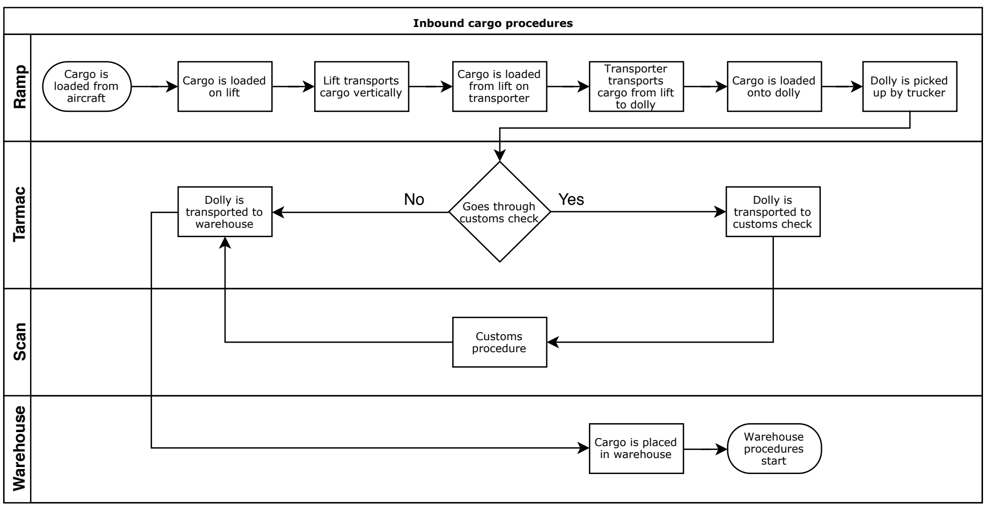


Figure 2.3: General inbound cargo processes

### Unloading from aircraft

The unloading of temperature-sensitive goods is ought to begin the minute the aircraft is landed and standing still on the ramp. Therefore, ground personnel is required to be at the ramp prior to arrival and prepared to unload shipments from the cargo hold. If necessary, the cargo hold should stay closed until the ground personnel and equipment is present. In general, the unloading of an aircraft usually requires less time than loading cargo, this stage of the process represents less of a risk to the load. Problems can still occur if procedures are not followed and therefore goods can still be damaged.

### Transfer aircraft to warehouse

The transport from the ramp location to the warehouse should begin as soon as possible. This to ensure that the shipments are less exposed to extreme temperatures or other weather conditions that could be harmful for the goods. During this transport, temperature-sensitive goods must be given the highest priority possible. The goods are required to move into a dedicated storage facility as soon as possible.

### Inbound customs clearance

Air cargo that comes from international borders has the chance that it has to be checked extra for security reasons. In this case, it must be cleared in the destination country prior to being delivered to the consignee. All cargo that is temperature-sensitive requires to have special instructions noted on the AWB so the customs clearance knows how to deal with the cargo.

### Storage

Temperature-sensitive shipments are required to be stored immediately. This should be done in the appropriate storage area as per the requirements of the perishable or pharmaceutical commodity type, regarding the temperature range as indicated on the AWB. If requested by the consignee or upon customs clearance, the shipment can also be transported to the delivery area to be picked up without going into a cooled area first.

## 2.4.2. Outbound processes

The outbound procedure follows the process description as inbound, but in the other direction as seen in figure 2.4. This procedure also has the restriction that all transport should be conducted quickly and that if a shipment requires storage at a moment, it should be in a temperature controlled area or the queue time should be as low as possible.

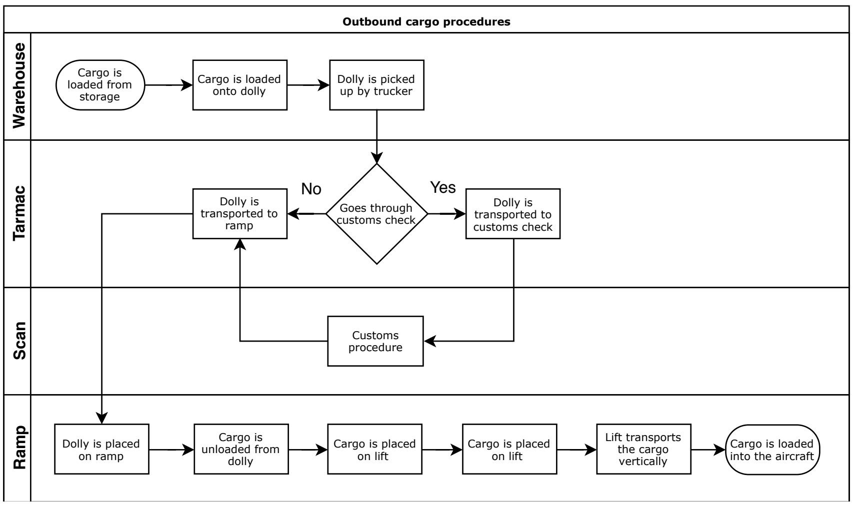


Figure 2.4: General outbound cargo processes

### Storage

For most ULD's, the procedure prior to loading consists of keeping the container as long as possible in an appropriate room that has the required temperature, or for a short time in a shaded area. IATA states that the storage in a shaded area should not take longer than two hours. IATA also states that temperature sensitive goods should stay in a temperature controlled area until three hours prior to the flight.

#### Transfer warehouse to ramp

Carriers are required to provide a process for transport between the warehouse and the aircraft that focuses on the minimisation of product exposure to temperatures that are beyond the allowable range. Special care should be taken to avoid long exposure to extreme ambient temperature, be it colder or warmer. This can be done by expedited running processes with dedicated freight runners, with expedited runners coinciding with products of the same sensitivity or by movement in insulated ULD carriers or, when available, cool dollies. Other options are the application of thermal/heat reflective blankets or processes that allow a 'last out first in' principle.

#### Loading onto aircraft

The loading of cargo that is temperature-sensitive should commence as soon as possible after the placement on the ramp. The packaging that is covering the ULD is designed to protect for a brief moment to exposure, all effors should be made by the ground personnel to load units quickly.

### 2.4.3. Resources

The manual labour that is conducted within the cargo transportation process can be distinguished in different roles. All ramp employees fulfil different processes and are often dependent on one another. Each role encounters different requirements of information that is needed to execute the work. Roles concerning monitoring and controlling are outside the scope of this report. The amount of labour capacity, i.e. the drivers transporting the cargo, is taken into account for this group of employees have a direct influence on the exposure time of the cargo.

The main impact of the resources are the availability of the equipment, the amount of drivers controlling the equipment and the speed of the vehicles. A maximum velocity restriction on the airport limits the possibility to decrease the transportation time to a certain extent.

## 2.5. Process performance

This section will describe how the performance of the transportation process is presented and which elements are important in defining the quality management of the cool chain.

### 2.5.1. Quality management

This research aims to protect cargo in the cool chain for exposure to ambient temperature, in order to maintain the quality of the goods that the cargo contains. All parties involved in the transport must ensure that a quality product is supplied to the consignee. What follows are the steps within the cool chain where extra care should be taken for a proper transportation of the goods.

- Transportation to airport
- Airport reception
- Airport storage
- Ground operations
- Loading operations

The ground and loading operations are the two steps that are relevant when looking at the transport between warehouse and aircraft. Both steps are affected by environmental conditions as temperature and weather. The dependence of time and employee training is relevant for both steps as well. Where the loading operations have to take into account the amount incompatible loads, the ground operations have to put extra care in the handling equipment regarding the utilisation and maintenance.

### 2.5.2. Relevant theories

Within the supply chain of flowers, it has been observed that a reduction in the exposure to temperatures different than is required for the flowers - measured as the average temperature of the product during transport multiplied with the number of hours exposed - has a direct effect on the lifespan of flowers. The value of temperature times hours is called 'Degree-Hours' and is used in the flower sector to indicate the vase-life [33].

Like summer weather temperatures, risks to pharmaceutical products in the supply chain are on the rise. The requirement to record temperature data has increased, especially with CRT cargo. The recorded data has revealed some alarming spikes and encourages cargo handlers to focus their mind on the need to protect the product. Literature study resulted in a list of relevant theories that are applicable in the analysis of accumulating heat transfer at cargo. Some of these are already used in the cool chain industry, as listed below. This research will focus on the most feasible to distinguish as Key Performance Indicator (KPI).

- Mean Kinetic Temperature (MKT)
- Arithmetic Mean Temperature (AMT)
- Exposure
- Time out of Refrigeration (ToR)
- Heat transfer at cargo

### Mean Kinetic Temperature

Regulatory organisations in manufacturing and distribution that deal with temperature-sensitive products are trying to create standards for cold chain monitoring. The reason for this is that organisations want to ensure the shelf life, quality and safety of cold chain products while also limiting temperature excursions. One of the challenges is to select a single reliable temperature that can be used in the testing of product viability [19].

Taking a simple average of temperature over time is not ideal. Averaged temperatures do not take into account phase change effects that may cause irreversible changes or defects in the quality of the goods. Therefore an equation has been defined that considers the expected temperature variability in a cold chain as well as the temperature excursions that can be endured without spoiling. This equation is used to show the impact of temperature variations in cold chain logistics.

The MKT has been defined by the International Council of Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) as: *"A single derived temperature that, if maintained over a defined period of time, affords the same thermal challenge to a drug substance or drug product as would be experienced over a range of both higher and lower temperatures for an equivalent defined period."*

The MKT has been identified as a potential tool for evaluating the impact of temperature on product quality over the last fifteen years [30]. Where it originally was proposed to guide studies, it is now often used for evaluating temperature excursions as part of GDP which will be discussed later. Literature also points out that the MKT is not always applicable. It is discouraged to use it for products that require controlled low temperatures and for temperatures above 25 degrees. Therefore, the CRT cargo seems like a feasible target for this measurement.

$$T_k = \frac{\frac{-\Delta H}{R}}{ln(\frac{t_1 e^{\frac{-\Delta H}{RT_1}} + t_2 e^{\frac{-\Delta H}{RT_2}} + ... + t_n e^{\frac{-\Delta H}{RT_n}}}{t_1 + t_2 + ... + t_n})} \tag{2.1}$$

$T_k = Mean\,Kinetic\,Temperature\,in\,Degrees\,Kelvin$
$\Delta H = Heat\,of\,activation\,in\,kJ\,per\,mol$
$R = Universal\,gas\,constant = 8.3144\,Joule\,per\,Degree\,Kelvin\,per\,mol$
$t_n = Time\,interval\,at\,each\,sample\,point\,in\,seconds$
$T_n = Temperature\,during\,n_t h\,measured\,point\,in\,Degrees\,Kelvin$

The values that are used in the MKT formula are shown above. It should be noted that H, the activation energy, describes the reaction rate for the degradation of the active ingredients in a drug. The default value is typically used for its accurate approximation for the most pharmaceutical compounds. This value is more difficult to use for perishable products due to differentiating values. For this research focuses on both perishable as pharmaceuticals, this KPI will not be used in the remainder of this research.

### Arithmetic Mean Temperature

The AMT has similarities with the MKT. Both KPIs are a mean temperature calculated over a defined period of time. The difference between the two is that the AMT is normally lower than the MKT, because with the MKT, higher temperatures have an exponentially higher degradation rate opposed to the AMT. The AMT would only be adequate if the degradation rate were to be linear, which is less common for this case study. Therefore, this KPI won't be utilised in the remainder of the research.

$$T_{AMT} = \frac{T_{warm_{in}} + T_{warm_{out}}}{2} - \frac{T_{cold\,in} + T_{cold\,out}}{2} \tag{2.2}$$

$T_{AMT}$ = $Arithmetic\,Mean\,Temperature\,in\,Degrees\,Kelvin$
$T_i$ = $Temperature\,in\,Degrees\,Kelvin$

However, due to the small time differences, the ambient temperature difference could be approached as a linear degradation rate and therefore it can be seen that the arithmetic mean temperature value comes back to the exposure KPI.

### Exposure in Degree-Hours

When a ULD with temperature-sensitive cargo is exposed to a given ambient temperature that is outside the range of the temperature that the AWB implies, the good will cross the temperature threshold and therefore will be at risk of damage. This ambient temperature can fluctuate widely depending upon the time of day, time of year and time spent during outside storage or transport. Temperature exposure along different steps of the cool chain can be calculated and compared with the *Degree-Hours* concept.

The exposure is calculated simply by multiplying the differences between the hourly ambient temperature and a standard reference temperature, in this research the temperature of the cargo should be suffice to the AWB. A good could be given a maximum of degree hours which it can be exposed to. The degradation of that number will thus exist of the combination of the factors temperature and time. With both high temperatures and long times, the degradation process will accelerate, opposed to low temperatures and short times.

$$E = \sum (t * T_{dif}) \tag{2.3}$$

$E$ = $Exposure\,in\,degree-hours$
$t$ = $Temperature\,recording\,interval\,in\,hours$
$T_{dif}$ = $Temperature\,difference\,in\,degrees\,Celsius\,between\,T_{awb}\,and\,T_{amb}$

Over the entire transportation process, the above mentioned equation will result in the total exposure of the temperature-sensitive product to the ambient temperature, expressed in Degree-Hours. This value can be used for comparison with the maximum degree-hour exposure that is set by a pharmaceutical or perishable company. The value can be seen similar to the MKT but less in detail.

### Time Out of Refrigeration

The ToR is the total time that a pharmaceutical product is outside of its specified temperature range. The total allowable excursion time is often determined by stability studies performed by the producer of the product. Therefore, the allowable excursion times often differ per product as each product has different molecular structures. The ToR is then compared with the allowable excursion time [3]. The ToR can be calculated for each process step a pharmaceutical goes through. From the ToR, pharmaceutical producers can establish time limits for their products [24]. Equation 2.3 shows how the ToR is determined, by taking the difference in time that the cargo is put in refrigeration and when it is taken out.

$$ToR = t_{end} - t_{start} \tag{2.4}$$

$t$ = $Time\,in\,hours$

This is an indicator that is barely used by the perishable market and therefore not taken into account in this research, for a KPI that is known in both sectors is preferred.

### Heat transfer at cargo

The Carnegie Mellon University has conducted a study case with Procter and Gamble to analyse a heat transfer model of large shipping containers Ostace et al. [25]. This study, conducted by G. S. Ostace, separated the heat transfer model in three parts: the heat transfer at the wall of the shipping container, from the wall to the inside air and at the cargo on the pallets inside the container. The case study provides a heat transfer equation for all three states, a combination of these can be used to look at the heat transfer at cargo without a container as protection.

$$M_C * Cp_C * \frac{\Delta T_C}{dt} = h_{FC} * A * (T_{air.out} - T_w) + h_{NCout} * A * (T_w - T_{air.out}) + h_{NCin} * A * (T_{air.in} - T_w) + \frac{k * A * (T - T_w)}{\Delta x} + A * \alpha_w * G_{solar} + A * \epsilon * \sigma(T_{Sky}^4 - T_w^4) \tag{2.5}$$

For the heat transfer solely on the cargo, the main equation is treated differently. The following equation is defined:

$$M_C * Cp_C * \frac{\Delta T_C}{dt} = h_{NC} * A * (T_{air} - T_C) + \frac{k_C * A * (T_{air} - T_C)}{\Delta x} \tag{2.6}$$

$M_C = Mass\, in\, kg$
$Cp_C = Specific\, heat\, Capacity\, in\, kJ/kg * K$
$T_i = Temperature\, cargo\, in\, degrees\, Kelvin$
$h_{NC} = Heat\, transfer\, coefficient\, in\, W/(M^2 * K)$
$A = Surface\, area\, in\, m^2$
$\epsilon = Emissivity\, [0,1]$
$\sigma = Stefan-Boltzmann\, constant\, [5.670e10^-8\, W/(m^2 * K^-4)$
$\Delta x = Thickness\, of\, material\, in\, m$
$k = Thermal\, conductivity\, in\, W/m * k$
$\alpha = Thermal\, diffusivity\, in\, m^2/s$

## 2.6. Conclusion literature study

The air freight processes, the importance of the cool chain and the characteristics of both the cargo as the climate it is located in are discussed in this chapter. This has been done to achieve a part of the objective of this research: gain knowledge about the elements that are involved in a proper transportation of temperature-sensitive cargo. This section contains the summary of this chapter and will answer the following sub-research questions:

*Sub-research question 1: What characteristics can be identified that relate to the transport of temperature-sensitive cargo?*

The corresponding characteristics that relate to the transport of temperature-sensitive cargo can be distinguished in a few categories:

- **Cargo type**
  The shipped cargo can be defined as various types, from live animals to dangerous goods. The temperature-sensitive cargo can be categorised under perishables and time/temperature-sensitive healthcare i.e. pharmaceuticals.
- **Temperature control**
  Temperature-sensitive cargo is defined by special handling codes, determined by IATA. These codes are COL, ERT, CRT and FRO, each indicating a different temperature range that the shipment is required to comply.
- **Climate characteristics**
  Distributing goods around the world exposes shipments to extreme weather conditions. The combination of time and temperature will determine if a shipment is affected by the ambient temperature and to what extent. This exposure will be strongly dependent on seasonality as well, for a cold shipment will be less exposed during winter and a warmer shipment has the same during spring or summer.
- **Availability of resources**
  Resources are equipped to ensure transportation of resources. With the use of truckers and transporters, ULD's are transported from the lift onto dollies and from dollies into the warehouse. The availability of these vehicles will affect the queue time of the subsystems that are present in the entire transportation process. The ramp transporters and warehouse transporters are active on the beginning and end of the process, where the truckers are active on the tarmac.

*Sub-research question 2: What operations are present in the transportation of temperature-sensitive cargo and how can the performance of these processes be measured?*

The operations that are present can be seen as either inbound or outbound shipments. The whole system can be seen as several subsystems linked to each other, the inbound and outbound system are mostly similar with equal transport and queue subsystems present and they share the present elements.

The inbound system regards the unloading of the aircraft, transporting the cargo from the ramp towards the warehouse. In certain occasions, depending on the origin of the aircraft, the cargo should pass the customs clearance first, for it may contain forbidden goods. When the warehouse is reached, the shipment will be transferred into a storage.

The outbound system goes the other way around. Temperature-sensitive shipments are unloaded from the storage and transferred outside the warehouse. From outside the warehouse, transport vehicles ensure the cargo gets delivered near the aircraft prior departure.

There are several theories that can be linked with the transportation of temperature-sensitive cargo. Part of the theories are related to the heat transfer from the environment onto the cargo, others are related to the transportation of the shipment. These are mostly influenced by the time duration that the shipment is exposed to ambient temperature.

# 3 Current processes at KLM Cargo

In the previous chapter the literature study has shown the general operations that are applicable in the air cargo sector. This chapter will specify the characteristics and conducted processes at KLM Cargo. It will comprehend the data regarding processing times and the amount of shipments that are handled at Schiphol Airport.

This chapter will answer the following sub-research question:

3. What are the current processes at the tarmac within the cool chain at KLM Cargo?

## 3.1. Cargo characteristics at KLM

At KLM Cargo, air cargo can be classified into four categories. The first product category is **dimension**, also known as general or bare cargo. This type of cargo requires minimum handling activities, and is shipped for the lowest rate compared to the other product types. Examples of general cargo are electronics and toys. This type of cargo is regarded the largest product category.

The second category is **variation**. This product category requires, next to the minimum handling activities necessary for transport, special handling activities. Within variation, three types of shipments can be distinguished: perishables, pharmaceuticals and live animals. Perishables are goods such as vegetables, fruit and flowers, and are very sensitive to damage. Temperature control is essential for these goods. Pharmaceuticals are either transported in active containers, which keep the temperature of the product constant, or in a controlled cool chain in which the trucks, storage facilities and the aircraft itself are cooled. The last category of variation shipments is live animals.

Last product categories are **equation** and **cohesion**. Equation shipments are time-sensitive, they have a high shipment priority. Examples of equation products are mail bags. Cohesion shipments are specialised products for specific industries, such as sport cars.

The cargo flow at KLM Cargo can be regarded in various ways. This distinction counts as support for the remainder of the research, to decide if a cargo variant encounters a negative effect due exposure to ambient temperature. Each type of cargo is transported in a different way and therefore should be treated differently.

This research focuses on the transportation of time and temperature sensitive goods, therefore will only focus on the cargo in the variation category. Within this category, the live animals are left out of consideration, leaving the distinction in types of cargo that remain as **pharmaceuticals and perishables**.

### 3.1.1. ULD characteristics

Dimensions of temperature-sensitive cargo is hard to standardise. These dimensions differ per type of cargo, per temperature range and still within those defined elements it can differ. Currently used combined air crafts transport both main and lower deck cargo. However, KLM is eliminating the use of these planes and this will result in transport of lower deck cargo only. Because this is a trend that is expected to be fulfilled within a few years, this research focuses on the lower deck cargo. The dimensions of the lower deck cargo can be defined as follows: 318 x 244 x 163 cm (l x b x h). The support for this decision is based on expert opinions and can be found in Appendix B.

### 3.1.2. Temperature control

Different types of temperature-sensitive products require different types of temperature. Whereas flowers tend to be kept cold, around a zero degrees Celsius, medicines can become life-threatening instead of life-saving if it drops below zero. Within KLM Cargo, the two types of cargo can be divided by three temperature ranges that are set by IATA as presented in table 3.1.

The cargo that is imported to or exported from Schiphol Airport can have different temperature ranged goods on one single ULD. Though these mixed ULD's are unfavourable, they do occur and have to be taken into account in the analysis. This resulted in assuming that a ULD only contains one temperature range. If historical data points out that a ULD is a mixed one, meaning multiple temperature ranges are present, the most unfavourable temperature will be used for the whole ULD.

The COL, CRT and ERT shipments all have a temperature range as stated in the previous chapter. Every ULD contains a SHC code distinguishing the temperature range that the cargo should be transported in. When the ambient temperature is outside this range, the cargo is exposed.

Table 3.1: Special Handling Codes at KLM Cargo

| Existing IATA SHC | Related Temperature Ranges |
|---:|---|
| COL | Both Fresh and Pharma products are present in this temperature range |
| ERT | Both Fresh and Pharma products are present in this temperature range |
| CRT | This temperature range only contains Pharma goods |

## 3.2. Climate characteristics

The influence of the climate on the transport could be dependent on seasonality, therefore the analysis will use data from all seasons. One of the concerning parameters within this research is the ambient temperature on the tarmac during the transport process. According to the World Health Organisation (WHO), the ambient temperature along this process should be sampled every 15-30 minutes [23]. The data that is obtained from Performance Management shows the temperature in degrees Celsius, measured on the tarmac on Schiphol Airport. This batch with data has a time interval of thirty minutes, which is in line with the interval prescribed by WHO.

The ambient temperature is relevant to the cargo, not the season in which the cargo is shipped. Therefore the meteorological seasons are dismissed in this report and the system is analysed based on warm, cold or medium months. Table 3.2 shows the months according to the measured average temperature in 2018. These seasons will be valued versus the overall of whole 2018. The temperature ranges are defined as these are the temperature ranges defined as cold or warm by the Koninklijk Nederlands Meteorologisch Instituut (KNMI) [7].

Table 3.2: Seasonality categories

| Season | Months | Average temperature range [Celsius] |
|---|---|---|
| COLD | January, February, March, November, December | till 10 degrees |
| MEDIUM | April, May, September, October | 10 - 20 degrees |
| WARM | June, July, August | 20+ degrees |
| OVERALL | All months | All temperatures |

## 3.3. Cargo and ground operations

The section will take the general operations from chapter 2.4 and specify these for KLM Cargo. Figure 3.1 contains an adjusted version of the Swimlane diagram of figure 2.3, adding the different destinations that incoming cargo could be appointed to. This analysis will address the inbound processes only, for the outgoing processes have the same transport and queue steps. With green dots, all the subsystems are indicated.

### 3.3.1. Process steps

The process steps concerning the transport system are described in this section, it will present the air cargo process as conducted at KLM Cargo. The difference with the general version is that the Swimlane has an extra lane for the airside lane, a parking lane outside the warehouse. If cargo is moved from the ramp to the warehouse, it is placed here by a trucker so that a transporter can later on move it into the warehouse. A trucker has the possibility to move up to five dollies in a train, where a transporter can only load/unload ULD's on dollies or into the warehouse. The other destinations are added on the tarmac, for the ULD's are transported over the tarmac and end directly at the border.

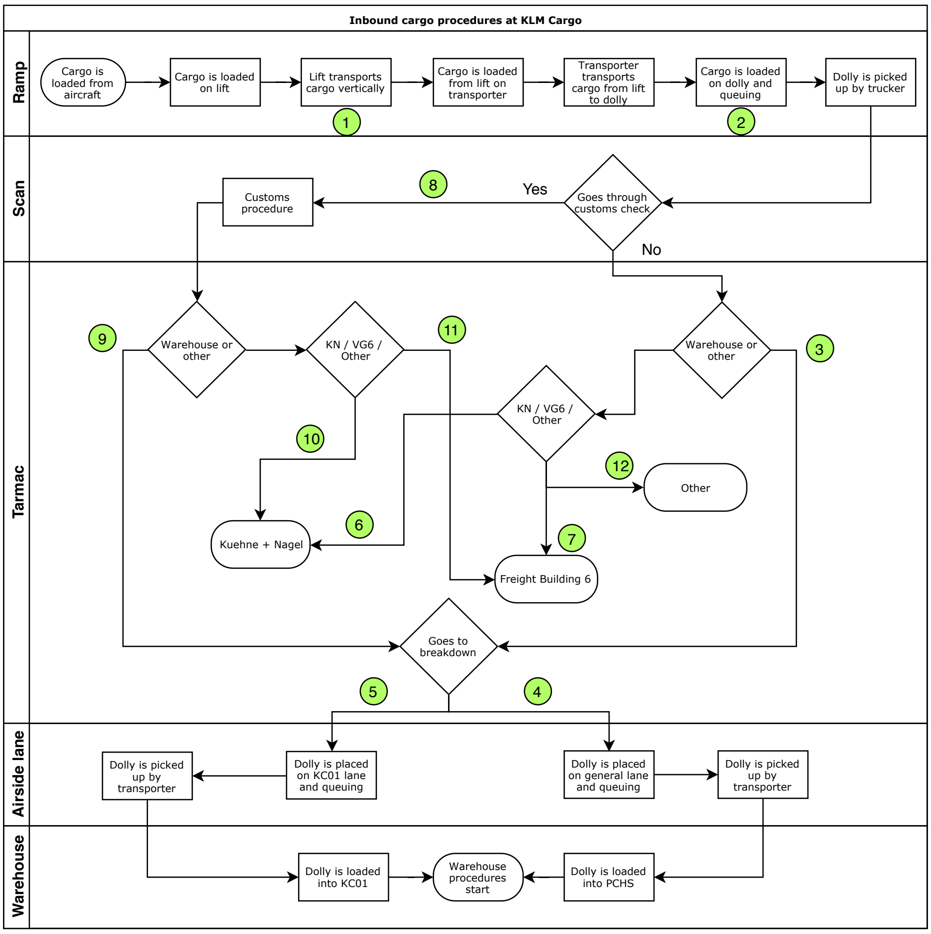

Figure 3.1: KLM Cargo inbound cargo procedures

## First process step: Unloading

Before an air plane lands on Schiphol Airport, the Transport department already receives information about the cargo that is aboard the plane. An itinerary shows the origin of the cargo, the amount of temperature-sensitive cargo that is in it and if a ULD needs to go to a security scan for security measures. The head of Transport creates a list of employees that are responsible of transporting the cargo from and to the air craft. There is always a small part of all available employees that is dedicated to cool chain rides, what means that they only transfer temperature-sensitive cargo from the airside lane into KC01.

When a plane is landed, a high-loader lift is always present to place next to the plane. The amount of times that this lift is not directly present is negligible. Ground personnel of Schiphol is responsible to operate this high-loader and makes sure that the cargo is unloaded in a continuous flow. A second Schiphol employee uses a transporter to unload the cargo from the high-loader onto one of the dollies. Dollies are plates with wheels that are used to move ULD's. Just as the high-loader, these dollies are always present in the right amount if the plane is landed.

The time that the high-loader takes to operate one piece of cargo down and go up again is estimated on 80 seconds. The unloading of cargo onto the high-loader takes only ten seconds. Moving the cargo from the high-loader onto a dolly does not take longer than forty seconds. A trucker can take a maximum of five dollies towards the warehouse in once, so the repeating of this process can take maximum up to four times. These time values are made available by the transport and planning department and with double checking with ground personnel these numbers are validated. To make sure, personal measurements have been conducted in one shift to double check the duration and these were in line with a deviation of maximum 1 minute on the total amount.

### Second process step: Queue on ramp

During the unloading, but also during the queuing on the dolly, the ULD is exposed to ambient temperature. These are the first steps of the transportation where the devaluation of the cargo quality starts. One part of the transport of cargo is the queue time of cargo on the ramp. When cargo is unloaded and placed on a dolly near the aircraft, it is not given that there always is a sufficient capacity of transport. Therefore it is common that dollies have to wait before being picked up.

### Third process step: Transport to airside lane

When, in the case of the longest duration, five dollies are ready to be taken to the warehouse they are picked up by a trucker. This trucker is one of the KLM Cargo drivers. The dollies can contain both general as cool cargo, there is no distinction between different types of dolly that are transported at the same time.

When picked up by the trucker, the dollies are transported in once from the ramp to the airside lanes outside the warehouse. The trucker has to pass the general customs check before entering the KLM Cargo perimeter, which can take a few seconds extra. Upfront, the employee knows on which airside lane the dollies have to be parked, being informed by a handheld. There is one exception: sometimes the cargo needs to go to a scan to get extra clearance, for example when the origin of the cargo is a suspicious country.

### Fourth and fifth process step: Airside lane queue

After cargo is placed on the airside lane, dedicated truckers will load the ULD's from a dolly and load it into the PCHS or KC01. This results in a queue time for the ULD on the airside lane, which often can take a while, and therefore results in an exposure. If a ULD needs to go to break down, it goes into the PCHS, which is distinguished by process step 4.

If a ULD is fully equipped with only one temperature range, it can go straight into the cooled area, or into KC01. This process leads to different lead times, for there is a dedicated driver for the KC01 shipments. This driver only transfers ULD's from the airside lane into the KC01. When the workload of the other drivers is too big, this dedicated driver is the first that is called in to support.

### Sixth and seventh process step: Transport to other destinations

Not all incoming ULD's are going into the warehouse. A significant amount is going to alternative destinations. These are distinguished as Kuehne+Nagel (KN), freight building 6 (VG6) or several smaller destinations assembled as *other*. KN is a forwarder and VG6 is a destination that lies on another location than the general warehouse. Transport of ULD's undergoes the same steps, but where the other steps include a queue step before the warehouse, the transport to KN, VG6 and other ends after transport over the tarmac.

### Attribute: Passing the customs clearance

The most common reason for cargo having to pass the customs clearance is if the shipment is departed in a country that is known for smuggling forbidden narcotics or dangerous goods. In each scenario, the transport and planning department is informed well ahead to prevent any congestion in the transport of cargo. This means that the cargo is picked up from the ramp, goes to the scan procedure and from there is dropped at the airside lane, KN or at VG6. The procedures that are conducted at the check are not in exposure and therefore is not taken into account during this analysis.

If the decision is made that a ULD has to pass the customs clearance before it goes to the airside lane, it results in an eighth and ninth process step that are added to the system. The transport to and from the check takes place on the tarmac and is therefore the cargo is exposed to ambient temperature.

A tenth and an eleventh process step are created if the cargo goes to the check and afterwards goes to respectively KN or VG6. These eleven steps together comprise all conducted processes for incoming cargo.

## 3.3.2. General operations

The process steps show that all incoming cargo can be sent to five different destinations, two in the warehouse, two that can be considered as external and one that is distinguished as *other*, being a large amount of shattered destinations. With a decision-making attribute that determines if the cargo has to pass through the scan, the general operations can be divided over nine paths. These nine paths stand for all operations that find place at the inbound process.

To create a benchmark of common execution operations, a few paths have been determined that together comprehend the gross of all conducted transportation of the incoming cargo. These paths are enlisted below and will be discussed in the next chapter.

1. From unloading on ramp, directly to airside lane and into PCHS. i = 1,2,3,4
2. From unloading on ramp, directly to airside lane and into KC01. i = 1,2,3,5
3. From unloading on ramp, going through customs check before going into PCHS. i = 1,2,8,9,4
4. From unloading on ramp, going through customs check before going into KC01. i = 1,2,8,9,5
5. From unloading on ramp, directly to KN. i = 1,2,6
6. From unloading on ramp, directly to VG6. i = 1,2,7
7. From unloading on ramp, going through customs check before going to KN. i = 1,2,8,10
8. From unloading on ramp, going through customs check before going to VG6. i = 1,2,8,11
9. From unloading on ramp, going to *other* destinations. i = 1,2,12

### Resources at KLM

The resources that are present in the system have an affect on the time duration of a subsystem, which is related to the exposure that a shipment experiences. The resources that are active at KLM Cargo are the following:

- High-loader
  Lift that vertically transfers ULD's from the aircraft to ground level. The high-loader lift is always present and ready to use when the unloading of the aircraft commences.
- Ramp transporter
  This vehicle transfers a ULD from the lift onto a dolly.
- Dolly
  This mobile platform has the capacity to store one ULD. There are always enough dollies put in place when a aircraft is landed, so when the unloading starts there is enough storage capacity on the ramp.
- Trucker
  These vehicles transport dollies containing ULD's from the ramp to their destination.
- Warehouse transporter
  These transporters have the same function as the transporters on the ramp. They transfer ULD's, in this setting from the dolly into the PCHS or KC01. When there are multiple warehouse transporters present, one is dedicated to move only KC01 cargo.

Before all above operations take place, the transport and planning department already has executed the logistic tasks by dividing tasks for the transporters and truckers. A planner has decided, with help of the latest information about actual flight times, where the dolly has to go and the transporter follows the information that is shown on his handheld. When the transporter picks up or drops a dolly, he can communicate this with the planner through his handheld. This action results in the time stamps of the transported cargo that is utilised in this research.

## 3.4. Process performance indicator

As the previous chapter has indicated, the process performance should be measured during the ground and loading operations. The mentioned relevant theories are compared in a morphological overview, presented in table 3.3. It cross checks the theories with KLM specific requirements to achieve the most suitable performance indicator, from now listed as the KPI.

This research tends to be applicable for both categories within the temperature-sensitive cargo shipments, as for the different temperature ranges. These two are paramount and is followed by the demand to look into smaller parts of the whole transportation process. The AMT and Exposure theories show potential to use, only the AMT on itself is not sufficient enough and can act more as a support because it only focuses on temperature, where the exposure also takes into account the time. This has resulted in the decision to use the **exposure** KPI as benchmark value to analyse the system and possible improvements that can be applied. The exposure KPI expresses the performance in Degree-Hours. Because this analysis uses two types of temperature; the ambient and the cargo according to the SHC, the AMT equation is used as support. It will be

Table 3.3: KPI selection

| Theory | COL / CRT / ERT applicable | Pharma & Fresh applicable | Availability and accessibility data | **Most feasible** |
|---|---|---|---|---|
| MKT | CRT | Pharma | Mainly pharma data | |
| AMT | ✓ | ✓ | ✓ | As support |
| Exposure | ✓ | ✓ | ✓ | ✓ |
| ToR | ✓ | Pharma | | |
| Heat transfer | ✓ | ✓ | Insufficient | |
| Least feasible | MKT | ToR | Heat Transfer | |

used integrated in the exposure equation as shown in equation 3.1. The temperature and time parameters are determined by historical data, chapter 5.3 will elaborate on how the KPI is calculated.

The cargo temperature that is used in the equation depends on the ambient temperature. If the ambient temperature is lower than the range according to the SHC, the lower boundary of this range will be used as cargo temperature. If the ambient temperature is higher than the SHC range, the upper boundary will be used as cargo temperature. When the ambient temperature is within the range regarding the SHC, the cargo is still exposed but this will be regarded as no violation of the temperature range in which the cargo is required to be maintained. The KPI will consider this situation as **no exposure**, even though the cargo is exposed to ambient temperatures.

To implement the improvement opportunities in the KPI, an insulation factor has been added that can be varied between zero and one. This parameter will be used to quantify the influence of possible improvements. When the K-value is one, it represents full exposure of the cargo to ambient temperatures, but when it is zero, the exposure will be eliminated in its total. Besides that, a parameter is added that decreases the queue time (DQT). This parameter is always 100% but can be lower for process steps on the ramp or outside the warehouse, for these steps are the only steps that involve queuing. Both values will be further explained in the next chapter.

The i behind every parameter indicates a single process step. The performance indicator will be used for every subsystem, where the mean will be taken to evaluate a longer time period per step. The mean values will be used if different steps are summed up to analyse path performances.

$$E = \sum (\Delta t_i * DQT_i * \frac{|T_{ambient} - T_{cargo}|_{start} + |T_{ambient} - T_{cargo}|_{end}}{2}_i * K_i) \tag{3.1}$$

$E = Exposure\, in\, Degree - Hours$
$\Delta t = Temperature\, recording\, interval\, in\, hours$
$DQT = Decrease\, Queue\, Time\, in\, percentage$
$T = Temperature\, in\, degrees\, Celsius$
$K = Insulation\, factor\, [0:1]$

## 3.5. Conclusion current processes

The general air cargo processes are specified for KLM Cargo in this chapter, distinguishing the relevant operations and performance indicators. This section contains the summary of this chapter and will answer the following sub-research questions:

*Sub-research question 3: What are the current processes at the tarmac within the cool chain at KLM Cargo?*

Currently, KLM Cargo regards processed cargo as one of four categories; dimension, variation, equation and cohesion. This research analyses the temperature-sensitive cargo, which is part of the variation category. These temperature-sensitive shipments are processed within one of three existing IATA special handling codes; COL, CRT and ERT. During the transport of the shipments, the cargo is exposed to ambient temperature. Depending on the season and the type of cargo, the intensity of the exposure can differ. To measure the performance of the transport, multiple relevant theories are discussed and two KPI's are chosen. The AMT and exposure KPI's are combined, where the AMT is used to calculate the difference in temperatures.

The main KPI is the exposure, this KPI determines the exposure of the cargo to the ambient temperature in Degree-Hours after processing the AMT.

# 4
# System analysis

This chapter focuses on the analysis of the current state processes. It will elaborate on the current state measurements that are conducted by the Performance Management department. With the received data, the current state will be concluded and this will show the weak points in the cool chain.

This chapter will answer the following sub-research question:

4. Which operations at KLM Cargo show room for improvement and how can this improvement be realised?

## 4.1. Data set for processes at KLM Cargo

The data that is used for the system analysis is derived from the Performance Management department at KLM Cargo. This section will briefly discuss what data is available and how it is filtered before analysing the system.

### 4.1.1. Available data

The data consists of a few excel files, one with all the inbound temperature-sensitive cargo for the year 2018 and one for the outbound. One excel presents the ambient temperature on Schiphol Airport for the year 2018, with a time interval of thirty minutes. Within this interval, the wind speed and direction is also given. The content of the cargo data sheet is shown in table 4.1.

Table 4.1: Available data set at KLM Cargo

| Number | Inbound |
|---:|---|
| 1. | AWB number |
| 2. | Actual arrival time |
| 3. | Scheduled arrival time |
| 4. | Time into cool cell |
| 5. | Time into PCHS |
| 6. | Ramp ride origin |
| 7. | Ramp ride destination |
| 8. | Time ramp ride start |
| 9. | Time ramp ride end |
| 10. | Ambient temperature ramp ride start |
| 11. | Ambient temperature ramp ride end |
| 12. | Special Handling Code of cargo |
| 13. | Minimum temperature of cargo by SHC |
| 14. | Maximum temperature of cargo by SHC |

### 4.1.2. Data collection and processing

This study utilises historical data, obtained from the performance management department. The data is used to determine the handling profiles of the temperature-sensitive ULD's during the year 2018 in this chapter and also used as basis for the input of the mathematical model in chapter 3. The following sections will present an insight on the data and how it has been representative for the system. The batch of data contained some incomplete points, therefore data filtering is applied to conduct a decent analysis on the transport processes. The applied filters can be found in Appendix C.

## 4.2. Transportation times

To gain insight in the time that a transporter needs to drive 1-5 dollies from the ramp to it's destination, the difference between the time stamps are analysed; from the ramp to the airside lane, the scan and the third party destinations. Per destination, the time difference is listed and the median and mean values are taken, representing a realistic value of the transport time of the transporter. After comparison, a rounded value of the 'worst case' value is used. Table 4.2 shows this duration for one transporter going *both ways*, so it stands for delivering a dolly on its destination and coming back to the ramp.

Table 4.2: Duration of transport ride retour

| **Ride** | **Median [min]** | **Mean [min]** | **Assumed worst case [min]** |
|---|---|---|---|
| Ramp to airside lane | 24 | 34 | 35 |
| Ramp to Scan | 44 | 50 | 50 |
| Ramp to KN | 46 | 54 | 55 |
| Ramp to VG6 | 50 | 58 | 60 |

## 4.3. General operations

This section will elaborate on the general operations as defined in the previous chapter. Table 4.3 gives an overview of the amount of ULD's that are processed during the inbound processes conducted in 2018. The percentages behind the numbers for ULD's from the ramp indicate the distribution relative to the total ramp queue input. The percentages at the three operations from the scan are related to the 17959 ULD's that are transported to the scan in the first place.

The percentage of appearance of the path will be used as weight factor to grant a value to the path, a so-called modal split. The summation of all these weight factors should result in 100 %. However, the added paths in this research will result in 96.3 %. The ninth path, the one for the transport from the ramp to *other*, will not be taken into account. Due to the shattered destinations and thus divergent distances, the outcome of this performance is not realistic.

Table 4.3: Number of inbound ULD's in 2018

| **Amount of ULD's** | **i. Process** | **Total** | **Percentage** |
|---|---|---|---|
| **Ramp** | *1. Ramp unloading*<br>*2. Ramp queue* | 65275 | 100 % |
| **Tarmac** | *3. Ramp to AL* | 32174 | 49,3% |
| | *8. Ramp to Scan* | 17959 | 27,5% |
| | *6. Ramp to KN* | 10570 | 16,2% |
| | *12.Ramp to Other* | 2410 | 3,7% |
| | *7. Ramp to VG6* | 2162 | 3,3% |
| | *9. Scan to AL* | 12118 | 67,5% |
| | *10. Scan to KN* | 4475 | 24,9% |
| | *11. Scan to VG6* | 1366 | 7,6% |
| **Warehouse** | *4. AL queue / PCHS* | 42330 | 95,6% |
| | *5. AL queue / KC01* | 1962 | 4,4% |

## Path 1

The first path is the most common one, which occurs 49.3 % of the time: the transportation from a ULD from the ramp straight to the airside lane. After unloading from the aircraft, the ULD is placed on a dolly by a ramp transporter. Here it is queuing until a trucker picks up the dolly and transports it to the airside lane, where the dolly is put in the final queue of the system. From here, the ULD is taken of the dolly by a warehouse transporter and put into the warehouse. The distribution from the airside lane into the PCHS and KC01 is respectively 95.6 & and 4.4 %. This results in a weight factor of 0.493 * 0.956 = 0.471.

## Path 2

Similar to the first path, with an occurrence of 49.3 % for the transport to the airside lane. However, the incoming shipments in this path go into the cooled area that is KC01. As mentioned above, the percentage of cargo going into KC01 is 4.5 % and therefore the weight factor for the second path is 0.493 * 0.044 = 0.022. Figure 4.1 shows the part of the Swimlane diagram that represents the first two paths.

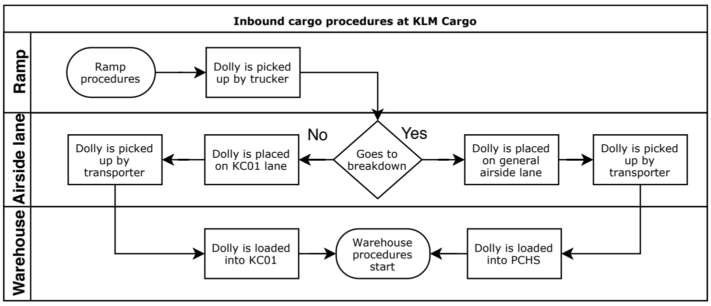


Figure 4.1: Path 1: ULD to PCHS. Path 2: ULD to KC01

## Path 3

The third path is similar to the first path but it contains an extra step in the system: passing by the customs check. From all inbound shipments, 27.5 % is ordered to pass the check. Afterwards, it is placed on the airside lane or it is moved to KN or VG6. The chance that it is placed on the airside lane is 67.5 %, here it is placed together with the cargo from the first paths and therefore the same distribution for the PCHS and KC01 destination is applicable. For the cargo going through the scan and into the PCHS, this results in a weight factor of 0.275 * 0.675 * 0.956 = 0.177.

## Path 4

The fourth path follows the same operations as the third path, with the same destination as the second path. From the ramp through the scan, ending up in the KC01. The weight factor for this path is 0.275 * 0.675 * 0.044 = 0.008. Figure 4.2 represents the two paths.

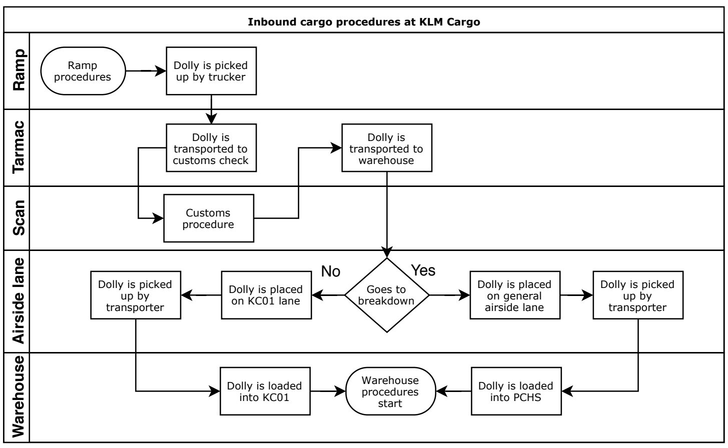


Figure 4.2: Path 3: ULD to PCHS. Path 4: ULD to KC01

### Path 5

The fifth path is a short path with only one queue step and one transportation step, from the ramp queue it is picked up and transported to the external party KN. This happens 16.2 % of the time, resulting in a weight factor of 0.162.

### Path 6

The sixth path is again a short path with only one queue step and one transportation step, from the ramp queue it is picked up and transported to VG6. This happens 3.3 % of the time, resulting in a weight factor of 0.033. Both path 5 and 6 are shown in figure 4.3.

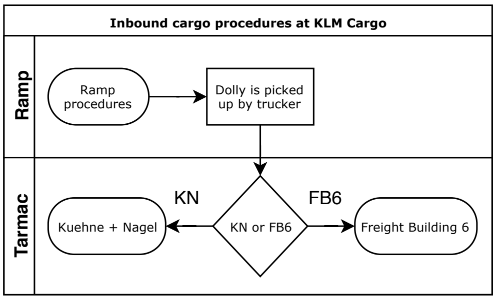


Figure 4.3: Path 5: ULD to KN. Path 6: ULD to VG6

### Path 7

The seventh path is a copy of the fifth path but it goes through the scan. The distribution based on historical data shows that 27.5 % of the inbound cargo goes through the scan, from here 24.9 % goes to KN. This results in a weight factor of 0.275 * 0.249 = 0.068.

### Path 8

The eighth path is a copy of the sixth path but it goes through the scan. The distribution based on historical data shows that 27.5 % of the inbound cargo goes through the scan, from here 7.6 % goes to VG6. This results in a weight factor of 0.275 * 0.076 = 0.021. The final two paths are shown in figure 4.4.

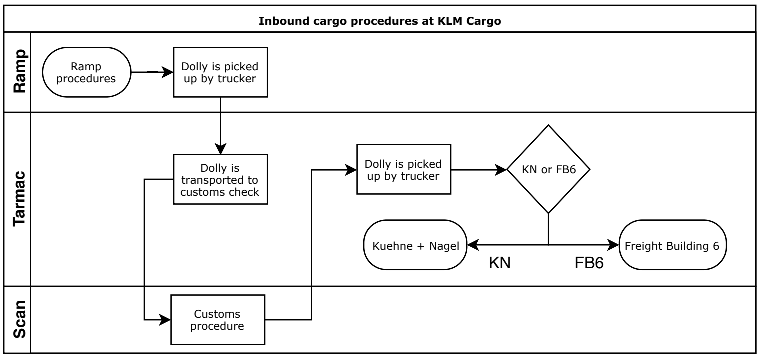


Figure 4.4: Path 7: ULD to KN. Path 8: ULD to VG6

## 4.4. Process improvement opportunities

Literature study has shown that all steps in the cool chain should be conducted precisely and that the transported cargo is sensitive to time and temperature. The availability of end-to-end temperature-controlled distribution lanes plus the greater access to data is allowing companies to gain more insight, and thus more control, over their supply chains. As a result of this shift, companies and their logistics partners are in a better position to specify cost-effective, fit-for-purpose thermal protection solutions. Regarding the Pharma or Fresh cargo, this insight is used in different ways.

The tendency to improve the cool supply chain can be realised by understanding and analysing possible improvement opportunities. In former research conducted by numerous airlines, a list of improvements is already analysed on a low level. This list focuses on decreasing the exposure the cargo experiences from environmental factors. The exposure is a function of temperature and time, therefore the list also contains improvement opportunities regarding time. Table 4.4 presents an overview of the references.

1. Increase personnel capacity during shift
2. Improve planning of dolly-drivers
3. Prioritise temperature-sensitive cargo before general
4. Invest in faster equipment
5. Set a maximum time duration that cargo can stand outside before flight departure or after flight arrival
6. Cool dolly
7. Animal dolly
8. Cool reefer
9. Thermal cover

Table 4.4: Overview improvement opportunities

| **References** | **Description** |
|---|---|
| Schaefer et al. [28], Niemans et al. [22] | Temperature controlled dollies |
| Schaefer et al. [28], Baas [2], Valentine [31] | Thermal blankets |
| Schaefer et al. [28], Mercier et al. [21] | Ground handling |
| Appendix B - discussion with experts | Animal dolly |
| Appendix B - Expert call with colleague from Dusseldorf, Lin [18] | Cool reefers |

### 4.4.1. Ground handling

There are several improvement possibilities that are applicable regarding the ground handling. These are all dependant on the airline and how handling procedures are determined and executed at their grounds. The performance of the ground handling is affected by the availability of resources and the execution of the processes.

At KLM, the transport and planning department is responsible for the prioritising of cargo transport and the scheduling of personnel. For this department, the temperature-sensitive cargo and the general cargo are put on one pile and the priority list is based on the time of departure or arrival, regardless of the temperature-sensitive goods.

Improvement opportunities that this research can analyse is the decrease of queue times, regarding the queues at the ramp and outside the warehouse. This could be achieved by expansion of personnel. There is more equipment available on the operational grounds than there is personnel active to utilise it. To schedule an extra pair of hands during the day could decrease certain process times. To have an extra pair of hands during a whole day of processing cargo, three employees need to be added for there are three working shifts. The cost for one employee is estimated on 100 euros per day, so for a full day of extra ground personnel results in 300 euros per day [12].

### 4.4.2. Temperature controlled dolly

Research has been done for temperature controlled dollies, or so-called cool dollies, which are basically mobile fridges. These active containers ensure that the cargo inside keeps a set temperature. Active containers in which ULD's are transported also exist, but they are loaded onto the aircraft as well. Cool dollies are only used for transport on the tarmac [36]. By the utilisation of these cool dollies, the temperature control of perishables and pharmaceuticals can be assured during the complete processes of airside transport and tarmac handling. Figure 4.5 shows an example of a temperature controlled dolly, which can contain one ULD.

Air France and KLM have executed joint projects to investigate the feasibility of purchasing these cool dollies. Cool dollies have a capacity of one ULD and tend to be expensive. Internal investigations prior to this research have gained proposals to acquire temperature controlled dollies, the cost of a dolly is estimated at 80,000 euros, including maintenance to reach a lifespan of 15 years.


Figure 4.5: Temperature controlled dolly [13]

### 4.4.3. Animal dolly

The animal dolly stands for the dollies that are currently used to transport animals, as presented in figure 4.6. These dollies are equipped with a roof and walls, to protect animals against weather conditions like sun and wind. This improvement possibility is not presented in any literature but a result of discussion within KLM Cargo. Appendix B presents a discussion with KLM employees on the advantages and disadvantages of the utilisation of this dolly.

Figure 4.6: Animal dolly [13]

The animal dollies are already part of the current equipment at KLM Cargo, with different purposes than transporting temperature-sensitive goods. The dollies have been purchased at an agreed price of 30,000 euros per dolly and have a lifespan of 15 years.

### 4.4.4. Temperature controlled reefer

A temperature controlled reefer, or cool reefer, can be acknowledged as the same category as the cool dolly, only does the reefer has a capacity for four ULD's. Appendix B describes the expert call with a project manager from Dusseldorf airport. From Dusseldorf airport, contact has been made with third parties regarding the investment in a cool reefer. The costs for such a protection method is 400,000 euros, this includes all the required maintenance to achieve a lifespan of 15 years.

### 4.4.5. Thermal cover

Thermal covers are blankets that can be put over a ULD to protect the cargo against ambient temperature influences, an example is shown in figure 4.7. The benefits of thermal covers are: low costs, low storage requirements, ease of deployment and ease of use [31]. These thermal covers do come with their own challenges.

The variability of performance testing and assessment methods for thermal protection covers is making it difficult to specify the right product. This difficulty can result in applying the cover incorrectly, which can lead to temperature excursions. This can cause temperature-sensitive cargo to be compromised and it could even jeopardise entire shipments.

Figure 4.7: Thermal blanket [13]

There are different types of blankets, from totally isolating material to 'breathable' material covers, the latter is used for cargo that needs oxygen to maintain its quality. This report will not take into account these different variations but this will be elaborated on in the recommendations. This analysis will see a thermal blanket as one method that has one characteristic, an insulation factor that will be discussed later. The average cost for a single thermal blanket is estimated on 20 euros, derived from invoices that are gained after contact with third parties that have offered a batch of products, further explained in Appendix B. The lifespan of one blanket is set on 1 day, assuming it will not return.

## 4.5. Process improvement parameters

To convert the process improvement opportunities into the analysis they are distinguished as a parameter that is present in the KPI. For the protection methods the insulation factor K is present, whereas for the ground handling opportunities the $\Delta t$ parameter is adjusted.

### 4.5.1. Insulation factor K

The motive behind this factor is to gain insight in the effect of one of the former mentioned improvement solutions. The factor is set between 0 and 1, with 1 being no protection and thus full exposure, where a K-value of zero eliminates all exposure.

The current processes don't have any protection and therefore the insulation factor will be 1. For the cool dolly, a K-value of 0 is taken as it is assumed it entirely blocks the ambient temperature and thus the exposure because of its active cooling. The cool reefer system acts similar as the cool dolly and therefore also has a K-value of 0.

The insulation factors for the thermal blanket and animal dolly will be determined using the original insulation factor that is expressed by the R-value of material. The R-value is currently the most widely-used measurement within the thermal cover industry [31]. The ability of insulation material to reduce heat flow through a surface is valued with the R-value. Because the surface of the cargo is taken the same in this analysis, only the R-values are compared to each other. The greater the R-value, the more the heat flow through the surface is reduced [4]. The value is expressed in $K * m^2/W$.

The animal dollies that are present consist mainly out of aluminium. The opening is covered with a fibre material, but all the types of fibre have a significant higher R-value than aluminium has. Without excluding the chance that the animal dolly is only exposed with its aluminium sides, the R-value of aluminium will be used, which is 0.61 $K * m^2/W$.

The R-value of a thermal blanket can have a broad range. The company that KLM Cargo is in contact with can offer a product with a R-value of 1.4 $K * m^2/W$. These blankets can easily be applied to a ULD and, when bought in a high quantity, come at a low cost. More information about this product can be found in appendix G.

To gain a insulation factor K for both methods, the ratio of the insulation factor R is used to determine a K-value relative to each other and to the 1 and 0 boundary. The ratio of the R-values is 0.61/1.4 = 0.43, with the thermal blanket being more protective. This ratio will be used to assume K-values, with the thermal blanket having a lower value for being more protective than the animal dolly. A thermal blanket is assumed to have a K-value of 0.3 and the animal dolly at 0.7, giving the ratio of 0.43. The different types of protection methods cannot be applied on each process step in the system. Table 4.5 will give an overview of which configuration can be used at which subsystem.

Table 4.5: Application of insulation factor K

| **Improvement** | **K-value** | **Unloading** | **Ramp queue** | **Tarmac transport** | **Airside queue** |
|---|---|---|---|---|---|
| No protection | 1 | 1 | 1 | 1 | 1 |
| Config 1: Animal dolly | 0.7 | 1 | 0.7 | 0.7 | 0.7 |
| Config 2: Thermal blanket | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Config 3: Cool dolly | 0 | 1 | 0 | 0 | 0 |
| Config 4: Cool reefer | 0 | 1 | 0 | 0 | 0 |

### 4.5.2. Decrease queue time

Reduction of queue time can be reached by applying more personnel. Currently, employees driving at the tarmac have no dedication towards the temperature-sensitive goods as there is no regulation about prioritising these shipments. The only drivers that are dedicated towards the cool chain are the people that bring shipments from the warehouse queue into KC01. This analysis looks into the effect of adding employees that are dedicated to transporting temperature-sensitive goods. With the addition of extra personnel, the goods can be picked up and dropped of quicker and therefore the queue time will be reduced. Reduced queue time results in a reduction of exposure and therefore is a valuable element to analyse.

Table 4.6 shows the assumptions that have been made regarding personnel and queue times. These configurations will decrease the $\Delta t_i$ parameter in the KPI if the i-parameter describes the queue time at the ramp or warehouse.

Table 4.6: Decrease of queue times

| **Improvement** | Decrease queue time [%] | Location | Personnel per day |
|---|---|---|---|
| Config 5 | 10 | Ramp | 3 |
| Config 6 | 10 | Warehouse | 3 |
| Config 7 | 25 | Ramp | 6 |
| Config 8 | 25 | Warehouse | 6 |
| Config 9 | 50 | Ramp | 9 |
| Config 10 | 50 | Warehouse | 9 |

## 4.6. Conclusion system analysis

This chapter has presented how the processes are conducted at KLM Cargo and what kind of data is available. It also elaborated on possible improvement opportunities. This section contains the summary of this chapter and will answer the following sub-research question:

*Sub-research question 4: Which operations at KLM Cargo show room for improvement and how can this improvement be realised?*

Nine paths have been distinguished that comprehend all operations as conducted by KLM Cargo. The ninth path has shown that it is not feasible to take into account, for it is only 3 % of the operations and concerns transport to multiple locations, shattered over KLM with divergent distances. The eight paths that are left concern most of the conducted operations. The system analysis has shown all steps that are in play and during which steps the cargo could get exposed.

The system analysis shows that the exposure commences when the cargo is unloaded from the air craft with the high-loader lift. On this point, a thermal blanket could be of added value in decreasing the exposure.

The remainder of the processes are open for any kind of improvement. These processes can be divided in transport or queuing processes.

The queue times of the ULD's could be reduced, which could be made possible by adding more personnel, by stricter planning or prioritising which shipment will be transported first. The cargo can also be protected against the weather conditions by applying a protection method, these appear in the form of an animal dolly, cool dolly or a cool reefer. It is also possible to cover the cargo with a thermal blanket, which has thermodynamic characteristics that decreases the heat transfer onto the cargo.

# 5
# Model design

The previous chapters have presented a clear image on how the general and KLM specific operations are conducted regarding the transport of cargo. The previous chapter gave a clear view on the available data and the potential to implement protection methods in order to protect the temperature-sensitive shipments. This chapter will elaborate on the creation of a model and how this can be used to analyse the performance of these operations.

This chapter will answer the following sub-research question:

5. How can a model be used to analyse the performance of the tarmac process within the cool chain?

## 5.1. Model objective

When assessing the elements that are present in the system, an equilibrium between costs and quality is preferred. Deployment of assets and resources are resembling the largest component of the process operation costs. The quality of the process can be illustrated by the indication of the performance, in this research the exposure in terms of Degree-Hours. In an ideal situation, high quality operation is conducted with a minimum member of assets and resources and whilst utilising the facilities in an optimal way [26].

1. **Quality**: Focus on the quality of the process. Achieving a high quality is important, because in this research the temperature-sensitive ULD's could devalue and this could lead to customer claims. Customer claims leave a small monetary impact but a large image impact, which on terms could lead to decreased revenues.
2. **Costs**: When high process quality is desired, how does this influence the costs of the operation or of the possible improvement opportunities that are integrated in the operational system? The lowest operational costs are desired, which influences the quality and efficiency of the process instantly. Keeping the exposure of the cargo low is of high importance and therefore some added operational steps should be taken into consideration to guarantee the quality of the cargo. The deployment of assets and resources is the largest component of the operational costs and therefore it could be stated that this capacity should be used to the fullest. However, it is important to know to which extent this optimum use of assets and resources affects the process quality in terms of exposure to the ambient temperature.

The main objective of this research is to determine the influence of the climate on the performance of the system regarding exposure. Whilst doing this, the above objectives and desired equilibrium has to be taken into account. The goal is to decrease the exposure of temperature-sensitive cargo against feasible expenses by the aggregation of subsequent operations, therefore this research will use a mathematical model to analyse the improved system.

## 5.2. Model output

The output of the model is equal to the performance of the system. This value is used to quantify the current state processes and at the same time can be used as a benchmark for future performance measurements that might be improved. The model processes all incoming ULD's from 2018 and will result in different performance values, to gain one value that represents the performance of the subsystem, the mean value is taken from every output set.

### 5.2.1. Key performance indicator

To analyse the current process and to improve it, a benchmark is required to quantify and qualify the performance of the processes. KPI's are quantifiable metrics that an organisation uses to measure its performance over time. These metrics are used to determine a company's progress and performance regarding the goals and objectives that it has set [27]. This section will describe the chosen KPI: thet exposure to ambient temperature. The KPI will be determined with the DSA approach, by regard all subsystems as a blackbox with an ULD as input and output, where the exposure is the outcome of parameters as time and ambient temperature as shown in figure 5.1.

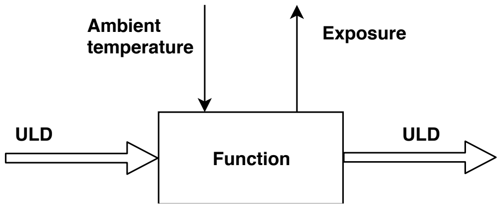


Figure 5.1: DSA approach, adapted from Veeke et al. [32]

#### Exposure to ambient temperature

During the transport in the system, the temperature-sensitive cargo is exposed to ambient temperature. The objective of this research is to analyse this exposure and to research the improvement possibilities. The exposure is a multiplication of the time that the ULD is exposed to the ambient temperature, and the difference between the ambient temperature and the closest temperature that the ULD can be, expressed in Degree-Hours.

This KPI is slightly modified and used to measure the performance of the current state to set this as benchmark, then it will be used to evaluate the improved state. The modified equation can be found in equation 5.1 and is similar to equation 3.1.

$$E = \sum \left(\Delta t_i \, * \, DQT_i \, * \, \frac{|T_{ambient} - T_{cargo}|_{start} + |T_{ambient} - T_{cargo}|_{end}}{2}_i \, * \, K_i\right) \tag{5.1}$$

$E = Exposure\,in\,Degree - Hours$
$\Delta t = Temperature\,recording\,interval\,in\,hours$
$DQT = Decrease\,Queue\,Time\,in\,percentage$
$T = Temperature\,in\,degrees\,Celsius$
$K = Insulation\,factor\,[0:1]$

### 5.2.2. Performance values

To gain a comprehensive overview of the system performance, the exposure will be calculated for every process step. The minimum, maximum, mean and average values will be presented. Due to outliers, there is a possibility that the average can give a distorted image of the performance. However, if more than 50 % has no exposure, the median will always be 0 even though the remaining ULD's can have a significant exposure. For this reason, the exposure rate and non-zero medians (regarding only the exposed values) are projected as well. The next chapter will analyse the data and thus the performance of every step in the system.

## 5.3. Model input

The input for the model will concern all ULD's that are processed in 2018. All ULD's can be categorised in different types under various climate circumstances. On top of that, each ULD will be sent to one out of four destinations and there is a possibility that the cargo has to pass the customs check before arriving at it's destination. The input parameters are the terms that are present in the performance equation 5.1; the difference in temperature, in time, the insulation factor and the decrease of queue time. The fifth element is the summation of the exposure per *i*, indicating the process step that the performance is related to. All parameters and how they are determined will be explained next.

### 5.3.1. Temperature difference

This subsection will comprehend the involved elements to calculate the AMT term. It will describe how the temperature of the cargo and the ambient temperature are considered and ends with an example on how the difference is calculated. The ambient temperature data is a historical data set, measured every half an hour on Schiphol Airport. This is measured by a sensor that is linked to the performance management department.

The COL, CRT and ERT shipments all have a temperature range as stated in the previous chapter. Every ULD contains a SHC code distinguishing the temperature range that the cargo should be transported in. When the ambient temperature is outside this range, the cargo is violating the temperature regulations.

### Determination of difference

The AMT term in the KPI will be calculated by taking the difference of the ambient temperature with the temperature according to the SHC. This difference will be taken on the beginning of the queue or transportation step, and in the end. The two values will be summed up and divided by two, taking the average value. Because all steps are conducted faster than that the ambient temperature rises or decreases with more than one degree Celsius, this approach has been determined as feasible.

During summer, the temperature difference will often be positive for ambient temperature will likely be higher or equal to the cargo temperature. If the ambient temperature is lower than the cargo temperature, the difference value will be taken *absolute*. This is done so the exposure is a summed up positive value and to prevent a positive and negative exposure cancelling each other out, resulting in a (near) zero exposure. If the ambient temperature is within the SHC range, the exposure is determined as zero as the cargo is not violating the temperature regulations that are set by IATA.

### 5.3.2. Time difference

The second term that is used to calculate the performance is the $\Delta t$ value. This is an indication of the time duration that the cargo is waiting in the queue or being transported. The ground operations personnel at KLM Cargo uses a handheld to register if a ULD is picked up at the origin or dropped of at the destination, leaving a time stamp in the system. These time stamps are used to determine the time duration in hours. This term is supported by the DQT term, which indicates a decrease of queue times in percentage. This parameter is initially 100% but can be adjusted in an improvement setting.

Not all steps are registered like above. There is a time stamp present when the plane lands, and when the cargo is picked up from the ramp. To separate steps, experts are consulted to determine the average time between landing and the start of the unloading process. The process of unloading is also estimated by this approach. This has resulted in a time duration between landing and pick up that can be decreased by two estimated time duration, leaving a final duration for the queue time on the ramp.

#### Example

For example, if the ambient temperature is 12 degrees Celsius, and a COL shipment is outside for an hour, the exposure is $12-8=4DH$. When the ambient temperature is lower, the exposure will be taken absolute. In the case of an ambient temperature of 8 degrees Celsius, for a CRT shipment that is outside for half an hour, the exposure will be $abs(8-15)*0.5=3.5DH$.

### 5.3.3. Insulation factor

The insulation factor is a term that has been added with support from expert calls, explained in more detail in chapter 4.5.1. It is a value with a range from 0 to 1 and acts as a distinction of the performance of a protection method that is used to protect the cargo against climate elements. When the K-value is zero, the ULD can be seen as isolated from the ambient temperature, whereas a value of 1 can indicate that no protection is present. For the analysis of the current state, the K-value is set on 1.

### 5.3.4. Process steps

The final term in equation 5.1 is the summation of the $i$-process. The process steps concerning the transport system are described in the previous chapter regarding the current state. The process steps show that all incoming cargo can be sent to four different destinations, two in the warehouse and two that can be considered as external. With a decision-making attribute that determines if the cargo has to pass through the scan, the general operations can be divided over eight paths. These eight paths stand for all operations that find place at the inbound process.

To create a benchmark of common execution operations, a few paths have been determined that together comprehend the gross of all conducted transportation of the incoming cargo. These paths are enlisted below and will be discussed in the next chapter.

1. From unloading on ramp, directly to airside lane and into PCHS. i = 1,2,3,4
2. From unloading on ramp, directly to airside lane and into KC01. i = 1,2,3,5
3. From unloading on ramp, going through customs check before going into PCHS. i = 1,2,8,9,4
4. From unloading on ramp, going through customs check before going into KC01. i = 1,2,8,9,5
5. From unloading on ramp, directly to KN. i = 1,2,6
6. From unloading on ramp, directly to VG6. i = 1,2,7
7. From unloading on ramp, going through customs check before going to KN. i = 1,2,8,10
8. From unloading on ramp, going through customs check before going to VG6. i = 1,2,8,11

### 5.3.5. Modal split

Chapter 4 has elaborated on the different paths that can be taken in the daily operations at KLM Cargo. A modal split is applied by determining a weight factor that every performance is multiplied with to gain a more realistic outcome. This weight factor is based on the occurrence of every operation, extracted from the historical data set. Table 5.1 shows all weight factors together, and the next chapter will show all performance values after being multiplied with this weight factor. This action enables this analysis to take the different destination possibilities into account while calculating the performance of a single ULD. As stated before, the ninth path will not be taken into account.

Table 5.1: Modal split

| Path | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Modal split | 0.471 | 0.022 | 0.177 | 0.008 | 0.162 | 0.033 | 0.068 | 0.021 | 0.038 | 1.00 |

### 5.3.6. Cargo split

The different types of cargo enter the system in a different amount of ULD's. For this reason, each exposure value is multiplied with a cargo split, different per season as well and presented in table 5.2. This will ensure that the performance of a single ULD is analysed with the possibility taken into account that it can be any type of cargo and that it won't be distorted by a extreme value that occurs significantly lower than others.

Table 5.2: Cargo split

| Season | Cold | | | Medium | | | Warm | | |
|---|---|---|---|---|---|---|---|---|---|
| Type | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Cargo split | 0.6487 | 0.0358 | 0.3155 | 0.6520 | 0.0364 | 0.3116 | 0.6242 | 0.0398 | 0.3360 |

## 5.4. Mathematical model description

This section will describe the mathematical model. The function will use the KPI that is used to analyse the system. This model will calculate the exposure of a single ULD that is processed by the inbound operations, next the mean values are taken per season, per type and per process step and path to gain the overall performance in 2018.

**Output**

$$E = \sum \left(\Delta t_i * DQT_i * \frac{|T_{ambient} - T_{cargo}|_{start} + |T_{ambient} - T_{cargo}|_{end}}{2}_i * K_i\right)$$

**Input**

$\Delta t = Time\ between\ pickup\ and\ drop-off\ in\ hours$
$DQT = Decrease\ Queue\ Time\ in\ percentage$
$T = Temperature\ in\ degrees\ Celsius$
$K = Insulation\ factor\ [0:1]$

**Constraints**
$t_i \geq 0$, $\Delta t_i \geq 0$, $T_i \geq 0$,
$K_i = [0,1]$
$DQT = [0,100]\%$

**Parameters**
$\Delta t_i = t_{i+1} - t_i$
$T_{ambient} < T_{cargo_{min}}$, $\Delta T_i = |T_{ambient} - T_{cargo_{min}}|$
$T_{ambient} > T_{cargo_{max}}$, $\Delta T_i = T_{ambient} - T_{cargo_{max}}$
$T_{ambient} \geq T_{cargo_{min}}$ AND $T_{ambient} \leq T_{cargo_{max}}$,$\Delta T_i = 0$

## 5.5. Verification and validation

Performance measurements that are extracted from a model only represent the real system if the model is a proper representation of the system. A model is more abstract than the system it represents. Assumptions are made to make a model less complex and so the focus can be on the paramount elements. A model verification can help in judging whether the model implements the assumptions correctly. A validation shows if the assumptions that have been made are reasonable with respect to the real system [6].

### 5.5.1. Verification

Verification is done to avoid errors during implementation, if there are 'odd' results these should be double checked. There are various ways of verification, this report will use the *one-step analysis*, which has been done with expert calls. It also takes into account the claims that are filed at KLM Cargo to investigate quality loss of transported goods.

### One-step analysis

For this verification method, every step in the model has been taken apart. The model contains a few input parameters that are all based on historical data. One equation, stated before as the KPI, brings these parameters together and this will result in an outcome. The summation of the KPI per step indicates the performance of the system. Supported by expert opinions, faulty data is filtered out the historical data set. This has led to a batch of data which is correct before it is used in the model. Together with experts, a structured walk-through is executed which acts as a verification.

### Claims at KLM Cargo

When a shipment is violating the temperature range that is setup by the special handling codes, the good can lose its quality when it arrives at the recipient. This party can choose to file an investigation request, which could result in a claim to the airline for mistreating the shipment. The amount of incoming claims, varied per type of cargo and per date, can support the data analysis in verifying which shipments are exposed to ambient temperature.

Appendix H gives an impression of how the claims are filed, extracted from a data set containing all claims of 2018. The claims are traceable to the AWB numbers, which gives the chance to verify the exposure of a few shipments. Table 5.3 shows shipments that have received a claim for decrease or increase of temperature. It shows the type of cargo with the path that they have been transported over, enabling this research to analyse the exposure of these shipments.

Of all claims, 71.3 % indicates the COL shipments suffering the most exposure during warmer months. 20.4 % of the claims concern CRT shipments in the cold months, as expected as well. The exposure values from table 5.3 can be used to compare the results in the latter chapters.

Table 5.3: Claims with exposure values

| AWB Number | SHC | Conducted path | Exposure [DH] |
|---|---|---|---|
| 057-66425461 | COL | 2 | 41.9138 |
| 074-16512510 | ERT | 1 | 0.1312 |
| 074-17958356 | COL | 4 | 44.5290 |
| 074-16945876 | COL | 2 | 51.5824 |
| 074-17269862 | ERT | 1 | 0.6011 |

### 5.5.2. Validation

Validation is used to demonstrate that the model is a feasible representation of the actual system. It shows that it reproduces system behaviour with enough correctness to satisfy analysis objectives. Often, a model is developed to analyse a problem and this could lead to a representation of different parts of the system at different levels of abstraction. This could result in different levels of validity for different parts of the system, therefore there are different aspects which should be considered during model validation. These are *assumptions, input parameter values* and *output values*. In terms of validation, these can be seen as *process validation, data validation* and *performance validation*.

In general, initial validation attempts will concentrate on the output of the model, and if that validation suggests a problem a more detailed validation should be conducted. This research analyses a system that has not been modelled before in this way therefore it is not possible to conduct the performance validation. For this reason there are more broader approaches to validate the model:

- Expert opinion
- Real system measurements
- Theoretical results/analysis

As the performance validation is not feasible for validation, the process and data that is used can be validated. This validation is similar with the actions that are done by the verification. The described processes, including every subsystem but also the operational paths, are discussed with experts and based on their intuition. The data is obtained by the performance management department and the filters that are applied is discussed with experts as well.

Real system measurements has already been done, for all available and used data is historical data, which has been measured during conducted operations of the real system. The outcome of the model can not be measured in real-time, but as long as the input is define by real system measurements it is assumed that the outcome is valid.

This analysis does not contain an advanced mathematical model or simulation that is able to undergo a theoretical analysis and therefore this third approach is not applicable. Such an approach requires a simulation model in which new data is generated, which is not the case in this research where only historical data is used.

This research tends to provide a performance benchmark that can be discussed with external parties in order to create a reference exposure value per type of cargo per season. With this in mind, further research could create a model that could compare its outcome with this benchmark. For example, it could be a validation to say that exposure during the ramp queue could never pass 20 Degree-Hours. This will be elaborated on in the recommendations.

## 5.6. Conclusion model design

The setup of a model is shown, including ways to validate and verify the model and its outcome. This section contains the summary of this chapter and will answer the following sub-research question:

*Sub-research question 5: How can a model be used to analyse the performance of the tarmac process within the cool chain?*

A model is used to analyse a system in a theoretical way. Different methods are possible to use in such an approach, where this research uses a mathematical model to analyse the system. The system being the flow of operations that is conducted at KLM Cargo during the transport of inbound shipments.

The earlier determined KPI is used as main equation in the model. The input data is historical and measured during the conducted operations, the time durations by the employees or by a sensor that measures the ambient temperature on Schiphol during the whole year each half an hour. All used data is verified and validated with support of expert opinions in order to continue using the model.

The difference in time between the pickup and drop-off of a ULD is used as time difference, where the difference in temperature is determined by both the ambient as cargo temperature. The difference between the ambient temperature and the cargo temperature, according to the special handling code, is taken on the first and second time stamp and the average temperature has been taken from these two values. When the ambient temperature is higher, the maximum SHC temperature is used to calculate the difference and if the ambient temperature is lower, the minimum is taken. When the ambient temperature lies within the SHC range, a temperature difference of zero is used for there is no exposure in that case.

The time and temperature differences are multiplied with each other and thereafter also with an insulation factor K, which is taken as 1 during the analysis of the current state. This is representing how processes are going now, without any protection method.

Eventually, this KPI is summed up over multiple process steps. This summation indicates the performance of an operational path that consists of subsequent processes, or subsystems. These performance values are determined per path, per seasonality and also per type of cargo in order to obtain a comprehensive representation of the systems performance.

# 6

# Data analysis

This chapter focuses on the analysis of the current state processes and on quantifying the performances. It will elaborate on the current state measurements that are conducted by the Performance Management department. With the received data, the current state will be concluded and this will show the weak points in the cool chain. The designed model from the previous chapter will be used to generate a performance benchmark of the current state.

This chapter will answer the following sub-research question:

6. What is the performance of the current system and which processes can be improved?

## 6.1. Performance per subsystem

Every step will present the performance according to the set KPI: the exposure in Degree-Hours. Each performance table shows the type of cargo and the seasonality, to give a clear insight when and which temperature-sensitive cargo is exposed the most. This section will show the table of the process step that is conducted on the ramp. The rest of the process steps and corresponding performance values can be found in Appendix D.

Every table also contains a rate of exposure. This percentages gives an indication of the factor of shipments that has been exposed to ambient temperature in the first place. For example, if a shipment was COL (2-8 degrees Celsius) cargo, and it is transported while the ambient temperature was 6 degrees Celsius, this cargo has an exposure of zero and therefore is not exposed. This percentage gives extra support to the consideration if a type of cargo is exposed or not and, if so, to what extend.

To present one subsystem, the **queue process on the ramp** is shown in table 6.1 The tables consisting of the other subsystems can be found in appendix D.

Table 6.1: Exposure during ramp queue in Degree-Hours

| Season | Type | Minimum | Maximum | Median | Mean | Exposure rate | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 84.3333 | 0 | 1.3850 | 41.8 % | 2.4000 |
| | CRT | 0 | 62.25 | 8.2333 | 9.8919 | 99.9 % | 8.2333 |
| | ERT | 0 | 26.6 | 0 | 0.5293 | 16.2 % | 1.9000 |
| MEDIUM | COL | 0 | 155.1 | 6.4167 | 7.8507 | 92.5 % | 6.9000 |
| | CRT | 0 | 29 | 0.4750 | 2.3780 | 51.0 % | 3.9000 |
| | ERT | 0 | 6.9 | 0 | 0.0170 | 1.1 % | 1.1000 |
| WARM | COL | 1.2667 | 132.3333 | 10.7667 | 13.0485 | 100 % | 10.7667 |
| | CRT | 0 | 9.8667 | 0 | 0.2811 | 14.8 % | 1.3167 |
| | ERT | 0 | 22.2833 | 0 | 0.2288 | 8.9 % | 1.8333 |
| OVERALL | COL | 0 | 155.1 | 2.8500 | 4.9649 | 72.3 % | 6.7500 |
| | CRT | 0 | 62.25 | 4.1667 | 6.2424 | 62.2 % | 6.6000 |
| | ERT | 0 | 26.600 | 0 | 0.2860 | 9.4 % | 1.8333 |

### 6.1.1. Process performance overview

The following section will revert to the eight paths as established in the previous chapter and this is presented in table 6.2. To link a performance value to each path for comparison, an exposure value has to be chosen to use for the analysis. The general median value can be used, but if more than fifty percent of the shipments is not exposed, the median will be zero and therefore less feasible to use for analysis. The mean value could give a distorted image as well due to extremely high values that are present due to human error or other, unforeseen actions.

This leads to the non-zero values, in which only the shipments are taken into account that are exposed. For these shipments, the median won't be zero which is more feasible for analysis.

However, if only the non-zero values are taken into account, the non-zero percentage of appearance has to be taken into account as well which makes the analysis too complex. The values of the non-zero median and the overall mean are compared with each other and differ only in small margins, which is the reason the mean exposure value of all temperature-sensitive shipments is used to indicate the performance of the system.

Table 6.2: Overview of mean exposures in Degree-Hours

| Process | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to AL | 0.3761 | 2.2113 | 0.1307 | 2.4974 | 0.4565 | 0.0041 | 3.8899 | 0.081 | 0.0511 |
| Ramp to KN | 0.6292 | 3.9032 | 0.1679 | 3.1478 | 0.8367 | 0.0032 | 5.4605 | 0.1671 | 0.1310 |
| Ramp to Scan | 0.5082 | 4.3245 | 0.1697 | 3.1509 | 0.6012 | 0.0114 | 5.2534 | 0.1002 | 0.1186 |
| Ramp to VG6 | 0.4554 | 3.6690 | 0.1952 | 2.8949 | 0.6433 | 0.0077 | 6.1665 | 0.0500 | 0.1399 |
| Scan to AL | 0.4542 | 2.0539 | 0.5056 | 1.9758 | 7.4701 | 0.0113 | 4.5196 | 0.0562 | 0.1782 |
| Scan to KN | 0.3776 | - | 0.0666 | 1.7805 | 0 | 0.0049 | 6.4663 | - | 0.0323 |
| Scan to VG6 | 1.2476 | - | 0.0107 | 2.5406 | 0 | 0.0048 | 15.6307 | - | 0.1750 |
| AL to PCHS | 0.6179 | 4.5516 | 0.2218 | 4.7043 | 1.7164 | 0.0123 | 12.2353 | 0.2039 | 0.2358 |
| AL to KC01 | 12.2869 | 34.673 | 9.1255 | 17.7703 | 11.7384 | 0.3058 | 30.4561 | 7.5537 | 2.0155 |

## 6.2. General operations

The general operations as defined in the previous chapter will be explained below and will be analysed in this section, using the mean exposure values of the involved step. This will lead to a performance indicator for each path, not only for the different types of cargo but also for the different seasons that are present during a year. This will be summarised in an overview that will count as benchmark for the model in the following chapters.

The performance of the path is determined by the summation of the mean values of every step. This decision has been made because if the mean is taken from all the data sets in once, the mean will get distorted by irregular dimensions of the data (the ramp data set is larger than the transport to airside data set).

1. From unloading on ramp, directly to airside lane and into PCHS.
2. From unloading on ramp, directly to airside lane and into KC01.
3. From unloading on ramp, going through customs check before going into PCHS.
4. From unloading on ramp, going through customs check before going into KC01.
5. From unloading on ramp, directly to KN.
6. From unloading on ramp, directly to VG6.
7. From unloading on ramp, going through customs check before going to KN.
8. From unloading on ramp, going through customs check before going to VG6.

Table 6.3 will contain the total performance of path 1, the rest of the tables is presented in Appendix E. The following page will contain all performance tables of the paths, with the bottom row resulting in a total performance in Degree-Hour for that path, when executed for different types of cargo in different seasons.

Table 6.3: Performance of Path 1 in Degree-Hours

| **Path 1** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to AL | 0.3761 | 2.2113 | 0.1307 | 2.4974 | 0.4565 | 0.0041 | 3.8899 | 0.081 | 0.0511 |
| AL to PCHS | 0.6179 | 4.5516 | 0.2218 | 4.7043 | 1.7164 | 0.0123 | 12.2353 | 0.2039 | 0.2358 |
| **Total** | 2.4055 | 16.8676 | 0.892 | 15.2174 | 4.5967 | 0.0338 | 29.4495 | 0.573 | 0.5209 |

## 6.2.1. Path performance overview

The mean values of the previous tables are added together to obtain an exposure value for a ULD in three seasons and this can be compared with the overall exposure, which takes into account all seasons. A modal split is applied in the form of a weight factor (WF), which multiplies the summation of COL, CRT and ERT cargo according to the distribution of appearance. These values are presented in chapter 5.3.5. By summing up the eight paths, the total performance value is an mean value that represents the exposure of a ULD during the inbound processes. Table 6.4 shows the path performance during cold months. Appendix E contains the remainder of the tables, where figure 6.1 is based on.

Table 6.4: Path performance during cold months in Degree-Hours

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 2.4055 | 14.0745 | 2.9918 | 14.6608 | 2.0407 | 1.8669 | 2.2973 | 3.1673 | 2.7044 |
| CRT | 16.8676 | 46.989 | 21.0347 | 51.1561 | 14.0079 | 13.7737 | - | - | 15.8346 |
| ERT | 0.892 | 9.7957 | 1.4366 | 10.3403 | 0.7074 | 0.7347 | 0.7758 | 0.7199 | 1.1794 |
| **After applying modal and cargo split** | | | | | | | | | |
| COL | 0.7350 | 0.2009 | 0.3435 | 0.0761 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.7543 |
| CRT | 0.2844 | 0.0370 | 0.1333 | 0.0147 | 0.0812 | 0.0163 | - | - | 0.5669 |
| ERT | 0.1326 | 0.0680 | 0.0802 | 0.0261 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3721 |
| **Total [DH]** | 1.1519 | 0.3059 | 0.5570 | 0.1168 | 0.3319 | 0.0639 | 0.1180 | 0.0479 | 2.6933 |

**Total Exposure = 2.6933 DH**

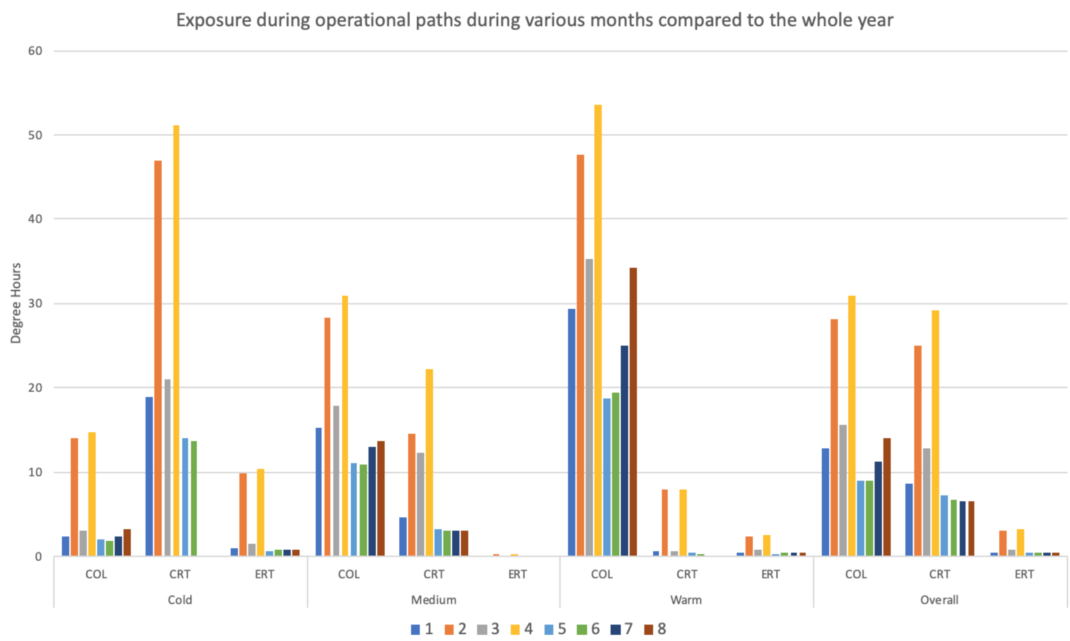


Figure 6.1: KLM Cargo inbound cargo processes

The graphs shows that during the cold months, the CRT shipments experience the most exposure. With the cargo temperature range between the 15 and 25 degrees Celsius and the ambient temperature under the 10 degrees Celsius, this was expected. With a contribution of 80 % of the total exposure, it can be said that this shipment will benefit from an improved transportation.

During the months where the ambient temperature is between 10 and 20 degrees Celsius, the COL shipments are exposed the most. It appears that the amount of COL shipments was high, it is also possible that the medium months were closer to a 20 degrees than to a 10 degrees Celsius as ambient temperature.

In the warmer months of the year, where the ambient temperature rises above 20 degrees Celsius, the COL shipments have the most quality decrease for having a temperature difference of at least 12 degrees Celsius. However, the contribution to the total is not more than 55 %, being less of influence in comparison with the CRT shipments in cold months.

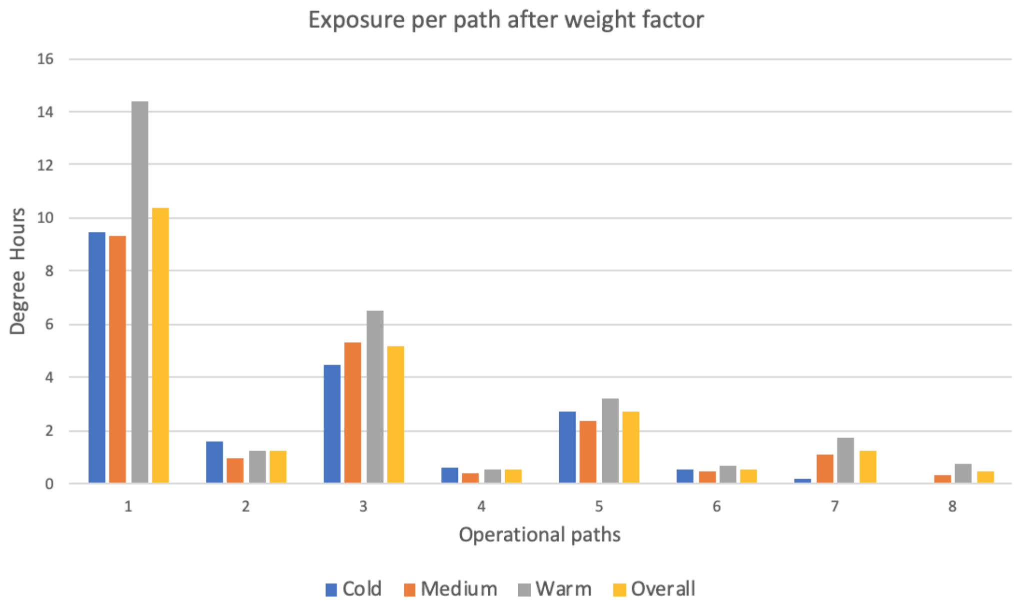


Figure 6.2: Exposure per path after weight factor

Figure 6.2 shows the exposure per path after it is multiplied with the weight factor, considering the appearance rate of the path. The cargo split is not taken into account in this graph, for the amount of occurrence is not relevant in this part. In contrast to figure 6.1, where path 2 and 4 look like the most exposed path, path 1 and 3 deliver the most exposure to the system (when looking at a single ULD).

## 6.3. Verification and validation

This data analysis has been discussed with experts of KLM Cargo and have been put next to the exposure that has been calculated in chapter 5.5.1. It shows that the values are similar to the mean values that are obtained with the model. A total exposure per ULD is calculated, supported by a modal and cargo split. Both splits have been discussed with experts in order to reach an exposure value that can be used as benchmark.

## 6.4. Conclusion data analysis

A benchmark is created that indicates the current performance of the system, supported by the model that has been setup in the previous chapter. This section contains the summary of this chapter and will answer the following sub-research question:

*Sub-research question 6: What is the performance of the current system and which processes can be improved?*

This chapter has analysed the available data set for the operations that are conducted during the inbound cargo process. Every step is provided with a time stamp and a corresponding temperature for both the environment on Schiphol as for the cargo. With this data, the exposure in Degree-Hours has been calculated.

The objective of this research is to analyse the exposure of temperature-sensitive cargo during transport on the tarmac, therefore the exposure is defined as performance indicator and determined for each step, for each type of cargo and for different seasons.

After all the steps have been analysed, eight paths have been distinguished that comprehend most of all operations as conducted by KLM Cargo. The mean exposure of every step is accumulated to a single value per type of cargo and per type of season, to create a benchmark for the system performance. This benchmark will be used as comparison in the following chapters.

The benchmark can also be used to compare the performance with each other, and by this it can be seen when the exposure is relatively high. This accounts for types of cargo during various seasons, it also shows that two paths have a higher exposure than others:

- CRT shipments during cold months
- COL shipments during medium months
- COL shipments during warm months
  The above type of cargo will be combined with the following paths:
- Path 1 during every season
- Path 3 during every season

The performances of the above mentioned (sub)systems will be keep in mind during the evaluation of the results, to indicate if they show a noteworthy improvement. This list does not yet take into account how often a shipment occurs.

# 7

# Experimental design

This chapter continues with the model that is defined in the fourth chapter and will adjust it with the improvement opportunities that are found in the literature. The experimental design contains multiple experiments that have been determined in order to gain insight in the resulting performance improvements.

This chapter will answer the following sub-research question:

7. How can an experimental design be used to quantify the performance improvement?

## 7.1. Experiment objective

Model scenarios are set up and these will be run through various model configurations. The data analysis already showed the diversity in cargo type and seasonality differences, these will be paramount as scenario input due to differences in the system performance. As explained in the fourth chapter, the purpose of the model and thus this experiment is to study the behaviour of the system in the trade-off between costs and quality. The goal is to reach an overview of which model configuration reaches a reduction in exposure and at what cost.

## 7.2. Model assumptions

To model the transportation system, the design will consist of a number of assumptions. These assumptions are made to simplify the model so the focus can lie on the main performance indicators. The assumptions regarding the insulation factor and the reduction of queue time are discussed before and not taken into account in the following list:

1. The model will have the ramp unloading as starting moment.
2. The model will have the airside lane queue as ending moment.
3. The step from the airside lane to the warehouse stands for the queuing on the airside lane.
4. Flights follow the aircraft arrival table without major disruptions.
5. There is no limit to the amount of ULD's that can be parked on the ramp.
6. Not all improvement opportunities are limitless available.
7. There is enough equipment available to be used if the amount of active personnel is extended.
8. ULD's will arrive equally divided in the system.

The first three assumptions are made based on the system analysis. Because the data set does not divide the queue time and transportation time from the airside lane, expert judgement is consulted which eventually led to neglecting the transport between airside lane and warehouse. The picking up of a ULD by a warehouse transporter is therefore the end point of the model.

Assumptions four and five are made to simplify the model. To add the possibility of disruptions would require a more comprehensive data set. The data set contains the arrived ULD's on Schiphol, data about delays or disruptions are not provided and therefore this assumption has been made. From expert consult, it is assumed that there are always enough dollies available to place ULD's on and therefore there is no limit on ULD's that can be parked on the ramp.

The sixth and seventh assumption support the analysis of the improvement opportunities, where the last assumption is used to enable this analysis to be conducted without simulation.

## 7.3. Model scenario's

Different scenarios will be used as model input, defining the cargo operations in different moments during the year, so that the outcome can deliver different views on the performance. The scenario's will describe the operational paths, conducted for different types of cargo. Every scenario will be run by all model configurations to achieve a complete image of the result with implemented improvements.

The model scenarios look into the amount of ULD's that arrive at Schiphol airport during a day. It divides the types of cargo to determine different performances. Firstly, the scenario will be run through the various configurations and decide how much equipment is necessary to achieve the performance that corresponds to the configuration. Afterwards, a cost-performance relation will be determined that will support in the determination of the most feasible improvement method.

Chapter 4.2.2 gives an indication of the time duration that a transporter requires to deliver a dolly from origin to destination. These values will be used to determine the amount of dollies are needed for transport and differ per scenario, therefore this will be determined in each subsection.

All determined performances are after the modal split is applied, so the performance per ULD can be compared. These outcomes will be set against the costs that are in play to achieve the performance, and with a cost-performance analysis the most feasible improvement opportunity will be determined.

### 7.3.1. Scenario 1

The first scenario will simulate a cold day in 2018; the 6th of February, so with ambient temperatures below 10 degrees Celsius. On this day, the maximum temperature was 1 degree Celsius and the minimum reached -4 degrees, confirming the cold day scenario. Table 6.4 presents the performance of each path during scenario 1. The table shows the exposure per type of cargo before and after multiplying it with the weight factor. It also multiplies the total exposure with a weight factor to gain one single exposure value for the exposure during cold months.

Table 7.1 shows the parameters that function to determine the required equipment and estimate the performance: the different types of cargo and the different destinations. The time duration between the first and last incoming ULD is shown and is divided by the amount of ULD's that are inbound in total, giving a time interval of 1 ULD per 5 minutes.

Table 7.1: Input data scenario 1

| Process | Type | Amount | Unit |
|---|---|---|---|
| Arrival of Cargo type | COL | 151 | ULD's |
| | CRT | 13 | ULD's |
| | ERT | 53 | ULD's |
| Time | duration | 15 | hours |
| | interval | 12 | ULD's / hour |
| Exposed ULD's in percentages | COL | 42 | % |
| | CRT | 100 | % |
| | ERT | 16 | % |
| New amount of ULD's | COL | 64 | ULD's |
| | CRT | 13 | ULD's |
| | ERT | 9 | ULD's |
| Protection methods required | Dollies | 5 | pieces |
| | Thermal blankets | 86 | pieces |

The longest ride that can be made is from the ramp to freight building 6, that is 60 minutes, being the worst case scenario. This scenario will use this duration for every transporter ride. This means that it takes 60 minutes to transport a maximum of 5 ULD's. With the assumption that the ULD's arrive at an interval of 5 minutes, 12 ULD's will arrive in the time that a max of 5 ULD's can be moved. This results in the need for 12 dollies to maintain transport.

Even though the ambient temperatures are low, table 7.2 shows that still 42 % of the incoming COL shipments is still exposed. Therefore, the arrival of the ULD's that require protection is adjusted to 64 COL shipments. From the ERT shipments, 16 % is exposed and therefore that amount of incoming cargo is adjusted to 9 ULD's. This results in a new inbound number of 86 ULD's. This is 40 % of the original incoming ULD's. Assuming that the cargo is divided normally, the amount of **protective dollies** that is necessary results in 5.

### 7.3.2. Scenario 2

The second scenario will simulate an medium temperature day in 2018, so with ambient temperatures between 10 and 20 degrees Celsius. The chosen day is the 29th of August, with a minimum ambient temperature of 11 degrees and a maximum of 20 degrees Celsius. Figure C.10, presented in Appendix C, shows the performance of all paths per type of cargo during the medium temperature months.

Table 7.2 shows the number of different shipments that arrived on the 29th of August and what the destination of each ULD was. Likewise to the first scenario, the COL shipments are in the majority again. With more ULD's coming in during a shorter total time duration, the amount of ULD's that have to be processed is 4 per minutes.

Table 7.2: Input data scenario 2

| Process | Type | Amount | Unit |
|---|---|---|---|
| Arrival of Cargo type | COL | 158 | ULD's |
| | CRT | 14 | ULD's |
| | ERT | 35 | ULD's |
| Exposed ULD's in percentages | COL | 92.5 | % |
| | CRT | 51 | % |
| | ERT | 1 | % |
| New amount of ULD's | COL | 147 | ULD's |
| | CRT | 8 | ULD's |
| | ERT | 0 | ULD's |
| Time | duration | 14 | hours |
| | interval | 15 | ULD's / hour |

The transport duration of 60 minutes will be taken again as the rides to freight building 6 is the longest ride that can be executed. With 1 ULD arriving every 4 minutes, 15 ULD's will arrive in an hour while 5 ULD's can be moved away at the same time, resulting in a total of 15 dollies.

Table 7.2 shows the amount of shipments that is not exposed during transport in medium temperature months. It shows that 92.5 % of the COl shipments is exposed and 51 % of the CRT shipments. The ERT shipments are negligible for having a low exposure percentage value. Redetermining the amount of inbound shipments, the COL shipments is reset on 147 ULD's that are exposed plus 8 exposed CRT shipments. Without the ERT shipments, the total amount of inbound ULD's in scenario 2 leads to 155 ULD's which is still 75% of the original amount of ULD's. With the assumption that the ULD's are normally distributed, the amount of **protective dollies** that is necessary results in 12.

### 7.3.3. Scenario 3

The third scenario will simulate a warm temperature day in 2018, so with ambient temperatures above 20 degrees Celsius. The chosen day is the 25th of July, with a maximum ambient temperature of 30 degrees and a minimum of 20 degrees Celsius. Figure C.11 in Appendix C shows the performance of all paths per type of cargo during the warmer months in 2018. Table 7.3 shows the number of different shipments that has arrived on the 25th of July.

This scenario processes 90 ULD's of temperature-sensitive cargo during the whole day, which operations being conducted over a time duration of 15 hours. This leads to a time interval of 1 ULD per 10 minutes, and 6 ULD's per hour. During this hour, maximum 5 ULD's and thus 5 dollies can be transported by one transporter. This means that there should be one dolly extra to store the sixth ULD, which results in a total of 6 dollies.

Table 7.3 presents the exposure percentages, showing that the COl shipments are entirely exposed during warm months. The CRT shipments are still quite exposed and even the ERT shipments a significant amount. With this exposure, the amount of incoming ULD's are redetermined and this results in 1 CRT shipment and 1 ERT shipment, which brings the total to 74 temperature-sensitive shipments. This amount is still more than 80 % of the original amount of ULD's. Assuming a normal distribution within the arrival of ULD's, the amount of **protective dollies** that is necessary results in 5.

Table 7.3: Input data scenario 3

| Process | Type | Amount | Unit |
|---|---|---|---|
| Arrival of Cargo type | COL | 72 | ULD's |
| | CRT | 6 | ULD's |
| | ERT | 12 | ULD's |
| Exposed ULD's in percentages | COL | 100 | % |
| | CRT | 15 | % |
| | ERT | 9 | % |
| New amount of ULD's | COL | 72 | ULD's |
| | CRT | 1 | ULD's |
| | ERT | 1 | ULD's |
| Time | duration | 15 | hours |
| | interval | 6 | ULD's / hour |

## 7.4. Model configurations

This section will discuss the various improvement opportunities that are listed as model configurations. The first four configurations represent the protection methods: the animal dolly, the thermal blanket, a temperature-controlled dolly or cool dolly and finally the cool reefer. The latter two configurations are regarding the increase of available equipment.

### 7.4.1. Configuration 1: Animal dolly

When the scenario is run by the first configuration, the exposure is reduced by using an animal dolly. The KPI will be improved because the insulation factor changes from 1 to 0.7. The results will show the improvement in percentages. However, to achieve this performance improvement, each incoming ULD should be able to be transported with an animal dolly. To make sure that all incoming cargo benefits from this protection method, each scenario has an amount of dollies that it requires, which will lead to a cost overview based on the following data:

- Capacity: 1 ULD
- Costs animal dolly: 30,000 euros
- Amount of animal dollies already in possession: 4
- Lifespan: 15 years

### 7.4.2. Configuration 2: Thermal blanket

The second configuration looks into the reduction of exposure by covering the cargo with thermal blankets. The thermodynamic characteristics of such a blanket are simplified for this research and therefore all taken as one sort, with an insulation factor of 0.3. It is assumed that a thermal blanket is used only once, for it goes around the cargo from an outstation and leaves again for the outbound shipments. The returnable logistics are not taken into account in this analysis.

Because the thermal blankets can be specified more accurate, for the amount of ULD's and the percentage of exposed values is known plus the fact that every ULD requires a blanket, the costs can be determined to protect each ULD against ambient temperature.

- Capacity: 1 ULD
- Costs thermal blanket: 20 euros
- Lifespan: 1 day

### 7.4.3. Configuration 3: Cool dolly

The third configuration stands for the climate-controlled dolly, also known as the cool dolly. The insulation factor of this dolly is assumed to be zero, due to its active cooling system. The integration of this improvement almost equals a perfect protection, which comes at a high cost. The lifespan is including the fact that battery maintenance is conducted multiple times, the costs for this maintenance is part of the 80,000 cost per dolly.

- Capacity: 1 ULD's
- Costs cool dolly: 80,000 euros
- Lifespan: 15 years

### 7.4.4. Configuration 4: Cool reefer

The fourth configuration stands for the climate-controlled reefer, also known as the cool reefer. The insulation factor of this dolly is assumed to be zero, due to its active cooling system. The integration of this improvement almost equals a perfect protection, which comes at a high cost like the cool dolly. Similar, the battery maintenance is conducted and both the lifespan as the costs have taken this already into account.

- Capacity: 4 ULD's
- Costs cool dolly: 400,000 euros
- Lifespan: 15 years

### 7.4.5. Configuration 5: Decrease queue time on ramp

The fifth configuration is related to the reduction of queue time by deploying more personnel and thus equipment. If there are more vehicles available to move the ULD's from origin to destination, the total time duration on the tarmac will decrease and this will result in a decrease in exposure. It is not possible to add an extra lift to the process, so the number of ground vehicles will be enlarged. Because all vehicles are limited by speed regulations, the added vehicles will not change the transportation time but only on the queue times. This configuration focuses on a decrease of queue time on the ramp as a result of adding more personnel, as the equipment is already present on cargo grounds.

- Extra equipment: already present
- Costs per employee per shift: 100 euros
- Cost for an extra employee during all shifts: 300 euros

### 7.4.6. Configuration 6: Decrease queue time outside warehouse

Like the fifth configuration, this configuration focuses on a reduction of queue time. By extending the amount of available equipment near the warehouse, the queue time on the airside lane is expected to decrease. Because the equipment is already present, the focus lies on extending the amount of personnel that is active.

- Extra equipment: already present
- Costs per employee per day: 100 euros
- Cost for an extra employee during all shifts: 300 euros

### 7.4.7. Configurations 7 - 10

Configurations 7 to 10 are related to the deployment of extra personnel and they come with a decrease of queue time near the ramp or near the warehouse. Table 7.4 will summarise the configurations with the amount of personnel and the queue time decrease.

Table 7.4: Personnel expansion configurations

| Configuration | Decrease queue time [%] | Location | Personnel per day |
|---:|---|---|---|
| 5 | 10 | Ramp | 3 |
| 6 | 10 | Warehouse | 3 |
| 7 | 25 | Ramp | 6 |
| 8 | 25 | Warehouse | 6 |
| 9 | 50 | Ramp | 9 |
| 10 | 50 | Warehouse | 9 |

### 7.4.8. Configurations costs

The exposure reduction that could be achieved with the above mentioned configurations come at certain costs, as shown in table 7.5. These costs will be used in the cost-performance relation overview in the results chapter. The cost of configuration 1, 3 and 4 should be seen as an investment that lasts for 15 years, where the other configuration costs are based on daily operations. The table presents the costs for these configurations also on daily basis, with as side-note that these configurations require a heavy investment. The cost for configuration 2, i.e. the thermal blanket, depends on the amount of ULD's that is processed.

Table 7.5: Configuration costs overview

| Configuration | Cost per unit in Euros | Lifespan | Cost per day in Euros |
|---|---|---|---|
| 1 - *Animal dolly* | 30,000 | 15 years | 5 |
| 2 - *Thermal blanket* | 20 | 1 day | 20 * # ULD's |
| 3 - *Cool dolly* | 80,000 | 15 years | 15 |
| 4 - *Cool reefer* | 400,000 | 15 years | 73 |
| 5 - *Queue time ramp -10%* | 300 | 1 day | 300 |
| 6 - *Queue time warehouse -10%* | 300 | 1 day | 300 |
| 7 - *Queue time ramp -25%* | 600 | 1 day | 600 |
| 8 - *Queue time warehouse -25%* | 600 | 1 day | 600 |
| 9 - *Queue time ramp -50%* | 900 | 1 day | 900 |
| 10 - *Queue time warehouse -50%* | 900 | 1 day | 900 |

## 7.5. Experiments

The three different scenarios that are analysed with the ten different configurations bring a total of 30 experiments. They are summarised in table 7.6 and the following chapter will elaborate on the results, being the performance of a ULD under different circumstances and at what costs these performances are achieved.

Table 7.6: Experiments

| **Experiment** | **Scenario** | **Configuration** |
|---|---|---|
| 1 | Cold | Animal dolly |
| 2 | Cold | Thermal blanket |
| 3 | Cold | Cool dolly |
| 4 | Cold | Cool reefer |
| 5 | Cold | Queue time ramp -10% |
| 6 | Cold | Queue time warehouse -10% |
| 7 | Cold | Queue time ramp -25% |
| 8 | Cold | Queue time warehouse -25% |
| 9 | Cold | Queue time ramp -50% |
| 10 | Cold | Queue time warehouse -50% |
| 11 | Medium | Animal dolly |
| 12 | Medium | Thermal blanket |
| 13 | Medium | Cool dolly |
| 14 | Medium | Cool reefer |
| 15 | Medium | Queue time ramp -10% |
| 16 | Medium | Queue time warehouse -10% |
| 17 | Medium | Queue time ramp -25% |
| 18 | Medium | Queue time warehouse -25% |
| 19 | Medium | Queue time ramp -50% |
| 20 | Medium | Queue time warehouse -50% |
| 21 | Warm | Animal dolly |
| 22 | Warm | Thermal blanket |
| 23 | Warm | Cool dolly |
| 24 | Warm | Cool reefer |
| 25 | Warm | Queue time ramp -10% |
| 26 | Warm | Queue time warehouse -10% |
| 27 | Warm | Queue time ramp -25% |
| 28 | Warm | Queue time warehouse -25% |
| 29 | Warm | Queue time ramp -50% |
| 30 | Warm | Queue time warehouse -50% |

## 7.6. Conclusion experimental design

Different scenarios and configurations are determined and the experimental design contains thirty experiments that will be run by the model and analysed. This section contains the summary of this chapter and will answer the following sub-research question:

*Sub-research question 7: How can an experimental design be used to quantify the performance improvement?*

An experimental design contains a model that is setup in advance and applied in different scenario's under various circumstances. Three scenario's have been distinguished, focusing on a cold day, an medium temperature day and a warm day in the Netherlands in 2018. Besides the scenario's, there are ten configurations determined that could have an impact on the current state in terms of decreasing the exposure of the cargo.

Every scenario is run by each configuration, resulting in 30 experiments. Each experiment shows the exposure for a different season and how this exposure is reduced as a result of an improvement method. These results are then compared per configuration to show the most feasible improvement.

With the characteristics per scenario, the amount of protective methods can be determined to achieve the exposure reduction. This amount can be linked to cost and eventually a cost-performance analysis can be conducted to end up with the most feasible improvement opportunity per scenario.

# 8

# Results and evaluation

This chapter will deepen in the experiments that are set up in the previous chapter, and it will discuss the outcome of these results. Every outcome will be compared with the system analysis, which functions as a benchmark. The chapter will end with an overview of the exposure reduction percentage for all configurations with the corresponding costs.

## 8.1. Exposure decrease

The performance of the experiments will be treated in threefold, for each scenario comprehends 10 experiments. Most of the results can be found in Appendix F, where three tables will show the exposure during each operational path for each type of cargo and the reduction that has been achieved due to the configurations. Each scenario shows a graph with the exposure reduction before the cargo split is applied, the table with the overall exposure reduction per experiment includes the cargo split.

### 8.1.1. Scenario 1

The first scenario required 5 protective dollies to transport the 86 ULD's that otherwise would be fully exposed. In case of the thermal blankets, 86 units should be applied to reduce the exposure. Table 8.1 shows an impression how the exposure is reduced in case of the first experiment, the application of an animal dolly. The first rows are the benchmark, followed by the improved state. The bold numbers give the total exposure of a single ULD, taking into account the possibility it could pass any path and could contain each type of cargo. This experiment gives an exposure decrease of 29.7 %.

Table 8.1: Experiment 1 in Degree-Hours

| Type | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | COL | 0.7350 | 0.2009 | 0.3435 | 0.0761 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.7543 |
| K=1 | CRT | 0.2844 | 0.0370 | 0.1333 | 0.0147 | 0.0812 | 0.0163 | - | - | 0.5669 |
| | ERT | 0.1326 | 0.0680 | 0.0802 | 0.0261 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3721 |
| Total | | 1.1519 | 0.3059 | 0.5570 | 0.1168 | 0.3319 | 0.0639 | 0.1180 | 0.0479 | **2.6933** |
| | COL | 0.5169 | 0.1407 | 0.2414 | 0.0533 | 0.1510 | 0.0281 | 0.0713 | 0.0303 | 1.2330 |
| K=0.7 | CRT | 0.2002 | 0.0260 | 0.0937 | 0.0103 | 0.0572 | 0.0115 | - | - | 0.3988 |
| | ERT | 0.0932 | 0.0476 | 0.0563 | 0.0183 | 0.0255 | 0.0054 | 0.0117 | 0.0034 | 0.2614 |
| Total | | 0.8103 | 0.2143 | 0.3914 | 0.0819 | 0.2337 | 0.0450 | 0.0830 | 0.0337 | **1.8931** |

Figure 8.1 gives a more graphical insight in the differences between the exposure during the current state and the first experiment on terms of COL, CRT or ERT for each operational path. As said in previous chapters, the first and third path of CRT shipments show the most decrease. When having in mind that in scenario 1 there are only 13 CRT shipments versus 64 COL shipments, this will not become the main focus of the results.

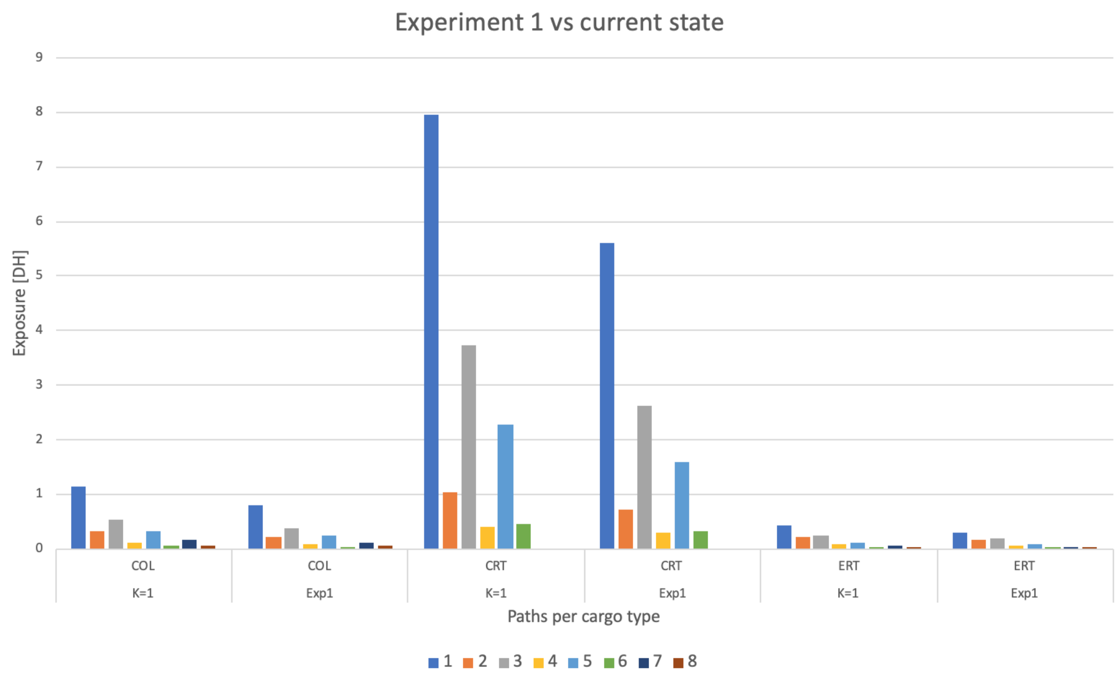


Figure 8.1: Experiment 1

Table 8.2 shows all experiments with the corresponding exposure reductions. It shows that the third and fourth experiment, consisting of the cool dolly and cool reefer, gain the most reduction in exposure whereas the personnel expansion in experiment 5 and 6 gain the least.

Table 8.2: Exposure decrease Scenario 1

| Experiment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction [%] | 29.7 | 70.0 | 99.0 | 99.0 | 5.0 | 2.9 | 12.4 | 7.2 | 24.8 | 14.4 |

### 8.1.2. Scenario 2

The second scenario required 12 protective dollies to transport 155 ULD's to it's destination. In the case of configuration 2, 155 thermal blankets are required. Table 8.3 shows how experiment 19 decreases the exposure with a total of 25.8 %, as result of expanding the personnel near the ramp. With three extra employees deployed, the queue time on the ramp is assumed to be halved.

Table 8.3: Experiment 19 in Degree-Hours

| Type | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| K=1 | COL | 4.6731 | 0.4057 | 2.0596 | 0.1612 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 9.4752 |
| | CRT | 0.0788 | 0.0117 | 0.0787 | 0.0065 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.2084 |
| | ERT | 0.0050 | 0.0022 | 0.0029 | 0.0009 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0132 |
| Total | | 4.7569 | 0.4196 | 2.1411 | 0.1686 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | **9.6968** |
| $\Delta t_{ramp} * 0.5$ | COL | 3.4677 | 0.3494 | 1.6066 | 0.1408 | 0.7645 | 0.1503 | 0.4000 | 0.1339 | 7.0132 |
| | CRT | 0.0584 | 0.0108 | 0.0710 | 0.0061 | 0.0122 | 0.0023 | 0.0045 | 0.0014 | 0.1667 |
| | ERT | 0.0037 | 0.0022 | 0.0024 | 0.0008 | 0.0006 | 0.0002 | 0.0005 | 0.0002 | 0.0106 |
| Total | | 3.5298 | 0.3623 | 1.6800 | 0.1477 | 0.7774 | 0.1527 | 0.4051 | 0.1355 | **7.1906** |

Figure 8.2 shows a graphical comparison between the two states and it can be seen that the COL shipments for the first and third path are improved significantly, as predicted in the sixth chapter. Taking into account the fact that this scenario processes an amount of 147 ULD's containing a COL shipment, this outcome will be return in the evaluation.

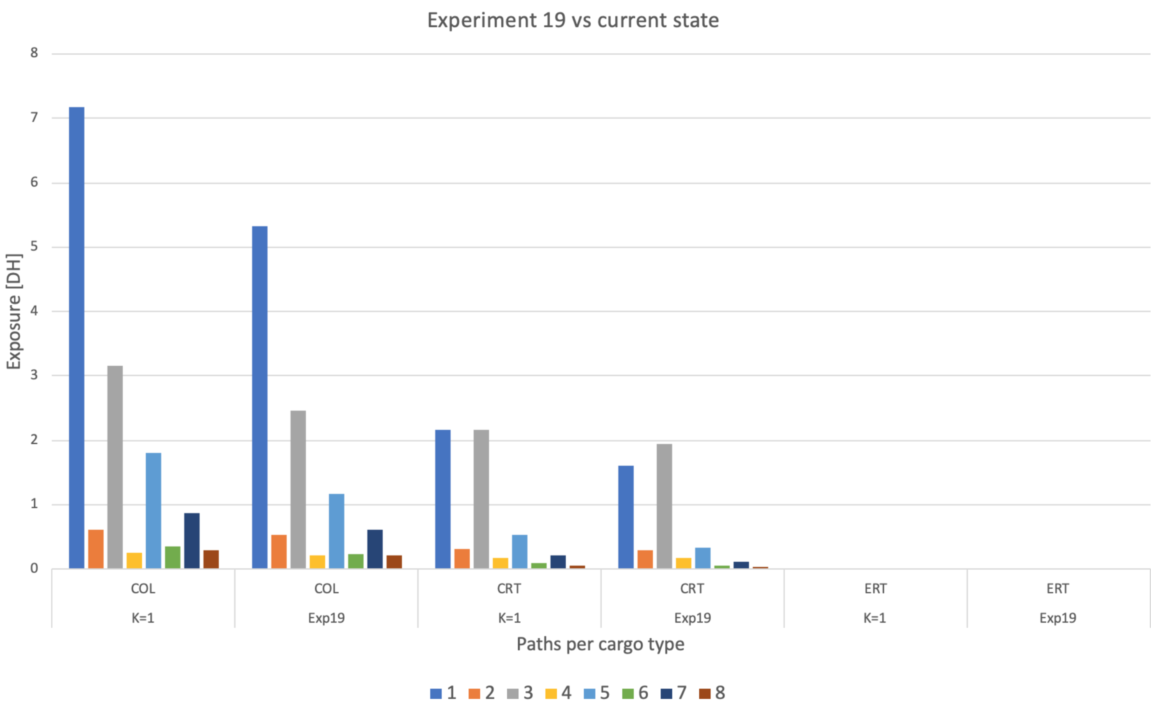


Figure 8.2: Experiment 19

If the exposure reductions of all experiments within scenario 2 are compared, it is not rare that the third and fourth again show the most improvement. With an insulation factor of K=0, this is expected for any case. It is important to look at the improvement scenario's that follow the cool dolly and cool reefer configurations, because eventually they will be compared in costs with the cool dolly and cool reefer. It shows that experiment 12 is a good runner-up, and after a large gap experiments 11 and 19 still retain a decent decrease in exposure.

Table 8.4: Exposure decrease Scenario 2

| Experiment | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction [%] | 29.7 | 70.0 | 98.9 | 98.9 | 5.2 | 2.5 | 12.9 | 6.2 | 25.8 | 12.3 |

### 8.1.3. Scenario 3

The third scenario required 5 protective dollies to transport 74 ULD's to it's destination. In the case of configuration 2, 74 thermal blankets are required. Table 8.5 shows how experiment 30 decreases the exposure with a total of 16.0 %, as result of expanding the personnel near the warehouse. With three extra employees deployed, the queue time near the warehouse is assumed to be halved.

Table 8.5: Experiment 30 in Degree-Hours

| Type | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| K=1 | COL | 8.6581 | 0.6546 | 3.9037 | 0.2674 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 17.2962 |
| | CRT | 0.0107 | 0.0069 | 0.0046 | 0.0025 | 0.0029 | 0.0004 | - | - | 0.0282 |
| | ERT | 0.0824 | 0.0170 | 0.0456 | 0.0068 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1884 |
| Total | | 8.7513 | 0.6786 | 3.9538 | 0.2768 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | **17.5128** |
| $\Delta t_{wh} * 0.5$ | COL | 6.8595 | 0.4455 | 3.2278 | 0.1914 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 14.5366 |
| | CRT | 0.0088 | 0.0036 | 0.0038 | 0.0013 | 0.0029 | 0.0004 | - | - | 0.0210 |
| | ERT | 0.0638 | 0.0096 | 0.0386 | 0.0041 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1526 |
| Total | | 6.9321 | 0.4587 | 3.2702 | 0.1969 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | **14.7102** |

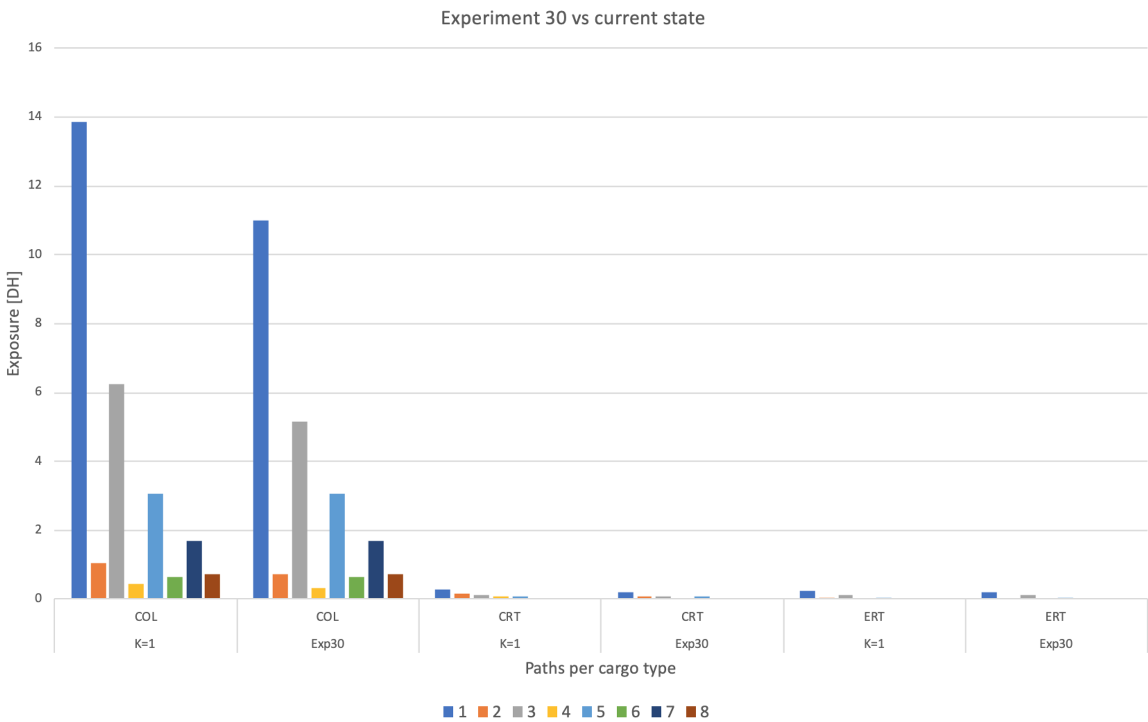


Figure 8.3: Experiment 30

Figure 8.3 graphically shows the exposure reduction of all types of cargo as a result of this experiment. As expected in the sixth chapter, the COL shipments again show the most decrease. The exposure for CRT and ERT shipments are practically zero in both the benchmark as for the improved state. Looking into the characteristics of the scenario, 97 % of the ULD's concern COL shipments stating that this could be of value.

Table 8.6 presents the final batch of exposure reductions as result of experiments 21 to 30, calculated for scenario 3. Again looking at the runners up behind the cool dolly and cool reefer, the thermal blanket is showing a decent decrease as well. Experiments 21 and 29, with respectively 29.7 % and 22.5 % will also be evaluated in the cost-performance analysis.

Table 8.6: Exposure decrease Scenario 3

| Experiment | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction | 29.7 | 70.0 | 99.0 | 99.0 | 4.5 | 3.2 | 11.3 | 8.0 | 22.6 | 16.0 |

## 8.2. Improvement costs

All scenario's come with different costs. This section will discuss the costs that are in play for each scenario separately and how it corresponds with the exposure reductions. It will look at the cost for a day, equal to the scenario characteristics, but it will also determine the long-term costs.

### 8.2.1. Scenario 1

The first scenario is based on the application of 5 dollies, or 86 thermal blankets. In the case of a cool reefer, which has a capacity of 4 ULD's, it is assumed that 2 cool reefers will be sufficient. Scenario 1 is set on a cold day, according to chapter 3.2 these cold days find place 5 months a year. The costs to cover for the cold part of 2018 will be analysed as well.

Table 8.7 gives a summary of the first ten experiments with the corresponding exposure reduction in percentages. The cost values marked with an asterisk indicate that these experiments require a large investment.

Table 8.7: Cost versus performance Scenario 1

| Experiment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction [%] | 29.7 | 70.0 | 99.0 | 99.0 | 5.0 | 2.9 | 12.4 | 7.2 | 24.8 | 14.4 |
| Total cost per day in Euros | 25* | 1720 | 75* | 146* | 300 | 300 | 600 | 600 | 900 | 900 |
| Cost in 2018 in 1000 Euros | 3.8 | 258.0 | 11.3 | 21.9 | 45.0 | 45.0 | 90.0 | 90.0 | 135.0 | 135.0 |

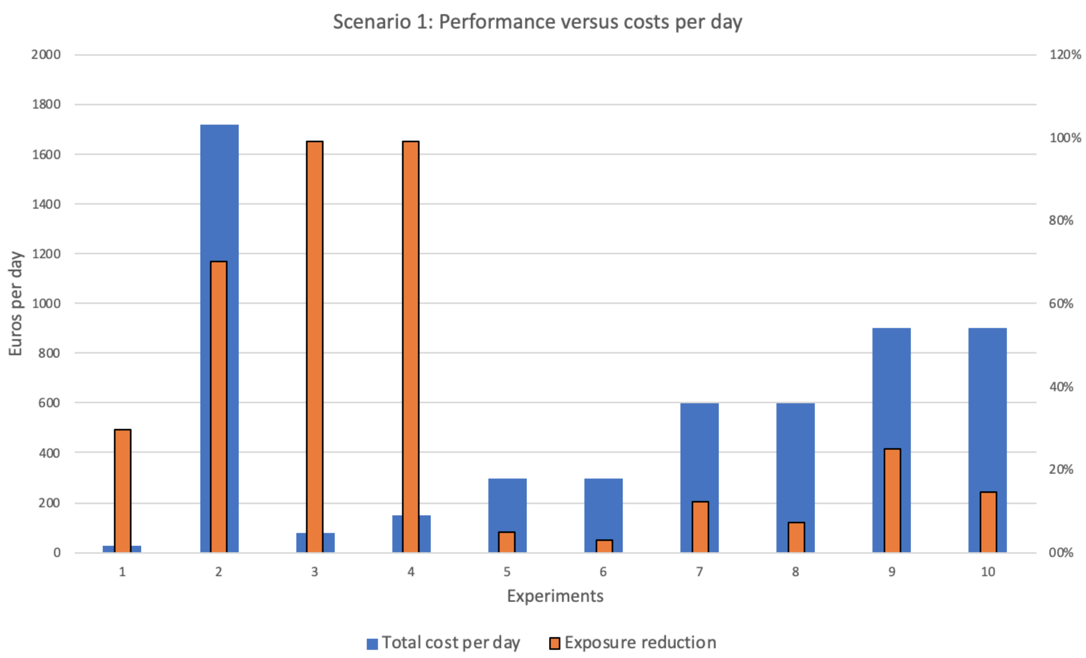


Figure 8.4: Cost versus performance Scenario 1

The table and figure above show that for the cold period in 2018, experiments 2, 9 and 10 are the most expensive. Experiments 9 and 10 offering less improvement than for experiment 1, 3 and 4 whilst being more expensive, although experiments 1, 3 and 4 require a higher investment plus storage capacity where experiments 9 and 10 can be deployed when needed.

### 8.2.2. Scenario 2

The second scenario is based on the application of 12 dollies, or 155 thermal blankets. In the case of a cool reefer, which has a capacity of 4 ULD's, it is assumed that 3 cool reefers will be sufficient. Scenario 2 is set on a day with medium temperatures, according to chapter 3.2 these medium days find place 4 months a year. The costs to cover for the cold part of 2018 will be analysed as well.
Table 8.8 gives a summary of the second ten experiments with the corresponding exposure reduction in percentages. The cost values marked with an asterisk indicate that these experiments require a large investment.

Table 8.8: Cost versus performance Scenario 2

| Experiment | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction [%] | 29.7 | 70.0 | 98.9 | 98.9 | 5.2 | 2.5 | 12.9 | 6.2 | 25.8 | 12.3 |
| Total cost per day in Euros | 60* | 3,100 | 180* | 219* | 300 | 300 | 600 | 600 | 900 | 900 |
| Cost in 2018 in 1000 Euros | 7.2 | 372.0 | 21.6 | 26.3 | 36.0 | 36.0 | 72.0 | 72.0 | 108.0 | 108.0 |

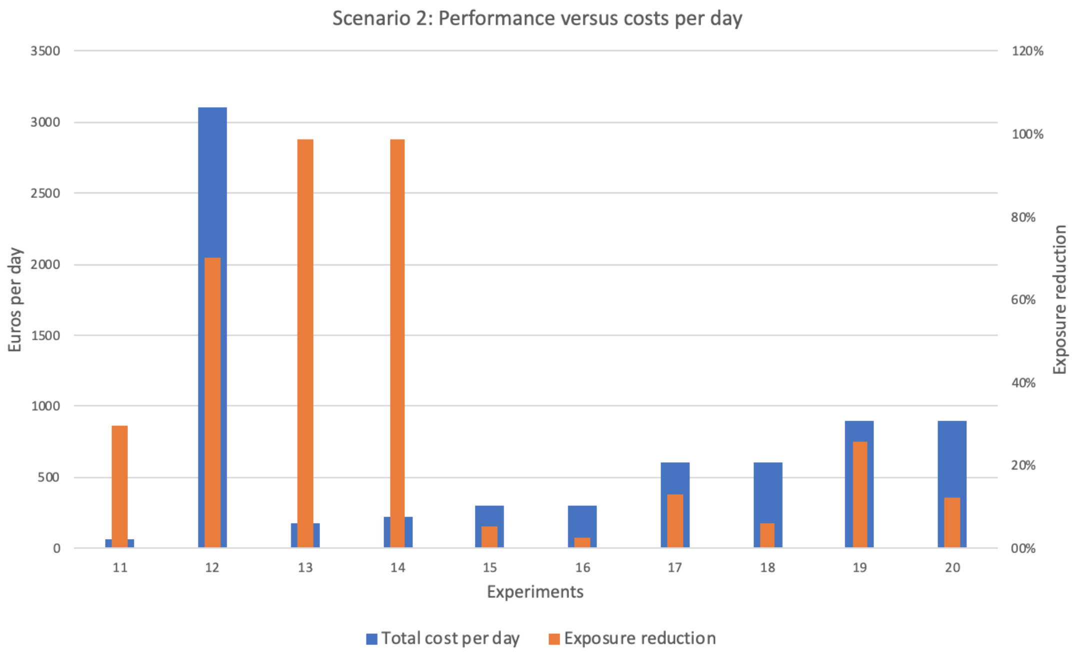


Figure 8.5: Cost versus performance Scenario 2

The table and figure are showing that the experiments containing the thermal blanket and maximum expansion of personnel are the most expensive. Experiments 17 and 18 are twice as expensive as experiments 15 and 16 but offer more than twice as much improvement in the performance.

### 8.2.3. Scenario 3

The final scenario is based on the application of 5 dollies, or 74 thermal blankets. In the case of a cool reefer, which has a capacity of 4 ULD's, it is assumed that 2 cool reefers will be sufficient. Scenario 3 is set on a warm day, according to chapter 3.2 these warm days find place 3 months a year. The costs to cover for the cold part of 2018 will be analysed as well.

Table 8.9 gives a summary of the second ten experiments with the corresponding exposure reduction in percentages. The cost values marked with a * indicate that these experiments require a large investment.

Table 8.9: Cost versus performance Scenario 3

| Experiment | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| Exposure reduction | 29.7 | 70.0 | 99.0 | 99.0 | 4.5 | 3.2 | 11.3 | 8.0 | 22.6 | 16.0 |
| Total cost per day in Euros | 25* | 1480 | 75* | 146* | 300 | 300 | 600 | 600 | 900 | 900 |
| Cost in 2018 in 1000 Euros | 2.3 | 133.2 | 6.8 | 13.1 | 27.0 | 27.0 | 54.0 | 54.0 | 81.0 | 81.0 |

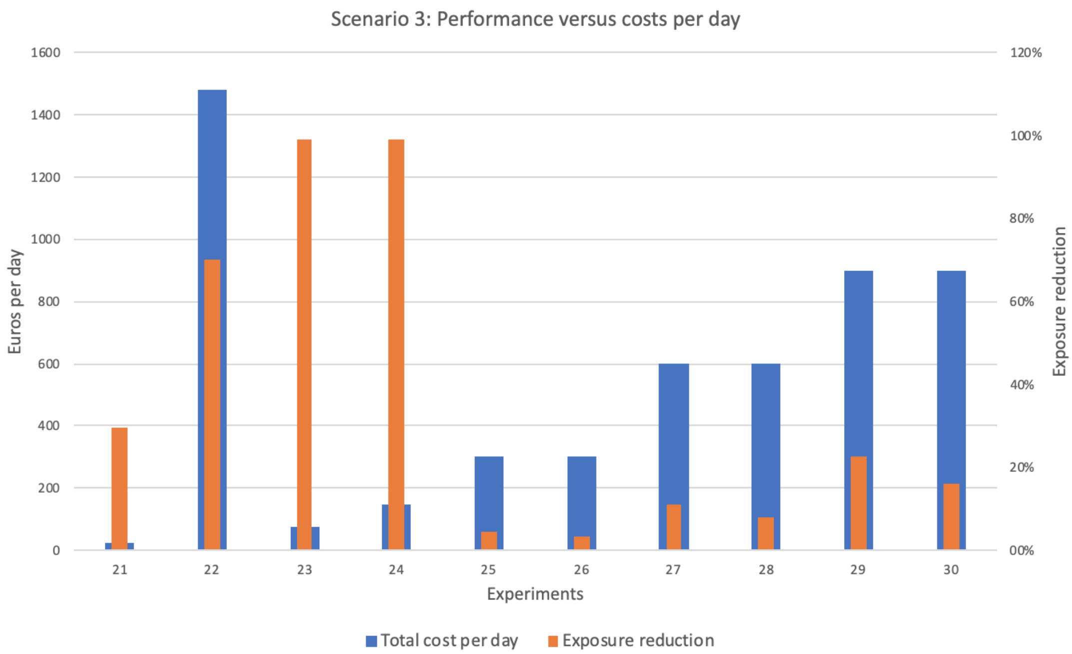


Figure 8.6: Cost versus performance Scenario 3

## 8.3. Evaluation

This section will finalise the results, evaluating the exposure decrease per improvement opportunity and the corresponding costs. It concludes with the most feasible improvement method for the short-term and long-term period at KLM Cargo.

The three scenario's have described the exposure of a ULD during a day. A cargo handling company like KLM Cargo tends to offer a certain performance for a longer period, therefore the results are put together to obtain a cost-performance overview for the whole year of 2018. Table 8.10 shows the aggregation of all scenario's, comparing the ten configurations and the corresponding exposure decreases. The exposure decrease is the average of the three scenario's, taking the lenght of the scenario's into account.

Table 8.10: Cost-Performance overview

| Configuration | Total costs per year in Euros | Exposure decrease |
|---|---|---|
| 1 - *Animal dolly* | 13,200 | 29.7% |
| 2 - *Thermal blanket* | 763,200 | 70.0% |
| 3 - *Cool dolly* | 39,600 | 99.0% |
| 4 - *Cool reefer* | 61,320 | 99.0% |
| 5 - *Queue time ramp -10%* | 108,000 | 4.9% |
| 6 - *Queue time warehouse -10%* | 108,000 | 2.8% |
| 7 - *Queue time ramp -25%* | 216,000 | 12.3% |
| 8 - *Queue time warehouse -25%* | 216,000 | 7.1% |
| 9 - *Queue time ramp -50%* | 324,000 | 24.6% |
| 10 - *Queue time warehouse -50%* | 324,000 | 14.1% |

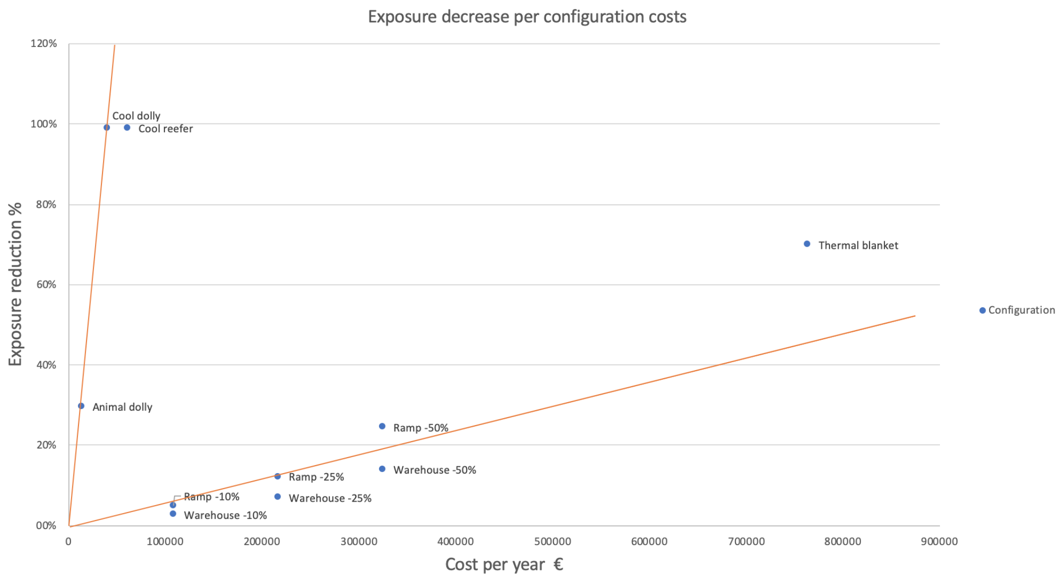


Figure 8.7: Cost-performance overview

Table 8.10 and figure 8.7 show the decrease in exposure for a whole year and at what cost this can be realised. It shows that all six configurations regarding the increase of personnel, and thus the decrease of the queue time, has a low impact at a high cost. This shows that the most exposure is experienced during the transport of ULD's, and that during this process the cargo needs to be protected from ambient temperature.

What remains are the four protective configurations, where there are more issues to take into account. The investment of a cool dolly or cool reefer is an expensive one and these need recharging possibilities as storage areas. For the dimensions of the cool reefer it is uncertain if it can operate on every spot of the airport. The thermal blankets, when looking at the one-use only characteristic, come at a high price. Besides the price, ground personnel should be trained extra to implement the extra handling of applying a thermal blanket. However, the utilisation of thermal blankets would not be limited to Amsterdam but offers protection during the flight and on outstations as well, where the dollies only can be active on Schiphol grounds.

For the short term, the animal dolly is a feasible improvement to the system. With already a few in the current equipment, measurements could be conducted to see if the exposure is decreased as analysed. For a small period, the performance of the system can increase while parallel the research to the cool dolly can be continued. For the long-term, the cool dolly proves a high decrease in the exposure at a proper cost price.

Eventually, when looking at the paths and the seasonality, it is shown that the first and third path are experiencing the most exposure to ambient temperature. The COL shipments suffer the most during the medium and warmer temperature months, where the CRT shipments have the most exposure during the cold months. However, it seems that the amount of CRT shipments in general is quite low. This means that when extreme weather circumstances are expected, the COL shipments during the first or third sequence of operations should have a high priority to be protected.

# 9 Conclusion and recommendations

This chapter concludes the case study that is conducted at KLM Cargo. By reflecting on the sub-research questions, the research will be finalised with conclusions that can be drawn from the answers. These will support in answering the main research question. Subsequently, recommendations will be discussed for future research, as for KLM specific.

## 9.1. Conclusions

The main research question will be answered more easily when the answers to the sub-research questions are known, therefore these will be discussed as buildup before answering the main question.

*Sub-research question 1: What characteristics can be identified that relate to the transport of temperature-sensitive cargo?*

The corresponding characteristics that relate to the transport of temperature-sensitive cargo can be divided over cargo types, cargo temperatures, climate characteristics and the availability of resources. The temperature-sensitive cargo can be categorised under perishables and pharmaceuticals. Temperature-sensitive cargo is defined by special handling codes; COL, ERT and ERT, each indicating a different temperature range that the shipment is required to comply. The combination of time and temperature will determine if a shipment is affected by the ambient temperature and to what extent. This exposure will be strongly dependent on seasonality as well, for a cold shipment will be less exposed during winter and a warmer shipment has the same during spring or summer.

*Sub-research question 2: What operations are present in the transportation of temperature-sensitive cargo and how can the performance of these processes be measured?*

The operations that are present can be seen as either inbound or outbound shipments. The whole system can be seen as several subsystems linked to each other, the inbound and outbound system are mostly similar with equal transport and queue subsystems present and they share the present elements.

The inbound system regards the unloading of the aircraft, transporting the cargo from the ramp towards the warehouse. In certain occasions, depending on the origin of the aircraft, the cargo should pass the customs clearance first, for it may contain forbidden goods. When the warehouse is reached, the shipment will be transferred into a storage. The outbound system goes the other way around. Temperature-sensitive shipments are unloaded from the storage and transferred outside the warehouse. From outside the warehouse, transport vehicles ensure the cargo gets delivered near the aircraft prior departure.

During the transfer from different transportation methods, the cargo is waiting to be picked up. During this queuing, but also during transport on the tarmac, the shipment is exposed to ambient temperature for a longer period than necessary and therefore can be seen as steps that have room for improvement. This improvement can come in the form of increasing the work capacity and thus decreasing the queue time, another possibility is to decrease the exposure by applying a protective solution on the cargo. To quantify the current system performance and the possible improvement, the key performance indicator will be used.

*Sub-research question 3: What is the current state of the tarmac process within the cool chain at KLM Cargo?*

The current state of the cool chain is described by looking into the transport of temperature-sensitive cargo at KLM grounds. Parmaceuticals and perishable cargo is transported in temperature ranges between 2 - 8 (COL), 15 - 25 (CRT) and 2 - 25 (ERT) degrees Celsius. Most of the operations that are conducted at KLM Cargo follow each other and therefore eight paths have been determined. These paths, when aggregated, contain the most of all inbound operations regarding temperature-sensitive cargo.

With help of the literature study and the analysis of the current state, a KPI is selected. To measure the performance of the current state it is chosen to analyse the exposure in Degree-Hours. This has been favourable for it takes into account all types of cargo and it is applicable to the transportation problem.

*Sub-research question 4: Which operations at KLM Cargo show room for improvement and how can this improvement be realised?*

The available data contains information about the time of pickup and drop-off of a ULD and also the location of both moments. With this data, the time duration of transport from origin to destination can be determined. This indicates which routes and which sequence of paths have been conducted in which numbers. This serves as a support to create a modal and cargo split, in which the performance of one ULD can be calculated while taking into account the possibility of all going to any destination, also taking into account the occurence of different types of cargo.

*Sub-research question 5: How can a model be used to analyse the performance of the tarmac process within the cool chain?*

A mathematical model is created to determine the current performance and can be adjusted to analyse the improved, possible future state at KLM Cargo. The exposure function is setup and can be run for different scenarios under several configurations. The model outcome shows the exposure in Degree-Hours and shows the current state that is used as benchmark and also the improved paths so a comparison can be conducted.

The earlier determined KPI is used as main equation in the model. The input data is historical and measured during the conducted operations, the time duration by the employees or by a sensor that measures the ambient temperature on Schiphol during the whole year each half an hour. All used data is verified and validated with support of expert opinions in order to continue using the model.

The time and temperature differences are multiplied with each other and thereafter also with an insulation factor K, which is taken as 1 during the analysis of the current state. This is representing how processes are going currently, without any protection method. The DQT factor indicates a possible decrease of queue times near the warehouse or on the ramp, supported by the assumption of personnel expansion to ensure the reduction.

Eventually, this KPI is summed up over multiple process steps. This summation indicates the performance of an operational path that consists of subsequent processes, or subsystems. These performance values are determined per path, per seasonality and also per type of cargo in order to obtain a comprehensive representation of the systems performance.

*Sub-research question 6: What is the performance of the current system and which processes can be improved?*

Every step is provided with a time stamp and a corresponding temperature for both the environment on Schiphol as for the cargo. With this data, the exposure in Degree-Hours has been calculated. The mean exposure of every step is accumulated to a single value per type of cargo and per type of season, to create a benchmark for the system performance per determined path. This benchmark will be used as comparison for the results.

The benchmark can also be used to compare the performance with each other, and by this it can be seen when the exposure is relatively high. This accounts for types of cargo during various seasons, it also shows that two paths have a higher exposure than others. This has led to the analysis and improvement of path 1 and 3, focusing on the CRT shipments in cold days and COL shipments during medium and warm days.

*Sub-research question 7: How can an experimental design be used to quantify the performance improvement?*

An experimental design contains a model that is setup in advance and applied in different scenario's under various circumstances. Three scenario's have been distinguished, focusing on a cold day, an medium temperature day and a warm day in the Netherlands in 2018. Besides the scenario's, there are ten configurations determined that could have an impact on the current state in terms of decreasing the exposure of the cargo.

Every scenario is run by each configuration, resulting in 30 experiments. Each experiment shows as outcome the KPI; the performance per subsystem and per path. The performance improvement, in this research being the exposure reduction, is shown per experiment and compared.

With the characteristics per scenario, the amount of protective methods can be determined to achieve the exposure reduction. This amount can be linked to cost and eventually a cost-performance analysis can be conducted to end up with the most feasible improvement opportunity per scenario.

The aggregation of the sub-research questions answers supports the answer to the main research question:

***How can the performance of the tarmac process within the cool chain be analysed and can this analysis show room for improvement?***

The performance of the cool chain operations on the tarmac have not been analysed before this research. This research has conducted a literature study into different performance indicators to eventually end up with the Degree-Hour KPI. With help of this KPI, the current state of the processes have been analysed. This has been done with the input of historical data regarding time duration, temperature of the cargo and the ambient temperature on Schiphol airport.

A data analysis resulted in a benchmark, projecting the exposure of COL, CRT and ERT shipments to the ambient temperatures during cold, warm and average months in 2018. All inbound, subsequently executed operations are divided into eight paths. These operational paths are adjusted with a modal and cargo split according to the distribution of presence of each path and type of cargo. This analysis showed the performance of the paths relative to each other and has shown two paths that were performing less than the others.

These paths have been analysed with a model. This model shows the performance, i.e. the exposure of the current state of the paths. The model is run through three different scenarios and ten configurations, showing the overall performance in 2018 per path regarding ground handling improvements and protection improvements.

All improvements are related to a cost price per year and an average exposure decrease. This shows that the ground handling improvements come at significantly higher cost than the protection improvements. The protection improvements require a high investment and also more storage area, which should be taken into account. It shows that for the short-term, the animal dolly should be used to test the exposure reduction in the actual system. This is feasible for there are already a few equipped at KLM Cargo. For the long-term, the cool dolly offer the most reduction in exposure but they require further research into the possibilities.

To conclude, when looking at the paths and the seasonality, it is shown that the first and third path are exposed to ambient temperature the most. The COL shipments suffer the most during the medium and warmer temperature months, where the CRT shipments have the most exposure during the cold months. However, it seems that the amount of CRT shipments in general is quite low. This means that when extreme weather circumstances are expected, the COL shipments during the first or third sequence of operations should have a high priority to be protected.

## 9.2. Limitations

There is a number of limitations that apply to this research. Firstly, the conclusions that are drawn from the model are specific for the tarmac operations at Schiphol Airport. The processes at KLM Cargo are assessed as subsystems when making a model. The approach to determine the exposure and the influence of improvement opportunities are applicable to other airports when the same parameters are used.

Secondly, the model is used for the inbound cargo shipments only. The inbound and outbound processes are similar in handling manoeuvres and therefore the choice was made to limit the scope of the research to the inbound flow only.

Finally, the exposure of the shipments is limited in a way that negative and positive exposure are assessed equally, using absolute values for when the ambient temperature was lower than the cargo temperature.

## 9.3. Recommendations

This research has analysed the performance of the Cool Chain at KLM Cargo, regarding the tarmac processes. The Cool Chain project is a novel department within KLM Cargo. There has not been any analysis conducted regarding the performance of temperature-sensitive cargo with relation to the ambient temperature, that is way this report will be of added value to KLM Cargo.

### 9.3.1. KLM Cargo

The availability and capacity of the protection methods have been assumed for this report. The animal dollies are in fact present at KLM Cargo, but the cool dolly is not (yet). It was assumed there was one to use in the model. The same accounts for the thermal blankets, these are not present but this research has shown that it is beneficial to invest in them and to apply them in the operation.

### 9.3.2. Further research

Because the available data was limited at some point, some assumptions had to be made to simplify the model. This has been done so the focus of the model could be with the elements that were paramount for this research. For this reason, it is recommended to explore some assumptions in future research and to tend to define these more accurate.

The statements above do support on the fact that the insulation factor K has been assumed relative to other methods. The K-value for a cool dolly will realistically not be zero, but it can come very close. With engineering background analysis into the R-value, the fact that the thermal blanket has a lower insulation factor than an animal dolly can be verified and taken as truth, but future research could further define a more accurate value.

The value for the decrease of queue time is an assumption that is relying on adding extra personnel that is dedicated to the cool chain. The main reason was to show if the reduction of queue time on the ramp and near the warehouse do have any significance in the total exposure or if it can be neglected.

The thermal blankets are regarded by the R-value, however, there are more aspects to this improvement method. The breath-ability, the possibility that green-house effects can occur within the blanket and reflective functionality of the material can also be of influence in the change of temperature of the cargo. These characteristics can be taken into account in further research.

In this research the negative exposure is treated absolutely and similar as positive exposure. It could be beneficial to research the differences during a year and to treat them separately. Different climate circumstances, such as wind speed and direction, could be of significant influence to the exposure as well. Finally, This research can be used as benchmark for further research, offering a comparable exposure value for validation purposes.

### 9.3.3. Reflection on exposure KPI

The chosen KPI has proven to be worthy to analyse the processes afterwards: besides only looking at the time, the system performance can be measured regarding the ambient temperature. It can also take into account the difference between the ambient temperature and the temperature according to the special handling code. The outcome of this research is somewhat limited by assumptions but this gives reason to conduct further research. When this is done according to the above mentioned limitations, expressing the performance in Degree-Hours can be an useful asset in the future of the cool chain project.

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# A
# Scientific Paper

# Decreasing the exposure of temperature-sensitive cargo to ambient temperature on the tarmac

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*Abstract*—**Temperature excursions show that goods that are transported from an aircraft to the warehouse are exposed to ambient temperature for too long, affecting the temperature of the cargo. KLM Cargo has a cool chain project that tends to gain more insight in the operational performance. With the exposure as KPI, defined as Degree-Hours, all subsequent operations are quantified and a performance value is appointed to each subsystem. The operations are not occurring in the same amount, therefore a modal and cargo split is applied to determine the exposure of a single ULD when taking into account the chance of any path and any type of cargo. All performances are compared to the performance when improvement opportunities are implemented in the system to reduce the exposure. The cost and performance rate per opportunity are put together to gain an insight in feasible improvements, showing that the use of an animal dolly can decrease the exposure on short-term.**

Keywords: Temperature-sensitive cargo, Cool chain, Exposure, Ambient temperature, Tarmac, Schiphol, Degree-Hours

## I. Problem definition

### A. Introduction

Air cargo connects the world by playing a crucial role in the air transport chain. Without air shipments, global supply chains would be unable to function and it would limit the availability of certain products. The transportation of time- and temperature-sensitive products, such as flowers, food and pharmaceuticals require fast handling that can be achieved by air transport. This market has shown growth over the past three decades and is expected to grow further, claiming a significant share in the total cargo market [1].

### B. KLM Cargo - Case study

This research addresses the transport of temperature-sensitive goods at KLM Cargo, where currently is a lack of performance measurements regarding the temperature excursions on the tarmac. This research aims to determine how the performance of transport on the tarmac can be quantified, analysed and be improved regarding the time and ambient temperature. A main research question is formulated and stated as follows:

*How can the performance of the tarmac process within the cool chain be analysed and can this analysis show room for improvement?*

The research scope is limited to inbound cargo, from the moment cargo is ready to unload out of the aircraft to the moment the cargo is being delivered at the airside lane queue, from where it will be picked up to be placed in the warehouse.

### C. Methodology

To structure and conduct the analysis, this research uses the Delft Systems Approach (DSA) [2]. It is used to describe the transportation system of the ULD's, by creating smaller subsystems and connecting these with one another. DSA is used because it considers any system as a blackbox, which transforms input into output by fulfilling requirement and expresses this transformation by performance. The requirements and performance are related to the objective of the function.

The effects of different handling strategies regarding temperature-sensitive cargo can be studied by looking at the system with a model. A mathematical model is used to express the performance per subsystem and the outcomes of these smaller systems is aggregated into an overall performance indication. MATLAB and Excel are used to conduct the analysis, for they are user-friendly and can be reviewed systematically.

### D. Research approach

This research uses a literature study to research the context of the objective. This study is used to generate a framework to support the research, defining the conducted operations for general cargo transport and the specific operations at KLM Cargo, with relation to the transport of temperature-sensitive cargo.

A model is created to transform data, obtained from the Performance Management department within KLM Cargo, into the performance of the system in its current state. System analysis and literature study reveal the process steps that would benefit from improvement opportunities and these will be discussed as model configurations in an experiment design. After the experiment, the results will be evaluated and concluded with recommendations.

### E. Literature study

To gain insight in the research problem, a literature study is conducted to identify the operations that occur during the transportation of temperature-sensitive cargo. The air freight processes regarding the cool chain, the characteristics of the cargo and the climate and possible improvement opportunities are found in literature and aggregated. The main sources that are used to describe the general operations are books from the International Air Transport Association [3][4][5].

Literature study has shown all characteristics that can be related to temperature-sensitive cargo, over the transportation of the goods and over the climate circumstances that have an effect on this transport. It shows general steps that are conducted during transport and how it is exposed to ambient temperature and at the same time it has shown opportunities to decrease this exposure.

## II. Current process

### A. Cargo characteristics

The temperature-sensitive cargo that is processed at KLM Cargo grounds can be defined as perishable (*fresh*) or pharmaceutical (*pharma*) goods. These goods are shipped under temperature controlled circumstances and goods can differ in temperature requirements. Special handling codes, as determined by IATA, indicate the temperature range that a good should be present in during transport. The airport operations are also regulated by IATA and followed by cargo handlers worldwide.

- COL: 2 - 8 degrees Celsius
- CRT: 15 - 25 degrees Celsius
- ERT: 2 - 25 degrees Celsius

### B. Climate characteristics

The most important factor for preserving the quality of temperature-sensitive cargo is the ambient temperature. Distributing goods around the world exposes loads to extreme temperatures, and the combination of time and temperature determine the gravity of damage to the products. The exposure to ambient temperature is depending on the season. When looking at the meteorological season definitions and the corresponding average temperatures of 2018, the 'cold' months are not longer extremely cold [6]. For this reason this research focuses on three new definitions of seasons; cold *(below 10 degrees Celsius)*; medium *(from 10 to 20 degrees Celsius)* and warm months *(above 20 degrees Celsius)*.

### C. Cargo operations

General cargo operations are similar for the inbound shipments are for outgoing procedures. The cargo is unloaded from an aircraft, placed next to the plane and from there it is picked up by a transporter to be transferred to the warehouse. There is a possibility that the goods have to pass the customs clearance, due to its origin it could contain dangerous or forbidden goods. In the warehouse the temperature-sensitive cargo is stored in a climatised area before it is loaded onto another mode of transport.

For KLM specific, there are several processes that are conducted on Schiphol Airport. These processes can be seen as subsystems, multiple subsystems in subsequent order form an operational path. Together a total of 9 operational paths are conducted over the tarmac. One of them is listed as *other*, having over thirty shattered locations and concerning only a small percentage of all operations. Table 1 will show the route of all paths, including a modal split which indicates in what percentage each operation occurs.

The first four paths have as destination the Pallet and Container Handling System (PCHS) or the refrigerated area (KC01), there is an attribute that decides if the shipments have to pass the customs clearance or not. The latter four go to external party Kuehne+Nagel (KN) or to freight building 6 (VG6). These destinations also have the possibility that the cargo has to be checked first.

TABLE I
OPERATIONAL PATHS

| Path | Route | Modal split [%] |
|---|---|---|
| 1 | Ramp - PCHS | 47.1 |
| 2 | Ramp - KC01 | 2.2 |
| 3 | Ramp - Scan - PCHS | 17.7 |
| 4 | Ramp - Scan - KC01 | 0.8 |
| 5 | Ramp - KN | 16.2 |
| 6 | Ramp - VG6 | 3.3 |
| 7 | Ramp - Scan - KN | 6.8 |
| 8 | Ramp - Scan - VG6 | 2.1 |
| 9 | Ramp - Other | 3.8 |
| Total | | 100 |

All paths come with different distances and thus transportation times. Transporters can move up to five ULD's at the same time and the longest distance that a transporter has to travel is one hour, including both directions. This value will be taken as worst scenario in defining the model scenario's.

Besides different paths, the types of cargo are also different in occurrence. Therefore a cargo split is also applied to the process performance measurements. This split is different per season and presented in table 2.

TABLE II
CARGO SPLIT

| Season | Type | Cargo split [%] |
|---|---|---|
| Cold | COL | 64.87 |
| Cold | CRT | 3.58 |
| Cold | ERT | 31.55 |
| Medium | COL | 65.20 |
| Medium | CRT | 3.64 |
| Medium | ERT | 31.16 |
| Warm | COL | 62.42 |
| Warm | CRT | 3.98 |
| Warm | ERT | 33.60 |

### D. Process performance

Relevant theories have been analysed in order to grant a performance value to the operational processes. Looking into heat transfer and transportation categories, the Degree-Hour value has been selected to use as performance indicator.

### E. Process improvement opportunities

Looking into the subsystems and the operational paths of the current state, it can be seen that some parts are vulnerable to the ambient temperature. As seen in literature, opportunities are available to decrease the exposure of temperature-sensitive cargo. An adjustment to the ground handling procedures could lead to a decrease in the time that a shipment is exposed.

Table 3 shows an overview of possible process improvement opportunities with references. It shows that the improvements are partly based on literature and partly on expert opinions within KLM Cargo.

TABLE III
IMPROVEMENT OPPORTUNITIES

| | Description |
|---|---|
| 1 | Adjust ground handling procedures [7] |
| 2 | Temperature-controlled dollies [7] |
| 3 | Thermal blankets[7][8][9] |
| 4 | Animal dolly [Appendix B] |
| 5 | Cool reefer [Appendix B] |

## III. MODEL DESIGN

A model is created to imitate with the system. This model ensures this research to conduct experiments in order to analyse possible improvements to the system. The output of the system is equal to the performance, this indicator is shown in equation 1. The model will be used to create a performance of the current system which can be used as benchmark afterwards. It will be applied to the separate types of cargo as for the different seasons. Because there is no performance of the current state regarding the exposure in degree-hours and because all the input data is historical data, measured by the Performance Management department at KLM Cargo, the model and the results are validated by expert opinions as support.

The equation can be divided in multiple terms: the summation over i; the average of the difference in temperature between cargo and ambient at the start and at the end; the difference in time, the insulation factor (K) and the percentage of queue time reduction (DQT).

$$E = \sum (\Delta t_i * DQT_i * \frac{|T_{ambient} - T_{cargo}|_{start} + |T_{ambient} - T_{cargo}|_{end}}{2}_i * K_i) \quad (1)$$

The summation over i stands for the consecutive subsystems that form a path, meaning that the exposure will be calculated for each system and be accumulated into one final performance. For a single ULD that is processing a path, the equation is executed. However, when a batch of data is known, the mean values of one process-step are used to create a performance value.

The difference in temperature is determined in two-fold. First, the difference of the ambient temperature and the temperature of the cargo according to the special handling code is determined. This difference will be taken on the start point and the final point of the process step. Next, the average of these two values will be used as difference in temperature. This approach can be used because in the worst case the ambient temperature only rises or decreases with 1 degree Celsius in the duration of any subsystem.

If the ambient temperature is within the range according to the special handling code, the cargo is not violating the temperature even though it is still exposed. The difference in temperature is set to zero in order to let the exposure be zero for it is not in violation. This will result in an exposure rate per type of cargo for each season.

The difference in time is using the time stamps that are registered by ground personnel that is handling the cargo. Whenever they use the handheld to log a shipment on or off on a location, the ULD is enlisted in the database. The difference between the time of drop-off and the time of pickup will be used as the delta time parameter in the equation.

The insulation factor K is a personal added element to the already existing exposure formula. It stands for the application of a protection method to the ULD that is transported. The K-value has a reach from 0 to 1, with 1 meaning there is no protection and 0 means that the exposure is completely removed. The current state regards the K-value as 1, where improvement opportunities are linked to a lower K-value.

The DQT term stands for 100 % in the current state but can be reduced at the queue processes at the ramp or near the warehouse. This term is assumed with as result that extra personnel is required to achieve this queue time reduction.

The model is simplified with some assumptions in order to let the outcome focus on the part that needs to be analysed; the processes on the tarmac. For this reason, it is assumed that the rate of incoming ULD's is equally divided.

## IV. DATA ANALYSIS

The model is used to create a insight in the performance of the current system. This has been done per subsystem, i.e. each process in the operational chain, and separately for each type of cargo and in different climate circumstances. The accumulation of the mean values delivered an exposure per process step in general. The accumulation of different process steps form the operational paths, using the mean values of each step to create a mean exposure per path as presented in figure 1.

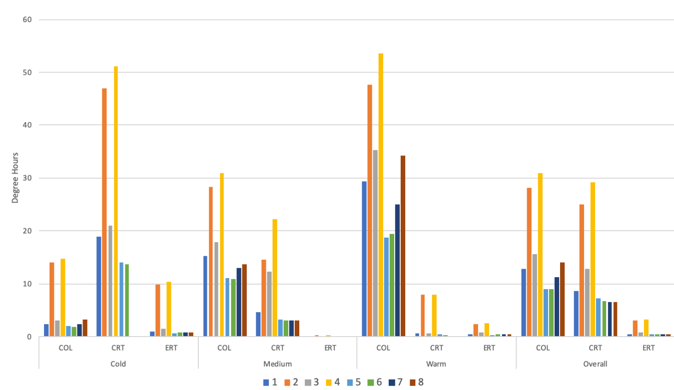


Fig. 1. Path exposure after modal split

This research regards all conducted processes on behalf of one ULD. Therefore the modal split will be applied to the overview with exposures per path, in order to include the chance that a ULD is going any path. This will add an extra magnitude to the paths that are conducted more often than others. Figure 2 presents this exposure, showing that the first and third path are conducted the most. It concerns the operations for COL, CRT and ERT together but is separated by the paths and climate circumstances.

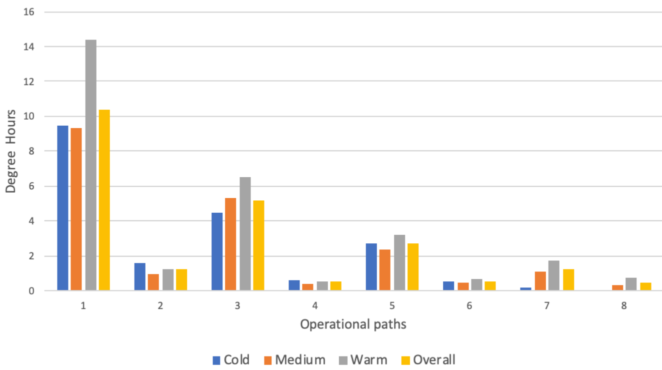


Fig. 2. Exposure per path after modal split

## V. Experimental design

To further analyse the performance of the operations that find place on the tarmac, several model scenario's are used to experiment with. The performance, distinguished as exposure, of each path will be analysed in three scenario's; during cold, medium and warm months. One day is chosen per scenario and these days come with a distribution of COL, CRT and ERT shipments. After applying the exposure rate, an amount of ULD's that enter the system is known.

Each scenario is run by one of the ten model configurations, indicating a protection improvement by using animal dollies, thermal blankets, cool dollies or a cool reefer. The final six configurations are regarding ground handling improvements, by decreasing the queue time of the ULD's at the ramp or at the warehouse, with 10, 25 and 50 %. Three scenario's that are run by 10 configurations each will result in thirty design alternatives.

The four protection configurations have a insulation value that is determined with support of expert opinions. The K-values for an animal dolly, thermal blanket and the cool dolly plus cool reefer are respectively 0.7, 0.3, 0 and 0. The cool dolly and reefer offer a similar exposure reduction but differ in capacity and cost price.

The costs that are linked to each configuration are determined with help of literature and expert calls. The cost for the dollies require a large investment and offer a lifespan of 15 years, where the cost for a thermal blanket depends on one-use only. Costs to decrease the queue times are linked to the deployment of one, two or three extra employees per shift. All configurations plus costs per day are shown in table 4.

Together with the maximum transport time and the knowledge that a maximum of 5 ULD's can be picked up at the same time, the amount of protective measures that is necessary can be determined in order to achieve the exposure decrease as calculated. In case of the thermal blankets, the amount of units is equal to the amount of exposed shipment per scenario. This does not affect the configurations with improvements regarding ground handling.

TABLE IV
Configuration costs overview

| Configuration | Cost per day in Euros |
|---|---|
| Animal dolly | 5 |
| Thermal blanket | 20 per ULD |
| Cool dolly | 15 |
| Cool reefer | 73 |
| Ramp queue -10% | 300 |
| Warehouse queue -10% | 300 |
| Ramp queue -25% | 600 |
| Warehouse queue -25% | 600 |
| Ramp queue -50% | 900 |
| Warehouse queue -50% | 900 |

## VI. Results and evaluation

Each design alternative has been compared with the benchmark to show if a decrease in exposure is present and if so, to what extent. Each scenario will be run by the ten configurations and all scenario's together represent a whole year. To evaluate the improvements and the corresponding costs, the rate of exposure decrease is averaged over the amount of months per season and the costs are accumulated, providing a final table that indicates how the overall exposure is decreased against what costs for the period of one year. The costs that are marked with an asterisk require a high investment and have more details to take into account, which are stated in the recommendations section.

TABLE V
Cost-Performance overview

| Configuration | Total costs [Euro] | Exposure decrease |
|---|---|---|
| 1 - *Animal dolly* | 13,200* | 29.7% |
| 2 - *Thermal blanket* | 763,200 | 70.0% |
| 3 - *Cool dolly* | 39,600* | 99.0% |
| 4 - *Cool reefer* | 61,320* | 99.0% |
| 5 - *Queue ramp -10%* | 108,000 | 4.9% |
| 6 - *Queue warehouse -10%* | 108,000 | 2.8% |
| 7 - *Queue ramp -25%* | 216,000 | 12.3% |
| 8 - *Queue warehouse -25%* | 216,000 | 7.1% |
| 9 - *Queue ramp -50%* | 324,000 | 24.6% |
| 10 - *Queue warehouse -50%* | 324,000 | 14.1% |

## VII. Conclusions and recommendations

### A. Conclusion

The performance of the tarmac operations within the cool chain have not been analysed before and therefore this research can be used as benchmark for it has shown the exposure of each type of cargo during different seasons and subsystems, quantified in Degree-Hours. The exposure to ambient temperature can be decreased by improving ground handling manoeuvres or by applying protection methods to the transportation of ULD's. The results with the cost-performance overview show that on the short term, the animal dolly is a feasible solution to validate the assumed insulation factor and requires a relative low investment, where the cool dolly shows more potential for the long-term.

## B. Limitations

The research outcomes are limited by the assumptions that are made in order to create a model. Firstly, the outcomes are specified for the tarmac operations at Schiphol Airport. The approach to determine the exposure and the influence of improvement opportunities are applicable in other airports when the same parameters are used.

Next, the research shows the exposure that is experienced during the inbound processes, hence the scope of the research neglected the outgoing shipments.

Finally, the exposure of the shipments is limited in a way that negative exposure and positive exposure are assessed equally, using absolute values for when the ambient temperature was lower than the cargo temperature.

## C. Further research

Because the available data was limited at some point, some assumptions had to be made to simplify the model. This has been done so the focus of the model could be with the elements that were paramount for this research. For this reason, it is recommended to explore some assumptions in future research and to tend to define these more accurate.

The statements above do support on the fact that the insulation factor K has been assumed relative to other methods. The K-value for a cool dolly will realistically not be zero, but it can come very close. With engineering background analysis into the R-value, the fact that the thermal blanket has a lower insulation factor than an animal dolly can be verified and taken as truth, but future research could further define a more accurate value.

The value for the decrease of queue time is an assumption that is relying on adding extra personnel that is dedicated to the cool chain. The main reason was to show if the reduction of queue time on the ramp and near the warehouse do have any significance in the total exposure or if it can be neglected.

The thermal blankets are regarded by the R-value, however, there are more aspects to this improvement method. The breath-ability, the possibility that green-house effects can occur within the blanket and reflective functionality of the material can also be of influence in the change of temperature of the cargo. These characteristics can be taken into account in further research.

In this research the negative exposure is treated absolutely and similar as positive exposure. It could be beneficial to research the differences during a year and to treat them separately. Different climate circumstances, such as wind speed and direction, could be of significant influence to the exposure as well. Finally, This research can be used as benchmark for further research, offering a comparable exposure value for validation purposes.

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# B

# Expert meetings

This appendix will contain the different expert calls that have been made regarding several issues.

## B.1. ULD characteristics

In discussion with the cool chain project members, Paul Crombach and Juliette Aloserij, it became clear that KLM Cargo tends to focus more on one sort aircraft to ship cargo and this aircraft is capable of only transporting lower deck cargo. Hence, this research has in mind of focusing on lower deck dimensions if needed.

## B.2. Improvement opportunities

In discussion with the cool chain project, with Paul Crombach, Juliette Aloserij, Marja van Cleef, but also a few people from outside the cool chain; Rene Overhaart from the animal department and Gerton Hulsman from Dusseldorf Airport.

### B.2.1. Ground handling

With the cool chain project it is discussed what kind of operations are done by the ground personnel and how this could be improved, in terms of quality increase or decreasing the time duration. It became clear that there is always a possibility to increase the personnel capacity during a shift. Improving the planning of the dolly-drivers is something that could be done as well, to implement such a thing is something that could not relate to the scope of this research. The investment in faster equipment was an mentioned option as well, however, all equipment is limited by speed regulations on Schiphol Airport so it would make not the difference that is wanted.

Literature study has shown the potential of thermal blankets and cool dollies. The cool dollies are used in the same way as the currently used dollies, for thermal blankets there are some rules to follow as well. For once, it is not allowed to apply or remove a blanket near the motor of the aircraft. If cargo should be protected by a blanket, it should be applied on the outside station for incoming cargo and it should go with the shipment to the outstation in case of outgoing shipments.

### B.2.2. Animal dolly

In discussion about the improvement opportunities that were found in literature study, the animal dolly was mentioned in one meeting. The dolly got the interest, because they are already equipped at KLM Cargo but for different purposes. Because the animal dolly has a roof and walls, it can be assumed that it offers a certain amount of protection against ambient temperature.

During this meeting, it was compared to a thermal blanket, a cool dolly and to no protection at all. It was decided it could be taken into the analysis and can be seen as a protection, better than none but not as good as a thermal blanket.

Afterwards there was contact with Rene Overhaart, responsible for the animal hotel, about the possibility of using an animal dolly for future tests. He stated that the animal dolly and normal cargo dollies are treated the same and that it was possible to test the animal dolly within the cool chain, this was when this research decided to take the animal dolly in consideration for this research.

There is a possibility to adjust a dolly that is already property of KLM Cargo. Within KLM, there is a so-called animal hotel that hosts a place for animals that require transportation. From dogs to batches of chickens, all transported in animal dollies. Animal dollies are like the normal dollies, only do they have a roof and walls to protect the animals against the sun and heavy weather conditions.

These animal dollies can be used and tested, there is also a possibility to modify the inner side of the walls and roof. Placing a thermal material against these sides could possibly increase the protection against ambient temperatures.

### B.2.3. Thermal blanket

The cool chain project is a joint program between Air France and KLM Cargo. Invoices and information is continuously shared in between the two parties, and so also invoices regarding an investment in thermal blanket. Experts from Air France have had contact with several parties and when a large batch was bought, one unit would cost 20 euros each. This price is used in the remainder of the research.

### B.2.4. Cool reefer

In contact with external parties, a few calls were made with Gerton Hulsman, managing director of Dusseldorf Airport Cargo. He shared his opinions about the implementation of thermal blankets and cool dollies. He made an impact when he mentioned the cool reefer, a trailer that has the dimensions of a truck trailer. This active reefer has the capacity of hosting 4 ULD's, and could be seen as a large cool dolly.

He stated that there currently is contact with one external party that leases such a reefer. Searching for a cost price of the cool reefer led to nothing. Gerton shared one invoice, which set the price of the lease at 2,000 Euros per month.

There are some regulations on Schiphol Airport that limit certain vehicles, and even though a cool reefer satisfies the limitations it is still expected to create a fuss.

Because the cool reefer and cool dolly offer the same protection and the cool reefer only differs in capacity and costs, it is decided to take the reefer into account for it differs in the evaluation of the results, where it links the performance to the costs.

# C

# Data collection and processing

This appendix will show what filters are applied to the data set that is retrieved from the performance management department. All filters have been discussed and run by different experts, ensuring the validity of the filters.

## C.1. General incoming data set

All data is retrieved from one big data set, containing rides from origin to destination. All data has been recorded by handhelds that were operated by ground personnel and all data is from the year 2018. Data is classified as faulty and therefore removed in the following cases:

- Timestamps that indicate the year 2001, expert call proved that this is a software error.
- Input with no time stamps at all, only a arrival time. Unfeasible to analyse only an arrival time.
- Rides where the ride from the ramp started before the plane has landed. Presumable that the ground personnel already checked the ride before picking up, making the ride data not worthy to analyse.

## C.2. Subsystem data set

The big data set is then divided in smaller data sets, all containing data that belong to one subsystem. For the ramp processes, the following filters are applied:

- Ramp rides start at least 7 minutes after the actual time of arrival, taking into account the opening of the cargo door and putting the high-loader lift in place.
- Cargo can be on the ramp for a maximum of 20 hours.
- Shipments that have a negative time duration between pick-up and drop-off are not taken into account, this data registration is presumably a fault by the ground personnel or by software.
- Depending on origin and location, for some subsystems the transport time takes at least 2 minutes, so the data with a time difference of 0 or 1 minute is not taken into account.

# D

# Inbound Degree Hour values

Table D.1: Degree-Hours for ramp unloading

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 0.2222 | 0 | 0.0265 | 41.8 % | .04444 |
| | CRT | 0 | 0.4889 | 0.2000 | 0.2128 | 99.9 % | 0.2000 |
| | ERT | 0 | 0.2222 | 0 | 0.0102 | 16.2 % | 0.0444 |
| MEDIUM | COL | 0 | 0.4667 | 0.1111 | 0.1650 | 92.5 % | 0.1556 |
| | CRT | 0 | 0.2667 | 0.0222 | 0.0458 | 51.0 % | 0.0667 |
| | ERT | 0 | 0.0667 | 0 | 0.0004 | 1.1 % | 0.0333 |
| WARM | COL | 0.0444 | 0.6000 | 0.2667 | 0.2758 | 100 % | 0.2667 |
| | CRT | 0 | 0.4889 | 0 | 0.0070 | 14.8 % | 0.0222 |
| | ERT | 0 | 0.2222 | 0 | 0.0052 | 8.9 % | 0.0444 |
| OVERALL | COL | 0 | 0.6000 | 0.1111 | 0.1304 | 72.3 % | 0.1778 |
| | CRT | 0 | 0.4889 | 0.0667 | 0.1053 | 62.2 % | 0.1778 |
| | ERT | 0 | 0.2222 | 0 | 0.0057 | 9.4 % | 0.0444 |

Table D.2: Degree-Hours for ramp queue

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 84.3333 | 0 | 1.3850 | 41.8 | 2.4000 |
| | CRT | 0 | 62.25 | 8.2333 | 9.8919 | 99.9 | 8.2333 |
| | ERT | 0 | 26.6 | 0 | 0.5293 | 16.2 | 1.9000 |
| MEDIUM | COL | 0 | 155.1 | 6.4167 | 7.8507 | 92.5 | 6.9000 |
| | CRT | 0 | 29 | 0.4750 | 2.3780 | 51.0 | 3.9000 |
| | ERT | 0 | 6.9 | 0 | 0.0170 | 1.1 | 1.1000 |
| WARM | COL | 1.2667 | 132.3333 | 10.7667 | 13.0485 | 100 | 10.7667 |
| | CRT | 0 | 9.8667 | 0 | 0.2811 | 14.8 | 1.3167 |
| | ERT | 0 | 22.2833 | 0 | 0.2288 | 8.9 | 1.8333 |
| OVERALL | COL | 0 | 155.1 | 2.8500 | 4.9649 | 72.3 | 6.7500 |
| | CRT | 0 | 62.25 | 4.1667 | 6.2424 | 62.2 | 6.6000 |
| | ERT | 0 | 26.600 | 0 | 0.2860 | 9.4 | 1.8333 |

### Transfer ramp to airside lane

This subsystem is conducted for almost 50 % of all incoming shipments. The same conclusions can be drawn as for the previous step, indicating which shipments have a relatively higher exposure.

Table D.3: Degree-Hours for ramp to airside lane

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 25.15 | 0 | 0.3761 | 44.2 % | 0.5500 |
| | CRT | 0.1667 | 29.75 | 1.650 | 2.2113 | 100 % | 1.6500 |
| | ERT | 0 | 10.40 | 0 | 0.1307 | 17.6 % | 0.4500 |
| MED | COL | 0 | 194.6 | 1.6333 | 2.4974 | 93.3 % | 1.7500 |
| | CRT | 0 | 11.30 | 0.0500 | 0.4565 | 50.8 % | 0.6667 |
| | ERT | 0 | 1.250 | 0 | 0.0041 | 0.9 % | 0.3000 |
| WARM | COL | 0.0500 | 139.2 | 2.8167 | 3.8899 | 100 % | 2.8167 |
| | CRT | 0 | 3.0750 | 0 | 0.0810 | 14.9 % | 0.2667 |
| | ERT | 0 | 6.3333 | 0 | 0.0511 | 8.2 % | 0.3417 |
| OVE | COL | 0 | 194.6 | 0.9167 | 1.8517 | 72.5 % | 1.6333 |
| | CRT | 0 | 29.75 | 0.5333 | 1.1019 | 62.5 % | 1.3333 |
| | ERT | 0 | 10.40 | 0 | 0.0702 | 9.9 % | 0.4167 |

### Inbound customs clearance

The scan procedure takes about half an hour, it is possible that the ambient temperature has increased or decreased with 1 degree Celsius which made sure that a shipment went from exposed to not exposed, explaining the difference in non-zero percentage in the two tables.

Table D.4: Degree-Hours for ramp to scan

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 8.75 | 0 | 0.5082 | 41.5 | 0.9 |
| | CRT | 0.15 | 41.25 | 3.4 | 4.3245 | 100 | 3.4 |
| | ERT | 0 | 8.75 | 0 | 0.1697 | 13.5 | 0.75 |
| MEDIUM | COL | 0 | 50.9917 | 2.3333 | 3.1509 | 89.9 | 2.6 |
| | CRT | 0 | 4.35 | 0.1667 | 0.6012 | 56 | 0.8 |
| | ERT | 0 | 2.5333 | 0 | 0.0114 | 2.2 | 0.3167 |
| WARM | COL | 0 | 31.35 | 4.4333 | 5.2534 | 96.4 | 4.5333 |
| | CRT | 0 | 1.15 | 0 | 0.1002 | 20.4 | 0.4667 |
| | ERT | 0 | 4.8 | 0 | 0.1186 | 13.1 | 0.6333 |
| OVERALL | COL | 0 | 50.9917 | 0 | 0.7545 | 73.3 | 2.7 |
| | CRT | 0 | 41.25 | 0 | 0 | 58 | 1.6667 |
| | ERT | 0 | 8.75 | 0 | 0.1500 | 9.4 | 0.6333 |

Table D.5: Degree-Hours for scan to airside lane

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 118 | 0 | 0.4542 | 40.4 | 0.4 |
| | CRT | 0 | 10.9667 | 0.8333 | 2.0539 | 70.6 | 1.5083 |
| | ERT | 0 | 95.9333 | 0 | 0.5056 | 12 | 0.2667 |
| MEDIUM | COL | 0 | 422.1167 | 0.925 | 1.9758 | 86.2 | 1.1333 |
| | CRT | 0 | 79.575 | 0.2667 | 7.4701 | 66.7 | 0.9417 |
| | ERT | 0 | 2.1667 | 0 | 0.0113 | 2.4 | 0.2 |
| WARM | COL | 0 | 567.7833 | 1.8333 | 4.5196 | 90 | 2.0167 |
| | CRT | 0 | 0.3 | 0 | 0.0562 | 18.8 | 0.3 |
| | ERT | 0 | 108.25 | 0 | 0.1782 | 13.4 | 0.375 |
| OVERALL | COL | 0 | 567.7833 | 0.5833 | 2.0165 | 70.2 | 1.1667 |
| | CRT | 0 | 79.575 | 0.2167 | 3.7737 | 54.4 | 1.05 |
| | ERT | 0 | 108.25 | 0 | 0.2377 | 8.9 | 0.3 |

## Airside lane queue

The performance indicator is split in two ways, table D.6 shows the Degree-Hours for the airside queue before the cargo is transferred into the PCHS. The second table, table D.7, shows the queue before the shipment is put in KC01.

The Degree-Hour value for KC01 is, in general, higher than for the PCHS. The reason for this is that the KC01 step does not use a handheld. When a ULD is placed into KC01, the responsible employee has to insert the timestamp for this action manually. This happens at the office, a few minutes walk from KC01. Human error is of higher appearance for this step, employees tend to forget to insert the time stamp right away and eventually do it but with a delay.

Table D.6: Degree-Hours for airside queue before PCHS

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 79.2029 | 0 | 0.6179 | 43.5 | 0.5574 |
| | CRT | 0.0033 | 281.3819 | 2.1722 | 4.5516 | 100 | 2.1722 |
| | ERT | 0 | 24.3521 | 0 | 0.2218 | 16.4 | 0.5178 |
| MEDIUM | COL | 0 | 270.7433 | 1.5032 | 4.7043 | 93.6 | 1.7072 |
| | CRT | 0 | 81.8375 | 0 | 1.7164 | 48.6 | 0.7386 |
| | ERT | 0 | 3.6053 | 0 | 0.0123 | 1.3 | 0.35 |
| WARM | COL | 0.0058 | 853.6157 | 3.21 | 12.2353 | 100 | 3.21 |
| | CRT | 0 | 11.5633 | 0 | 0.2039 | 16 | 0.5388 |
| | ERT | 0 | 94.0717 | 0 | 0.2358 | 10.4 | 0.7748 |
| OVERALL | COL | 0 | 853.6157 | 0.7642 | 4.5870 | 72.9 | 1.5853 |
| | CRT | 0 | 281.3819 | 0.4511 | 2.5126 | 61.8 | 1.615 |
| | ERT | 0 | 94.0717 | 0 | 0.1547 | 9.8 | 0.5975 |

Table D.7: Degree-Hours for airside queue before KC01

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 238.7925 | 5.9325 | 12.2869 | 86.8 | 8.1179 |
| | CRT | 1.44 | 1072.4 | 9.5099 | 34.673 | 100 | 9.5099 |
| | ERT | 0 | 44.0214 | 0 | 9.1255 | 25 | 36.5019 |
| MEDIUM | COL | 0 | 425.5743 | 10.4514 | 17.7703 | 99.5 | 10.475 |
| | CRT | 0 | 135.7389 | 2.7649 | 11.7384 | 66.7 | 4.8678 |
| | ERT | 0 | 5.1994 | 0 | 0.3058 | 5.9 | 5.1994 |
| WARM | COL | 0.115 | 598.1325 | 18.4644 | 30.4561 | 100 | 18.4644 |
| | CRT | 0 | 106.9022 | 1.4647 | 7.5537 | 55.6 | 5.9284 |
| | ERT | 0 | 12.6736 | 1.9234 | 2.0155 | 56.3 | 2.8242 |
| OVERALL | COL | 0 | 598.1325 | 11.1229 | 19.9757 | 95.1 | 11.8389 |
| | CRT | 0 | 1072.4 | 4.3263 | 18.8319 | 75.5 | 7.6631 |
| | ERT | 0 | 44.0214 | 0 | 2.6939 | 29.3 | 2.8639 |

## Transport to other destinations

Not all incoming ULD's are going into the warehouse. A significant amount is going to alternative destinations. These are distinguished as Kuehne+Nagel (KN), freight building 6 (VG6) or several smaller destinations assembled as *other*. Kuehne+Nagel is a forwarder and freight building 6 is a destination that lies on another location than the general warehouse. Transport of ULD's undergoes the same steps, but where the other steps include a queue step before the warehouse, the transport to KN, VG6 and other ends after transport over the tarmac.

Table D.8: Degree-Hours for ramp to Kuehne+Nagel

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 135.3 | 0 | 0.6292 | 42.7 | 0.8333 |
| | CRT | 0 | 17.9667 | 3.4667 | 3.9032 | 99.1 | 3.4667 |
| | ERT | 0 | 7.7917 | 0 | 0.1679 | 16.2 | 0.7333 |
| MEDIUM | COL | 0 | 25.65 | 2.5083 | 3.1478 | 92 | 2.8 |
| | CRT | 0 | 6.9667 | 0.3167 | 0.8367 | 57.9 | 1.2 |
| | ERT | 0 | 1.0667 | 0 | 0.0032 | 0.6 | 0.3 |
| WARM | COL | 0 | 111.35 | 4.8333 | 5.4605 | 98.8 | 4.9333 |
| | CRT | 0 | 2.8 | 0 | 0.1671 | 17 | 0.8 |
| | ERT | 0 | 6.3333 | 0 | 0.131 | 9.6 | 0.95 |
| OVERALL | COL | 0 | 135.3 | 1.5750 | 2.6108 | 72.5 | 2.75 |
| | CRT | 0 | 17.9667 | 1.4458 | 2.2239 | 68.9 | 2.6667 |
| | ERT | 0 | 7.7917 | 0 | 0.1059 | 9.6 | 0.8333 |

Table D.9: Degree-Hours for ramp to Freight Building 6

| Season | Type | Minimum | Maximum | Median | Mean | Non-zeros | Non-zero median |
|---|---|---|---|---|---|---|---|
| COLD | COL | 0 | 5.0667 | 0 | 0.4554 | 36.3 | 0.9667 |
| | CRT | 0.6667 | 10.325 | 3 | 3.669 | 100 | 3 |
| | ERT | 0 | 4.35 | 0 | 0.1952 | 17.4 | 0.6667 |
| MEDIUM | COL | 0 | 21.6583 | 2.175 | 2.8949 | 90.2 | 2.375 |
| | CRT | 0 | 2.6 | 0 | 0.6433 | 40 | 2.0083 |
| | ERT | 0 | 0.7167 | 0 | 0.0077 | 1.5 | 0.5167 |
| WARM | COL | 0.15 | 111.35 | 4.6 | 6.1665 | 100 | 4.6 |
| | CRT | 0 | 0.5667 | 0 | 0.05 | 13.3 | 0.375 |
| | ERT | 0 | 2.85 | 0 | 0.1399 | 12.5 | 0.8917 |
| OVERALL | COL | 0 | 111.35 | 1.4667 | 2.5473 | 68.3 | 2.6 |
| | CRT | 0 | 10.325 | 0.3750 | 1.5925 | 54.2 | 2.5667 |
| | ERT | 0 | 4.35 | 0 | 0.1177 | 10.8 | 0.7167 |

# E

# Path performances

## E.1. Performance per path

Table E.1: Performance of Path 1

| Path 1 | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to AL | 0.3761 | 2.2113 | 0.1307 | 2.4974 | 0.4565 | 0.0041 | 3.8899 | 0.081 | 0.0511 |
| AL to PCHS | 0.6179 | 4.5516 | 0.2218 | 4.7043 | 1.7164 | 0.0123 | 12.2353 | 0.2039 | 0.2358 |
| **Total** | 2.4055 | 16.8676 | 0.892 | 15.2174 | 4.5967 | 0.0338 | 29.4495 | 0.573 | 0.5209 |

Table E.2: Performance of Path 2

| Path 2 | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to AL | 0.3761 | 2.2113 | 0.1307 | 2.4974 | 0.4565 | 0.0041 | 3.8899 | 0.081 | 0.0511 |
| AL to KC01 | 12.2869 | 34.673 | 9.1255 | 17.7703 | 11.7384 | 0.3058 | 30.4561 | 7.5537 | 2.0155 |
| **Total** | 14.0745 | 46.989 | 9.7957 | 28.2834 | 14.6187 | 0.3273 | 47.6703 | 7.9228 | 2.3006 |

Table E.3: Performance of Path 3

| Path 3 | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to Scan | 0.5082 | 4.3245 | 0.1697 | 3.1509 | 0.6012 | 0.0114 | 5.2534 | 0.1002 | 0.1186 |
| Scan to AL | 0.4542 | 2.0539 | 0.5056 | 1.9758 | 7.4701 | 0.0113 | 4.5196 | 0.0562 | 0.1782 |
| AL to PCHS | 0.6179 | 4.5516 | 0.2218 | 4.7043 | 1.7164 | 0.0123 | 12.2353 | 0.2039 | 0.2358 |
| **Total** | 2.9918 | 21.0347 | 1.4366 | 17.8467 | 12.2115 | 0.0524 | 35.3326 | 0.6484 | 0.7666 |

Table E.4: Performance of Path 4

| **Path 4** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to Scan | 0.5082 | 4.3245 | 0.1697 | 3.1509 | 0.6012 | 0.0114 | 5.2534 | 0.1002 | 0.1186 |
| Scan to AL | 0.4542 | 2.0539 | 0.5056 | 1.9758 | 7.4701 | 0.0113 | 4.5196 | 0.0562 | 0.1782 |
| AL to KC01 | 12.2869 | 34.673 | 9.1255 | 17.7703 | 11.7384 | 0.3058 | 30.4561 | 7.5537 | 2.0155 |
| **Total** | 14.6608 | 51.1561 | 10.3403 | 30.9127 | 22.2335 | 0.3459 | 53.5534 | 7.9982 | 2.5463 |

Table E.5: Performance of Path 5

| **Path 5** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to KN | 0.6292 | 3.9032 | 0.1679 | 3.1478 | 0.8367 | 0.0032 | 5.4605 | 0.1671 | 0.1310 |
| **Total** | 2.0407 | 14.0079 | 0.7074 | 11.1635 | 3.2605 | 0.0206 | 18.7848 | 0.4552 | 0.365 |

Table E.6: Performance of Path 6

| **Path 6** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.1650 | 0.0458 | 0.0004 | 0.2758 | 0.0070 | 0.0052 |
| Ramp queue | 1.3850 | 9.8919 | 0.5293 | 7.8507 | 2.3780 | 0.0170 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to VG6 | 0.4554 | 3.6690 | 0.1952 | 2.8949 | 0.6433 | 0.0077 | 6.1665 | 0.0500 | 0.1399 |
| **Total** | 1.8669 | 13.7737 | 0.7347 | 10.9106 | 3.0671 | 0.0251 | 19.4908 | 0.3381 | 0.3739 |

Table E.7: Performance of Path 7

| **Path 7** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.165 | 0.0458 | 0.0004 | 0.2758 | 0.007 | 0.0052 |
| Ramp queue | 1.385 | 9.8919 | 0.5293 | 7.8507 | 2.378 | 0.017 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to Scan | 0.5082 | 4.3245 | 0.1697 | 3.1509 | 0.6012 | 0.0114 | 5.2534 | 0.1002 | 0.1186 |
| Scan to KN | 0.3776 | no ULD’s | 0.0666 | 1.7805 | 0 | 0.0049 | 6.4663 | no ULD’s | 0.0323 |
| **Total** | 2.2973 | no ULD’s | 0.7758 | 12.9471 | 3.025 | 0.0337 | 25.044 | no ULD’s | 0.3849 |

Table E.8: Performance of Path 8

| **Path 8** | Season | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | COLD | | | MEDIUM | | | WARM | | |
| **Process** | COL | CRT | ERT | COL | CRT | ERT | COL | CRT | ERT |
| Ramp unloading | 0.0265 | 0.2128 | 0.0102 | 0.165 | 0.0458 | 0.0004 | 0.2758 | 0.007 | 0.0052 |
| Ramp queue | 1.385 | 9.8919 | 0.5293 | 7.8507 | 2.378 | 0.017 | 13.0485 | 0.2811 | 0.2288 |
| Ramp to Scan | 0.5082 | 4.3245 | 0.1697 | 3.1509 | 0.6012 | 0.0114 | 5.2534 | 0.1002 | 0.1186 |
| Scan to VG6 | 1.2476 | no ULD’s | 0.0107 | 2.5406 | 0 | 0.0048 | 15.6307 | no ULD’s | 0.175 |
| **Total** | 3.1673 | no ULD’s | 0.7199 | 13.7072 | 3.025 | 0.0336 | 34.2084 | no ULD’s | 0.5276 |

## E.2. Performance of path per season

Table E.9: Path performance during cold months

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COL | 2.4055 | 14.0745 | 2.9918 | 14.6608 | 2.0407 | 1.8669 | 2.2973 | 3.1673 |
| CRT | 16.8676 | 46.989 | 21.0347 | 51.1561 | 14.0079 | 13.7737 | - | - |
| ERT | 0.892 | 9.7957 | 1.4366 | 10.3403 | 0.7074 | 0.7347 | 0.7758 | 0.7199 |
| **Weight factor** | **0.4710** | **0.0220** | **0.1770** | **0.0080** | **0.1620** | **0.0330** | **0.0680** | **0.0210** |
| COL | 1.1330 | 0.3096 | 0.5295 | 0.1173 | 0.3306 | 0.0616 | 0.1562 | 0.0665 |
| CRT | 7.9446 | 1.0338 | 3.7231 | 0.4092 | 2.2693 | 0.4545 | - | - |
| ERT | 0.4201 | 0.2155 | 0.2543 | 0.0827 | 0.1146 | 0.0242 | 0.0528 | 0.0151 |
| **Total [DH]** | **9.4978** | **1.5589** | **4.5070** | **0.6093** | **2.7145** | **0.5404** | **0.2090** | **0.0816** |

**Total Exposure = 19.7185 DH**

Table E.10: Path performance during medium months

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COL | 15.2174 | 28.2834 | 17.8467 | 30.9127 | 11.1635 | 10.9106 | 12.9471 | 13.7072 |
| CRT | 4.5967 | 14.6187 | 12.2115 | 22.2335 | 3.2605 | 3.0671 | 3.0250 | 3.0250 |
| ERT | 0.0338 | 0.3273 | 0.0524 | 0.3459 | 0.0206 | 0.0251 | 0.0337 | 0.0336 |
| **Weight factor** | **0.4710** | **0.0220** | **0.1770** | **0.0080** | **0.1620** | **0.0330** | **0.0680** | **0.0210** |
| COL | 7.1674 | 0.6222 | 3.1589 | 0.2473 | 1.8085 | 0.3600 | 0.8804 | 0.2879 |
| CRT | 2.1650 | 0.3216 | 2.1614 | 0.1779 | 0.5282 | 0.1012 | 0.2057 | 0.0635 |
| ERT | 0.0159 | 0.0072 | 0.0093 | 0.0028 | 0.0033 | 0.0008 | 0.0023 | 0.0007 |
| **Total [DH]** | **9.3484** | **0.9510** | **5.3296** | **0.4279** | **2.3400** | **0.4621** | **1.0884** | **0.3521** |

**Total Exposure = 20.2995 DH**

Table E.11: Path performance during warm months

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COL | 29.4495 | 47.6703 | 35.3326 | 53.5534 | 18.7848 | 19.4908 | 25.0440 | 34.2084 |
| CRT | 0.5730 | 7.9228 | 0.6484 | 7.9982 | 0.4552 | 0.3381 | - | - |
| ERT | 0.5209 | 2.3006 | 0.7666 | 2.5463 | 0.3650 | 0.3739 | 0.3849 | 0.5276 |
| **Weight factor** | **0.4710** | **0.0220** | **0.1770** | **0.0080** | **0.1620** | **0.0330** | **0.0680** | **0.0210** |
| COL | 13.8707 | 1.0487 | 6.2539 | 0.4284 | 3.0431 | 0.6432 | 1.7030 | 0.7184 |
| CRT | 0.2699 | 0.1743 | 0.1148 | 0.0640 | 0.0737 | 0.0112 | - | - |
| ERT | 0.2453 | 0.0506 | 0.1357 | 0.0204 | 0.0591 | 0.0123 | 0.0262 | 0.0111 |
| **Total** | **14.3859** | **1.2737** | **6.5043** | **0.5128** | **3.1760** | **0.6667** | **1.7292** | **0.7295** |

**Total Exposure = 28.9780 DH**

Table E.12: Path performance during the whole year

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| COL | 12.8116 | 28.2003 | 15.6258 | 31.0145 | 8.9837 | 8.9201 | 11.2268 | 13.9568 |
| CRT | 8.6848 | 25.0039 | 12.8779 | 29.1971 | 7.2940 | 6.6627 | 6.5915 | 6.5915 |
| ERT | 0.5166 | 3.0558 | 0.7850 | 3.3242 | 0.3976 | 0.4094 | 0.4310 | 0.4139 |
| **Weight factor** | **0.4710** | **0.0220** | **0.1770** | **0.0080** | **0.1620** | **0.0330** | **0.0680** | **0.0210** |
| COL | 6.0343 | 0.6204 | 2.7658 | 0.2481 | 1.4554 | 0.2944 | 0.7634 | 0.2931 |
| CRT | 4.0905 | 0.5501 | 2.2794 | 0.2336 | 1.1816 | 0.2199 | 0.4482 | 0.1384 |
| ERT | 0.2433 | 0.0672 | 0.1389 | 0.0266 | 0.0644 | 0.0135 | 0.0293 | 0.0087 |
| **Total** | **10.3681** | **1.2377** | **5.1841** | **0.5083** | **2.7014** | **0.5277** | **1.2410** | **0.4402** |

**Total Exposure = 22.2085 DH**

## E.3. Performance graphs

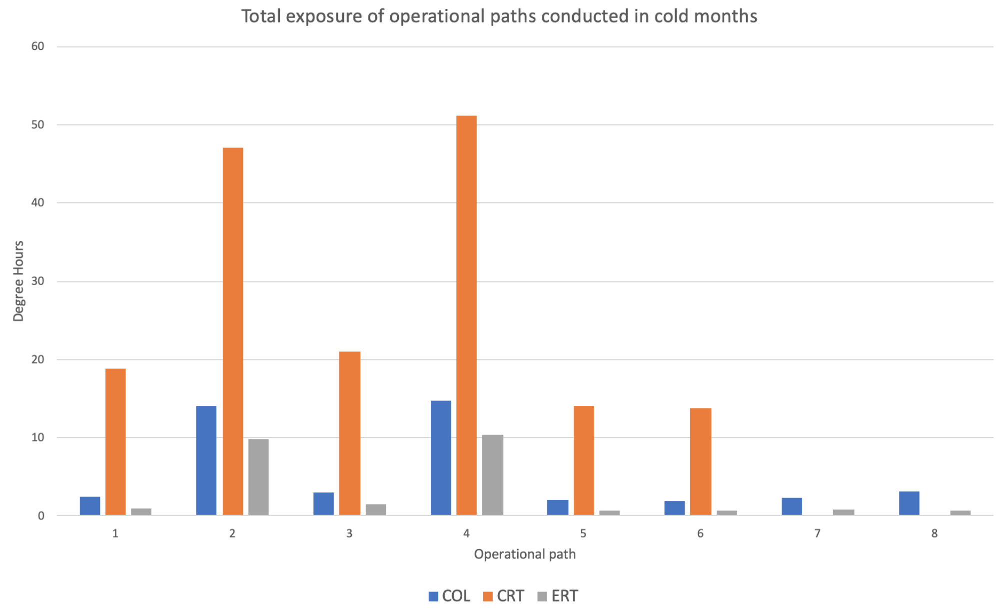


Figure E.1: Exposure of operational paths in cold months

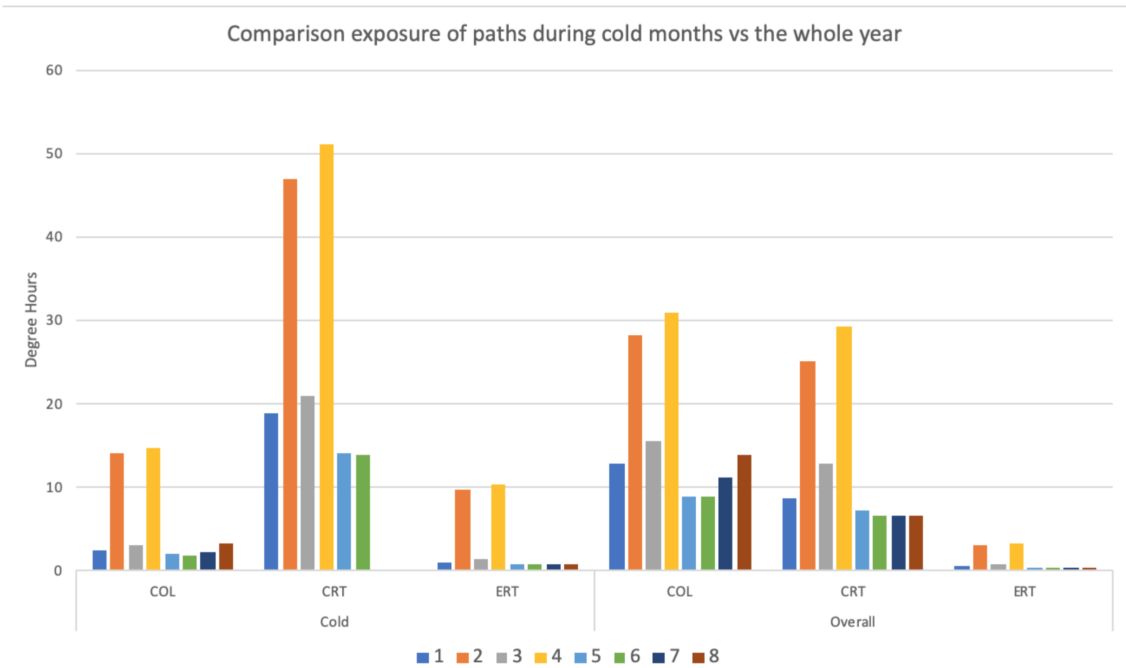


Figure E.2: Exposure of paths in cold months vs whole year

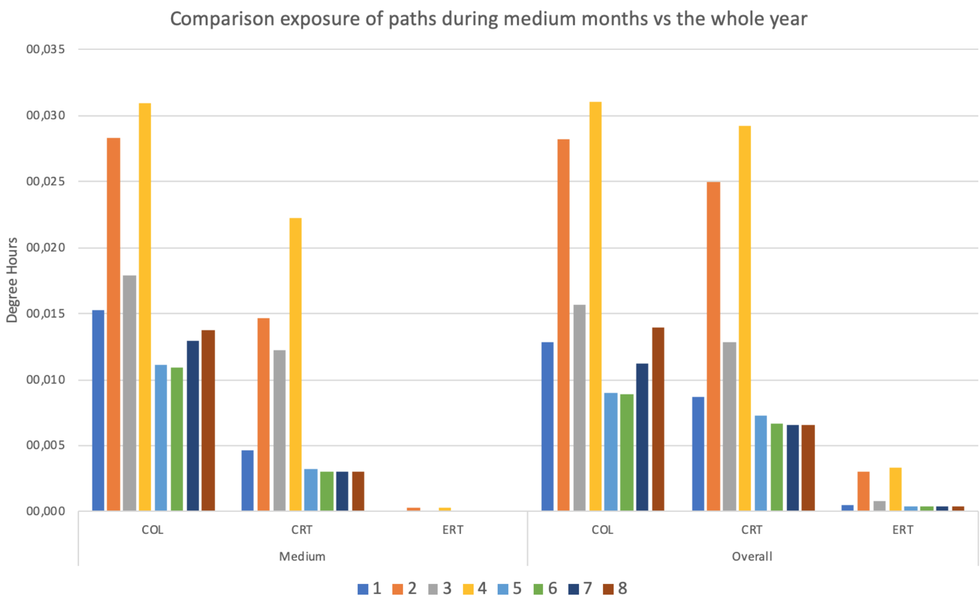


Figure E.3: Exposure of paths in medium months vs whole year

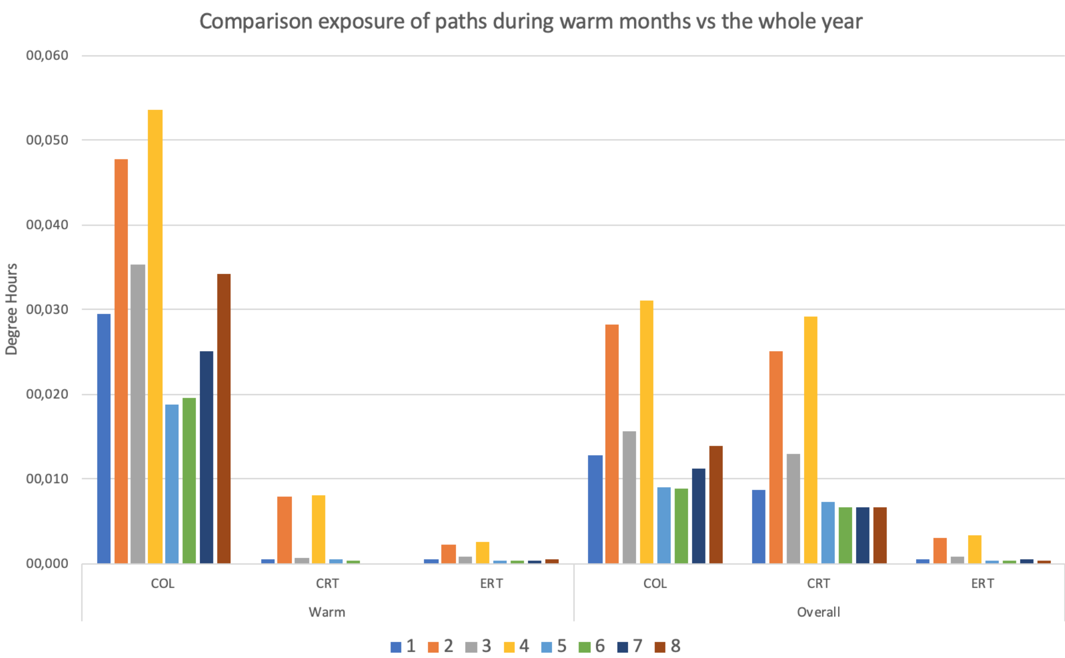


Figure E.4: Exposure of paths in warm months vs whole year

# F Results

This appendix chapter will contain six tables. The first table will show the first ten experiments exposure reductions in values, compared with the current state. The second table will show the reduction in percentages relative to the current state benchmark. The third and fourth tables will make the same comparison for the second scenario, these are experiments 11 up to 20. The final two tables will comprehend experiments 21 to 30, representing the third scenario.

Table F.1: Experiments scenario 1

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 0.7350 | 0.2009 | 0.3435 | 0.0761 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.7543 |
| CRT | 0.2844 | 0.0370 | 0.1333 | 0.0147 | 0.0812 | 0.0163 | - | - | 0.5669 |
| ERT | 0.1326 | 0.0680 | 0.0802 | 0.0261 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3721 |
| Total | 1.1519 | 0.3059 | 0.5570 | 0.1168 | 0.3319 | 0.0639 | 0.1180 | 0.0479 | 2.6933 |
| Experiment 1 | | | | | | | | | |
| COL | 0.5169 | 0.1407 | 0.2414 | 0.0533 | 0.1510 | 0.0281 | 0.0713 | 0.0303 | 1.2330 |
| CRT | 0.2002 | 0.0260 | 0.0937 | 0.0103 | 0.0572 | 0.0115 | - | - | 0.3988 |
| ERT | 0.0932 | 0.0476 | 0.0563 | 0.0183 | 0.0255 | 0.0054 | 0.0117 | 0.0034 | 0.2614 |
| Total | 0.8103 | 0.2143 | 0.3914 | 0.0819 | 0.2337 | 0.0450 | 0.0830 | 0.0337 | 1.8931 |
| Experiment 2 | | | | | | | | | |
| COL | 0.2205 | 0.0603 | 0.1031 | 0.0228 | 0.0643 | 0.0120 | 0.0304 | 0.0129 | 0.5263 |
| CRT | 0.0853 | 0.0111 | 0.0400 | 0.0044 | 0.0244 | 0.0049 | - | - | 0.1701 |
| ERT | 0.0398 | 0.0204 | 0.0241 | 0.0078 | 0.0108 | 0.0023 | 0.0050 | 0.0014 | 0.1116 |
| Total | 0.3456 | 0.0918 | 0.1671 | 0.0350 | 0.0996 | 0.0192 | 0.0354 | 0.0144 | 0.8080 |
| Experiment 3+4 | | | | | | | | | |
| COL | 0.0081 | 0.0004 | 0.0030 | 0.0001 | 0.0028 | 0.0006 | 0.0012 | 0.0004 | 0.0165 |
| CRT | 0.0036 | 0.0002 | 0.0013 | 0.0001 | 0.0012 | 0.0003 | - | - | 0.0067 |
| ERT | 0.0015 | 0.0001 | 0.0006 | 0.0000 | 0.0005 | 0.0001 | 0.0002 | 0.0001 | 0.0031 |
| Total | 0.0132 | 0.0006 | 0.0050 | 0.0002 | 0.0045 | 0.0009 | 0.0014 | 0.0004 | 0.0263 |
| Experiment 5 | | | | | | | | | |
| COL | 0.6926 | 0.1989 | 0.3276 | 0.0754 | 0.1999 | 0.0370 | 0.0952 | 0.0413 | 1.6679 |
| CRT | 0.2677 | 0.0362 | 0.1270 | 0.0144 | 0.0755 | 0.0151 | - | - | 0.5360 |
| ERT | 0.1247 | 0.0676 | 0.0773 | 0.0260 | 0.0334 | 0.0071 | 0.0155 | 0.0044 | 0.3560 |
| Total | 1.0850 | 0.3027 | 0.5319 | 0.1157 | 0.3089 | 0.0592 | 0.1107 | 0.0457 | 2.5598 |
| Experiment 6 | | | | | | | | | |
| COL | 0.7161 | 0.1833 | 0.3364 | 0.0697 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.7044 |
| CRT | 0.2767 | 0.0343 | 0.1304 | 0.0137 | 0.0812 | 0.0163 | - | - | 0.5526 |
| ERT | 0.1292 | 0.0617 | 0.0790 | 0.0238 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3589 |
| Total | 1.1220 | 0.2793 | 0.5458 | 0.1072 | 0.3318 | 0.0639 | 0.1180 | 0.0479 | 2.6159 |
| Experiment 7 | | | | | | | | | |
| COL | 0.6291 | 0.1959 | 0.3038 | 0.0743 | 0.1781 | 0.0326 | 0.0861 | 0.0384 | 1.5382 |
| CRT | 0.2427 | 0.0351 | 0.1176 | 0.0139 | 0.0669 | 0.0134 | - | - | 0.4896 |
| ERT | 0.1129 | 0.0671 | 0.0728 | 0.0258 | 0.0294 | 0.0063 | 0.0138 | 0.0039 | 0.3319 |
| Total | 0.9847 | 0.2981 | 0.4942 | 0.1140 | 0.2744 | 0.0522 | 0.0999 | 0.0423 | 2.3597 |
| Experiment 8 | | | | | | | | | |
| COL | 0.6877 | 0.1570 | 0.3258 | 0.0601 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.6296 |
| CRT | 0.2652 | 0.0302 | 0.1261 | 0.0122 | 0.0812 | 0.0163 | - | - | 0.5312 |
| ERT | 0.1243 | 0.0522 | 0.0771 | 0.0203 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3391 |
| Total | 1.0773 | 0.2394 | 0.5290 | 0.0927 | 0.3318 | 0.0639 | 0.1180 | 0.0479 | 2.4999 |
| Experiment 9 | | | | | | | | | |
| COL | 0.5234 | 0.1910 | 0.2640 | 0.0725 | 0.1417 | 0.0251 | 0.0708 | 0.0337 | 1.3222 |
| CRT | 0.2010 | 0.0331 | 0.1019 | 0.0132 | 0.0526 | 0.0104 | - | - | 0.4123 |
| ERT | 0.0932 | 0.0662 | 0.0654 | 0.0254 | 0.0226 | 0.0049 | 0.0110 | 0.0030 | 0.2917 |
| Total | 0.8176 | 0.2902 | 0.4314 | 0.1112 | 0.2169 | 0.0405 | 0.0818 | 0.0367 | 2.0262 |
| Experiment 10 | | | | | | | | | |
| COL | 0.6405 | 0.1132 | 0.3080 | 0.0442 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.5049 |
| CRT | 0.2460 | 0.0234 | 0.1189 | 0.0097 | 0.0812 | 0.0163 | - | - | 0.4955 |
| ERT | 0.1161 | 0.0363 | 0.0740 | 0.0146 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3062 |
| Total | 1.0026 | 0.1729 | 0.5009 | 0.0685 | 0.3318 | 0.0639 | 0.1180 | 0.0479 | 2.3065 |

Table F.2: Exposure decrease experiments scenario 1

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 0.7350 | 0.2009 | 0.3435 | 0.0761 | 0.2145 | 0.0400 | 0.1013 | 0.0431 | 1.7543 |
| CRT | 0.2844 | 0.0370 | 0.1333 | 0.0147 | 0.0812 | 0.0163 | - | - | 0.5669 |
| ERT | 0.1326 | 0.0680 | 0.0802 | 0.0261 | 0.0362 | 0.0076 | 0.0166 | 0.0048 | 0.3721 |
| Total | 1.1519 | 0.3059 | 0.5570 | 0.1168 | 0.3319 | 0.0639 | 0.1180 | 0.0479 | 2.6933 |
| Experiment 1 | | | | | | | | | |
| COL | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| CRT | 30% | 30% | 30% | 30% | 30% | 29% | - | - | 30% |
| ERT | 30% | 30% | 30% | 30% | 30% | 29% | 30% | 29% | 30% |
| Total | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Experiment 2 | | | | | | | | | |
| COL | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| CRT | 70% | 70% | 70% | 70% | 70% | 70% | - | - | 70% |
| ERT | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 71% | 70% |
| Total | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| Experiment 3 + 4 | | | | | | | | | |
| COL | 99% | 100% | 99% | 100% | 99% | 99% | 99% | 99% | 99% |
| CRT | 99% | 99% | 99% | 99% | 99% | 98% | - | - | 99% |
| ERT | 99% | 100% | 99% | 100% | 99% | 99% | 99% | 98% | 99% |
| Total | 99% | 100% | 99% | 100% | 99% | 99% | 99% | 99% | 99% |
| Experiment 5 | | | | | | | | | |
| COL | 6% | 1% | 5% | 1% | 7% | 8% | 6% | 4% | 5% |
| CRT | 6% | 2% | 5% | 2% | 7% | 7% | - | - | 5% |
| ERT | 6% | 1% | 4% | 0% | 8% | 7% | 7% | 8% | 4% |
| Total | 6% | 1% | 5% | 1% | 7% | 7% | 6% | 5% | 5% |
| Experiment 6 | | | | | | | | | |
| COL | 3% | 9% | 2% | 8% | 0% | 0% | 0% | 0% | 3% |
| CRT | 3% | 7% | 2% | 7% | 0% | 0% | - | - | 3% |
| ERT | 3% | 9% | 1% | 9% | 0% | 0% | 0% | 0% | 4% |
| Total | 3% | 9% | 2% | 8% | 0% | 0% | 0% | 0% | 3% |
| Experiment 7 | | | | | | | | | |
| COL | 14% | 2% | 12% | 2% | 17% | 19% | 15% | 11% | 12% |
| CRT | 15% | 5% | 12% | 5% | 18% | 18% | - | - | 14% |
| ERT | 15% | 1% | 9% | 1% | 19% | 17% | 17% | 19% | 11% |
| Total | 15% | 3% | 11% | 2% | 17% | 18% | 15% | 12% | 12% |
| Experiment 8 | | | | | | | | | |
| COL | 6% | 22% | 5% | 21% | 0% | 0% | 0% | 0% | 7% |
| CRT | 7% | 18% | 5% | 17% | 0% | 0% | - | - | 6% |
| ERT | 6% | 23% | 4% | 22% | 0% | 0% | 0% | 0% | 9% |
| Total | 6% | 22% | 5% | 21% | 0% | 0% | 0% | 0% | 7% |
| Experiment 9 | | | | | | | | | |
| COL | 29% | 5% | 23% | 5% | 34% | 37% | 30% | 22% | 25% |
| CRT | 29% | 11% | 24% | 10% | 35% | 36% | - | - | 27% |
| ERT | 30% | 3% | 18% | 3% | 38% | 36% | 34% | 38% | 22% |
| Total | 29% | 5% | 23% | 5% | 35% | 37% | 31% | 23% | 25% |
| Experiment 10 | | | | | | | | | |
| COL | 13% | 44% | 10% | 42% | 0% | 0% | 0% | 0% | 14% |
| CRT | 14% | 37% | 11% | 34% | 0% | 0% | - | - | 13% |
| ERT | 12% | 47% | 8% | 44% | 0% | 0% | 0% | 0% | 18% |
| Total | 13% | 43% | 10% | 41% | 0% | 0% | 0% | 0% | 14% |

Table F.3: Experiments scenario 2

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 4.6731 | 0.4057 | 2.0596 | 0.1612 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 9.4752 |
| CRT | 0.0788 | 0.0117 | 0.0787 | 0.0065 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.2084 |
| ERT | 0.0050 | 0.0022 | 0.0029 | 0.0009 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0132 |
| Total | 4.7569 | 0.4196 | 2.1411 | 0.1686 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | 9.6968 |
| Experiment 11 | | | | | | | | | |
| COL | 3.2864 | 0.2847 | 1.4474 | 0.1131 | 0.8306 | 0.1654 | 0.4040 | 0.1321 | 6.6637 |
| CRT | 0.0554 | 0.0082 | 0.0552 | 0.0045 | 0.0135 | 0.0026 | 0.0053 | 0.0016 | 0.1463 |
| ERT | 0.0035 | 0.0016 | 0.0020 | 0.0006 | 0.0007 | 0.0002 | 0.0005 | 0.0002 | 0.0093 |
| Total | 3.3453 | 0.2945 | 1.5046 | 0.1183 | 0.8449 | 0.1682 | 0.4098 | 0.1338 | 6.8193 |
| Experiment 12 | | | | | | | | | |
| COL | 1.4019 | 0.1217 | 0.6179 | 0.0484 | 0.3537 | 0.0704 | 0.1722 | 0.0563 | 2.8426 |
| CRT | 0.0236 | 0.0035 | 0.0236 | 0.0019 | 0.0058 | 0.0011 | 0.0022 | 0.0007 | 0.0625 |
| ERT | 0.0015 | 0.0007 | 0.0009 | 0.0003 | 0.0003 | 0.0001 | 0.0002 | 0.0001 | 0.0040 |
| Total | 1.4271 | 0.1259 | 0.6423 | 0.0506 | 0.3598 | 0.0716 | 0.1747 | 0.0571 | 2.9091 |
| Experiment 13+14 | | | | | | | | | |
| COL | 0.0507 | 0.0024 | 0.0190 | 0.0009 | 0.0174 | 0.0035 | 0.0073 | 0.0023 | 0.1035 |
| CRT | 0.0008 | 0.0000 | 0.0003 | 0.0000 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | 0.0016 |
| ERT | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Total | 0.0515 | 0.0024 | 0.0194 | 0.0009 | 0.0177 | 0.0036 | 0.0074 | 0.0023 | 0.1052 |
| Experiment 15 | | | | | | | | | |
| COL | 4.4321 | 0.3944 | 1.9690 | 0.1571 | 1.0962 | 0.2179 | 0.5392 | 0.1769 | 8.9828 |
| CRT | 0.0747 | 0.0115 | 0.0771 | 0.0064 | 0.0178 | 0.0034 | 0.0069 | 0.0021 | 0.2000 |
| ERT | 0.0047 | 0.0022 | 0.0028 | 0.0009 | 0.0010 | 0.0002 | 0.0007 | 0.0002 | 0.0127 |
| Total | 4.5115 | 0.4082 | 2.0489 | 0.1644 | 1.1150 | 0.2215 | 0.5468 | 0.1793 | 9.1956 |
| Experiment 16 | | | | | | | | | |
| COL | 4.5287 | 0.3802 | 2.0053 | 0.1520 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 9.2417 |
| CRT | 0.0759 | 0.0108 | 0.0776 | 0.0061 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.2030 |
| ERT | 0.0048 | 0.0020 | 0.0028 | 0.0008 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0127 |
| Total | 4.6093 | 0.3930 | 2.0857 | 0.1589 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | 9.4574 |
| Experiment 17 | | | | | | | | | |
| COL | 4.0704 | 0.3775 | 1.8331 | 0.1510 | 0.9718 | 0.1925 | 0.4870 | 0.1608 | 8.2442 |
| CRT | 0.0686 | 0.0112 | 0.0748 | 0.0063 | 0.0157 | 0.0030 | 0.0060 | 0.0019 | 0.1876 |
| ERT | 0.0043 | 0.0022 | 0.0027 | 0.0009 | 0.0008 | 0.0002 | 0.0006 | 0.0002 | 0.0119 |
| Total | 4.1434 | 0.3910 | 1.9106 | 0.1582 | 0.9884 | 0.1957 | 0.4936 | 0.1629 | 8.4437 |
| Experiment 18 | | | | | | | | | |
| COL | 4.3120 | 0.3420 | 1.9239 | 0.1381 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 8.8915 |
| CRT | 0.0715 | 0.0094 | 0.0759 | 0.0056 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.1950 |
| ERT | 0.0045 | 0.0017 | 0.0027 | 0.0007 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0119 |
| Total | 4.3879 | 0.3530 | 2.0025 | 0.1444 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | 9.0984 |
| Experiment 19 | | | | | | | | | |
| COL | 3.4677 | 0.3494 | 1.6066 | 0.1408 | 0.7645 | 0.1503 | 0.4000 | 0.1339 | 7.0132 |
| CRT | 0.0584 | 0.0108 | 0.0710 | 0.0061 | 0.0122 | 0.0023 | 0.0045 | 0.0014 | 0.1667 |
| ERT | 0.0037 | 0.0022 | 0.0024 | 0.0008 | 0.0006 | 0.0002 | 0.0005 | 0.0002 | 0.0106 |
| Total | 3.5298 | 0.3623 | 1.6800 | 0.1477 | 0.7774 | 0.1527 | 0.4051 | 0.1355 | 7.1906 |
| Experiment 20 | | | | | | | | | |
| COL | 3.9508 | 0.2782 | 1.7881 | 0.1149 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 8.3077 |
| CRT | 0.0641 | 0.0070 | 0.0731 | 0.0048 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.1817 |
| ERT | 0.0041 | 0.0012 | 0.0026 | 0.0005 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0105 |
| Total | 4.0190 | 0.2865 | 1.8638 | 0.1201 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | 8.4999 |

Table F.4: Exposure decrease experiments scenario 2

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 4.6731 | 0.4057 | 2.0596 | 0.1612 | 1.1791 | 0.2348 | 0.5740 | 0.1877 | 9.4752 |
| CRT | 0.0788 | 0.0117 | 0.0787 | 0.0065 | 0.0192 | 0.0037 | 0.0075 | 0.0023 | 0.2084 |
| ERT | 0.0050 | 0.0022 | 0.0029 | 0.0009 | 0.0010 | 0.0003 | 0.0007 | 0.0002 | 0.0132 |
| Total | 4.7569 | 0.4196 | 2.1411 | 0.1686 | 1.1994 | 0.2387 | 0.5822 | 0.1902 | 9.6968 |
| Experiment 11 | | | | | | | | | |
| COL | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| CRT | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 29% | 30% |
| ERT | 30% | 30% | 30% | 30% | 29% | 30% | 29% | 30% | 30% |
| Total | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Experiment 12 | | | | | | | | | |
| COL | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| CRT | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| ERT | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| Total | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| Experiment 13+14 | | | | | | | | | |
| COL | 99% | 99% | 99% | 99% | 99% | 98% | 99% | 99% | 99% |
| CRT | 99% | 100% | 100% | 100% | 99% | 99% | 98% | 98% | 99% |
| ERT | 99% | 100% | 99% | 100% | 98% | 98% | 99% | 99% | 99% |
| Total | 99% | 99% | 99% | 99% | 99% | 98% | 99% | 99% | 99% |
| Experiment 15 | | | | | | | | | |
| COL | 5% | 3% | 4% | 3% | 7% | 7% | 6% | 6% | 5% |
| CRT | 5% | 2% | 2% | 1% | 7% | 8% | 8% | 8% | 4% |
| ERT | 5% | 1% | 3% | 0% | 8% | 7% | 5% | 5% | 4% |
| Total | 5% | 3% | 4% | 2% | 7% | 7% | 6% | 6% | 5% |
| Experiment 16 | | | | | | | | | |
| COL | 3% | 6% | 3% | 6% | 0% | 0% | 0% | 0% | 2% |
| CRT | 4% | 8% | 1% | 5% | 0% | 0% | 0% | 0% | 3% |
| ERT | 4% | 9% | 2% | 9% | 0% | 0% | 0% | 0% | 4% |
| Total | 3% | 6% | 3% | 6% | 0% | 0% | 0% | 0% | 2% |
| Experiment 17 | | | | | | | | | |
| COL | 13% | 7% | 11% | 6% | 18% | 18% | 15% | 14% | 13% |
| CRT | 13% | 4% | 5% | 3% | 18% | 19% | 20% | 20% | 10% |
| ERT | 13% | 1% | 8% | 1% | 20% | 17% | 12% | 13% | 10% |
| Total | 13% | 7% | 11% | 6% | 18% | 18% | 15% | 14% | 13% |
| Experiment 18 | | | | | | | | | |
| COL | 8% | 16% | 7% | 14% | 0% | 0% | 0% | 0% | 6% |
| CRT | 9% | 20% | 4% | 13% | 0% | 0% | 0% | 0% | 6% |
| ERT | 9% | 23% | 6% | 22% | 0% | 0% | 0% | 0% | 10% |
| Total | 8% | 16% | 6% | 14% | 0% | 0% | 0% | 0% | 6% |
| Experiment 19 | | | | | | | | | |
| COL | 26% | 14% | 22% | 13% | 35% | 36% | 30% | 29% | 26% |
| CRT | 26% | 8% | 10% | 5% | 36% | 39% | 39% | 39% | 20% |
| ERT | 25% | 3% | 16% | 2% | 41% | 34% | 25% | 25% | 19% |
| Total | 26% | 14% | 22% | 12% | 35% | 36% | 30% | 29% | 26% |
| Experiment 20 | | | | | | | | | |
| COL | 15% | 31% | 13% | 29% | 0% | 0% | 0% | 0% | 12% |
| CRT | 19% | 40% | 7% | 26% | 0% | 0% | 0% | 0% | 13% |
| ERT | 18% | 47% | 12% | 44% | 0% | 0% | 0% | 0% | 20% |
| Total | 16% | 32% | 13% | 29% | 0% | 0% | 0% | 0% | 12% |

Table F.5: Experiments scenario 3

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 8.6581 | 0.6546 | 3.9037 | 0.2674 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 17.2962 |
| CRT | 0.0107 | 0.0069 | 0.0046 | 0.0025 | 0.0029 | 0.0004 | - | - | 0.0282 |
| ERT | 0.0824 | 0.0170 | 0.0456 | 0.0068 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1884 |
| Total | 8.7513 | 0.6786 | 3.9538 | 0.2768 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | 17.5128 |
| Experiment 21 | | | | | | | | | |
| COL | 6.0850 | 0.4594 | 2.7417 | 0.1876 | 1.3380 | 0.2827 | 0.7476 | 0.3150 | 12.1570 |
| CRT | 0.0076 | 0.0049 | 0.0032 | 0.0018 | 0.0021 | 0.0003 | - | - | 0.0198 |
| ERT | 0.0579 | 0.0119 | 0.0320 | 0.0048 | 0.0140 | 0.0029 | 0.0062 | 0.0026 | 0.1324 |
| Total | 6.1505 | 0.4761 | 2.7769 | 0.1942 | 1.3541 | 0.2860 | 0.7538 | 0.3176 | 12.3092 |
| Experiment 22 | | | | | | | | | |
| COL | 2.5974 | 0.1964 | 1.1711 | 0.0802 | 0.5699 | 0.1204 | 0.3189 | 0.1345 | 5.1889 |
| CRT | 0.0032 | 0.0021 | 0.0014 | 0.0008 | 0.0009 | 0.0001 | - | - | 0.0085 |
| ERT | 0.0247 | 0.0051 | 0.0137 | 0.0021 | 0.0060 | 0.0012 | 0.0026 | 0.0011 | 0.0565 |
| Total | 2.6254 | 0.2036 | 1.1861 | 0.0830 | 0.5767 | 0.1218 | 0.3215 | 0.1356 | 5.2538 |
| Experiment 23+24 | | | | | | | | | |
| COL | 0.0811 | 0.0038 | 0.0305 | 0.0014 | 0.0279 | 0.0057 | 0.0117 | 0.0036 | 0.1656 |
| CRT | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | - | - | 0.0002 |
| ERT | 0.0008 | 0.0000 | 0.0003 | 0.0000 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | 0.0017 |
| Total | 0.0820 | 0.0038 | 0.0308 | 0.0014 | 0.0282 | 0.0057 | 0.0118 | 0.0037 | 0.1675 |
| Experiment 25 | | | | | | | | | |
| COL | 8.2745 | 0.6367 | 3.7595 | 0.2609 | 1.7676 | 0.3746 | 1.0076 | 0.4313 | 16.5127 |
| CRT | 0.0102 | 0.0069 | 0.0044 | 0.0025 | 0.0028 | 0.0004 | - | - | 0.0272 |
| ERT | 0.0788 | 0.0168 | 0.0442 | 0.0068 | 0.0186 | 0.0039 | 0.0083 | 0.0036 | 0.1810 |
| Total | 8.3635 | 0.6605 | 3.8081 | 0.2702 | 1.7890 | 0.3789 | 1.0159 | 0.4349 | 16.7209 |
| Experiment 26 | | | | | | | | | |
| COL | 8.2984 | 0.6128 | 3.7685 | 0.2522 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 16.7443 |
| CRT | 0.0104 | 0.0063 | 0.0044 | 0.0023 | 0.0029 | 0.0004 | - | - | 0.0267 |
| ERT | 0.0787 | 0.0155 | 0.0442 | 0.0063 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1812 |
| Total | 8.3874 | 0.6346 | 3.8171 | 0.2608 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | 16.9523 |
| Experiment 27 | | | | | | | | | |
| COL | 7.6990 | 0.6098 | 3.5433 | 0.2511 | 1.5697 | 0.3343 | 0.9245 | 0.4056 | 15.3374 |
| CRT | 0.0094 | 0.0069 | 0.0041 | 0.0025 | 0.0025 | 0.0004 | - | - | 0.0257 |
| ERT | 0.0734 | 0.0166 | 0.0422 | 0.0067 | 0.0168 | 0.0035 | 0.0075 | 0.0033 | 0.1699 |
| Total | 7.7818 | 0.6333 | 3.5895 | 0.2603 | 1.5889 | 0.3382 | 0.9320 | 0.4090 | 15.5330 |
| Experiment 28 | | | | | | | | | |
| COL | 7.7588 | 0.5501 | 3.5657 | 0.2294 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 15.9164 |
| CRT | 0.0098 | 0.0053 | 0.0042 | 0.0019 | 0.0029 | 0.0004 | - | - | 0.0246 |
| ERT | 0.0731 | 0.0133 | 0.0421 | 0.0055 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1705 |
| Total | 7.8417 | 0.5686 | 3.6120 | 0.2368 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | 16.1115 |
| Experiment 29 | | | | | | | | | |
| COL | 6.7400 | 0.5650 | 3.1828 | 0.2348 | 1.2398 | 0.2671 | 0.7861 | 0.3629 | 13.3785 |
| CRT | 0.0081 | 0.0068 | 0.0036 | 0.0025 | 0.0020 | 0.0003 | - | - | 0.0233 |
| ERT | 0.0643 | 0.0162 | 0.0388 | 0.0065 | 0.0136 | 0.0029 | 0.0062 | 0.0029 | 0.1514 |
| Total | 6.8124 | 0.5880 | 3.2252 | 0.2439 | 1.2555 | 0.2702 | 0.7923 | 0.3658 | 13.5532 |
| Experiment 30 | | | | | | | | | |
| COL | 6.8595 | 0.4455 | 3.2278 | 0.1914 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 14.5366 |
| CRT | 0.0088 | 0.0036 | 0.0038 | 0.0013 | 0.0029 | 0.0004 | - | - | 0.0210 |
| ERT | 0.0638 | 0.0096 | 0.0386 | 0.0041 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1526 |
| Total | 6.9321 | 0.4587 | 3.2702 | 0.1969 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | 14.7102 |

Table F.6: Exposure decrease experiments scenario 3

| Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
|---|---|---|---|---|---|---|---|---|---|
| COL | 8.6581 | 0.6546 | 3.9037 | 0.2674 | 1.8995 | 0.4015 | 1.0630 | 0.4484 | 17.2962 |
| CRT | 0.0107 | 0.0069 | 0.0046 | 0.0025 | 0.0029 | 0.0004 | - | - | 0.0282 |
| ERT | 0.0824 | 0.0170 | 0.0456 | 0.0068 | 0.0199 | 0.0041 | 0.0088 | 0.0037 | 0.1884 |
| Total | 8.7513 | 0.6786 | 3.9538 | 0.2768 | 1.9223 | 0.4061 | 1.0718 | 0.4521 | 17.5128 |
| Experiment 21 | | | | | | | | | |
| COL | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| CRT | 29% | 29% | 30% | 28% | 28% | 25% | - | - | 30% |
| ERT | 30% | 30% | 30% | 29% | 30% | 29% | 30% | 30% | 30% |
| Total | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Experiment 22 | | | | | | | | | |
| COL | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| CRT | 70% | 70% | 70% | 68% | 69% | 75% | - | - | 70% |
| ERT | 70% | 70% | 70% | 69% | 70% | 71% | 70% | 70% | 70% |
| Total | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| Experiment 23+24 | | | | | | | | | |
| COL | 99% | 99% | 99% | 99% | 99% | 99% | 99% | 99% | 99% |
| CRT | 99% | 100% | 100% | 100% | 100% | 100% | - | - | 99% |
| ERT | 99% | 100% | 99% | 100% | 98% | 98% | 99% | 100% | 99% |
| Total | 99% | 99% | 99% | 99% | 99% | 99% | 99% | 99% | 99% |
| Experiment 25 | | | | | | | | | |
| COL | 4% | 3% | 4% | 2% | 7% | 7% | 5% | 4% | 5% |
| CRT | 5% | 0% | 4% | 0% | 3% | 0% | - | - | 4% |
| ERT | 4% | 1% | 3% | 0% | 7% | 5% | 6% | 3% | 4% |
| Total | 4% | 3% | 4% | 2% | 7% | 7% | 5% | 4% | 5% |
| Experiment 26 | | | | | | | | | |
| COL | 4% | 6% | 3% | 6% | 0% | 0% | 0% | 0% | 3% |
| CRT | 3% | 9% | 4% | 8% | 0% | 0% | - | - | 5% |
| ERT | 4% | 9% | 3% | 7% | 0% | 0% | 0% | 0% | 4% |
| Total | 4% | 6% | 3% | 6% | 0% | 0% | 0% | 0% | 3% |
| Experiment 27 | | | | | | | | | |
| COL | 11% | 7% | 9% | 6% | 17% | 17% | 13% | 10% | 11% |
| CRT | 12% | 0% | 11% | 0% | 14% | 0% | - | - | 9% |
| ERT | 11% | 2% | 7% | 1% | 16% | 15% | 15% | 11% | 10% |
| Total | 11% | 7% | 9% | 6% | 17% | 17% | 13% | 10% | 11% |
| Experiment 28 | | | | | | | | | |
| COL | 10% | 16% | 9% | 14% | 0% | 0% | 0% | 0% | 8% |
| CRT | 8% | 23% | 9% | 24% | 0% | 0% | - | - | 13% |
| ERT | 11% | 22% | 8% | 19% | 0% | 0% | 0% | 0% | 10% |
| Total | 10% | 16% | 9% | 14% | 0% | 0% | 0% | 0% | 8% |
| Experiment 29 | | | | | | | | | |
| COL | 22% | 14% | 18% | 12% | 35% | 33% | 26% | 19% | 23% |
| CRT | 24% | 1% | 22% | 0% | 31% | 25% | - | - | 17% |
| ERT | 22% | 5% | 15% | 4% | 32% | 29% | 30% | 22% | 20% |
| Total | 22% | 13% | 18% | 12% | 35% | 33% | 26% | 19% | 23% |
| Experiment 30 | | | | | | | | | |
| COL | 21% | 32% | 17% | 28% | 0% | 0% | 0% | 0% | 16% |
| CRT | 18% | 48% | 17% | 48% | 0% | 0% | - | - | 26% |
| ERT | 23% | 44% | 15% | 40% | 0% | 0% | 0% | 0% | 19% |
| Total | 21% | 32% | 17% | 29% | 0% | 0% | 0% | 0% | 16% |

# G

# Thermal Blanket

# Goodcape® Box

Contact us (/aircargo/contact)

The GoodCape® BOX is part of a family of cargo insulation concepts especially for storage and transport of temperature sensitive goods. From our experience with cargo protection during transport with our GoodCape® insulation covers, we have developed a second level of cargo insulation that benefits from:

– Excellent insulation values

– Weather proof

– Low volume

– Low weight

– Easy operation

The GoodCape® box comes in a bundle of flat, light weight, panels that can easily be placed on a standard transport pallet. Panels are connected by simple metal clamps. Once, all panels are placed together, around your product and the clamps are fixed, a solid stiff box protects your cargo.

### Insulation performance

The box panels itself, will offer an insulation value of approximately 1,4 (Rc in m2, K/W). The real advantage of the GoodCape® BOX concept is the possibility of combining the box with a GoodCape® cover. GoodCape® covers have been used successfully for years in Cargo temperature protection. This product has a track record of decades and is used by numerous transportation companies throughout the world.

### GoodCape® BOX + GoodCape® Cover a winning team!

The real fun begins, when the BOX puts his winter coat on. Once the GoodCape® cover is put on, over the BOX, all mechanisms are well resisted. The cover offers a rigid protection against wind and rain. Draft will no longer spoil the insulation but what's more, both inside and outside of the cover carry a pure aluminium surface. This aluminium surface reflects more than 90% radiation. For this particular purpose, the outer skin of the BOX is equipped with eps profiles forming 2 cm wide air chambers which add up in insulation and will service the optimal space for best radiation performance of the GoodCape® cover.

### Extra internal insulation

On top of this, GoodCape® covers carry double layers of air bubbles internally. Obviously, this is another contribution to the insulation effectiveness. This internal insulation is very flexible separation of the two aluminium surfaces. This prevents the thin metal surfaces to conduct heat or cold in or outwards. The

# H

# Incoming claims

This appendix shows a table that shows how the claims are filed at KLM Cargo. It shows the type of cargo, the date and it says for what reason the claim has been filed. Temperature means that the shipment has been exposed to a temperature lower or higher than the special handling code requires.

Table H.1: Incoming claims

| Insured Object | Claim Number | AWB Number | Incident/AWB Date | Product | SHC | Commodity Detail | Incident Detail |
|---|---|---|---|---|---|---|---|
| Air France | 201804244 | 057-66425461 | 12/06/2018 | Variation Pharma | COL | Vaccines | Temperature |
| KLM | 201806023 | 074-16512510 | 16/06/2018 | Variation Fresh 3 | ERT | Perishables | Temperature |
| KLM | 201807632 | 074-17958356 | 19/06/2018 | Variation Fresh 2 | COL | Other Fruits | Temperature |
| KLM | 201970029 | 074-16945876 | 19/06/2018 | Variation Fresh 2 | COL | Fresh Flowers | Temperature |
| KLM | 201805348 | 074-16687705 | 20/06/2018 | Variation Fresh 2 | COL | Various Other Goods | Temperature |
| KLM | 201804172 | 074-17338985 | 22/06/2018 | Variation Fresh 2 | COL | Various Other Goods | Temperature |
| KLM | 201806140 | 074-17269862 | 22/06/2018 | Variation Fresh 3 | ERT | Various Other Goods | Temperature |
| Air France | 201805395 | 057-67325624 | 25/06/2018 | Variation Fresh 2 | COL | Other Fruits | Temperature |
| KLM | 201804239 | 074-16871956 | 26/06/2018 | Variation Fresh 3 | ERT | Other Vegetables | Temperature |
| Air France | 201804477 | 057-64563590 | 28/06/2018 | Variation Fresh 2 | COL | Fresh Flowers | Temperature |
| KLM | 201806209 | 074-17959325 | 30/06/2018 | Variation Fresh 2 | COL | Various Other Goods | Temperature |
| Air France | 201804594 | 057-66929122 | 02/07/2018 | Variation Fresh 2 | COL | Other Vegetables | Temperature |
| KLM | 201805825 | 074-14471763 | 03/07/2018 | Variation Fresh 2 | COL | Fresh Flowers | Temperature |
| KLM | 201806210 | 074-17960401 | 07/07/2018 | Variation Fresh 2 | COL | Fresh Flowers | Temperature |
| KLM | 201805162 | 074-17324112 | 08/07/2018 | Variation Fresh 2 | COL | Salmon | Weather conditions |
| KLM | 201806613 | 074-15279950 | 10/07/2018 | Variation Fresh 2 | COL | Berries | Temperature |
| KLM | 201972701 | 074-17918795 | 14/07/2018 | Variation Pharma | COL | Pharmaceutical Products | Temperature |
| KLM | 201973509 | 074-16749121 | 16/07/2018 | Variation Fresh 3 | ERT | Mangoes | Temperature |
| KLM | 201806158 | 074-14844572 | 30/07/2018 | Variation Fresh 2 | COL | Various Other Goods | Temperature |
| KLM | 201806850 | 074-18969742 | 30/07/2018 | Variation Pharma | COL | Pharmaceutical Products | Temperature |