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Title: **Redesign the cool chain for air transport of perishable goods by KLM Cargo**

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Title (in Dutch) Herinrichting van de koelketen voor luchttransport van bederfelijke goederen door KLM Cargo

Assignment: Master's thesis

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Initiator (university): Prof. dr. ir. G. Lodewijks

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Subject: **KLM Cargo Perishable Transportation Optimization**

The transportation of flowers by air from Kenya to the Netherlands is an important source of income for Air France-KLM-Martinair Cargo. The requirements for the integrated cool chain are becoming stricter by the day and some producers even hire Supply Chain Analysts/Specialists to analyze the entire cool chain from farm to final destination. They then turn to the airlines with all sorts of good questions about, for example, temperature settings on board. With that they put the whole cool chain, from farm to destination, under a magnifying glass.

As a result of the above the trend certain carriers (DHL, Cathay Pacific) go just a little bit further in optimizing the supply chain, whilst flying the same aircraft types, and take away the business because they are better in ensuring the quality of the flowers during flight. KLM Cargo (located at Schiphol airport) aims at optimizing the supply chain to ensure the right quality for their customers and to stay competitive. For this, an analysis is needed on supply chain level since each of the actors within the supply chain contribute to the total performance of it. Temperature spikes and weak spots of the chain should be indicated and improved.

This focus of this assignment is to analyse the current situation of KLM Cargo regarding the cool chain, time and temperature. It should be clear what changes are needed to measure and improve this cool chain to stay competitive within this market. Approaches and goals of this research project include as follows:

- A definition of the current situation, including its biological and logistical aspect of the system.
- A system analysis focused on time and temperature measurements, the cool chain performance and the impact of the cool chain on freshness of flowers
- A redesign of the cool chain for perishable goods

This report should be arranged in such a way that all data is structurally presented in graphs, tables, and lists with belonging descriptions and explanations in text. The report should comply with the guidelines of the section. Details can be found on the website.

The professor,

Prof. dr. ir. G. Lodewijks

Redesign the cool chain for air transport of perishable goods by KLM Cargo

Master of Science Thesis

by

F. C. T. van der Voort

in partial fulfillment of the requirements for the degree of

Master of Science
in Mechanical Engineering

at the Delft University of Technology

Supervisors: *Delft University of Technology*
Prof. dr. ir. G. Lodewijks
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KLM Cargo
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This thesis is confidential and cannot be made public until December 14, 2021.

Delft University of Technology

Preface

This thesis is the final academic project for the master 'Transport, Engineering & Logistics' at Delft University of Technology. This track is a specialisation of the master Mechanical Engineering at the faculty of 3mE. The project is performed at Air France - KLM - Martinair Cargo and is executed from April to December 2016. It is part of the Variation-Fresh department of KLM Cargo, located at Schiphol Airport. For this department, the focus is to improve the cool chain during movement of perishable goods.

When this project started I was impressed by the tonnage of flowers transported on a yearly basis from East Africa to Europe. There is a high likelihood that roses you buy at the market or at a store like Albert Heijn are from Kenya. In many cases, sellers guarantee on the vase that the flowers will have a certain lifespan. To ensure that the flowers last as long as promised this flowers should be transported as quickly as possible at a temperature as low as possible. KLM Cargo is responsible for the air transport and the cool chain is an important part of this. Working on such a project at the cargo division of KLM was a great experience and it showed the strong international network, the challenges and the capabilities of the airline.

I would like to thank Professor Lodewijks, Mr Beelaerts van Blokland and Mr Lin of the university for the feedback and productive discussions we had. These discussions gave new insight into the problem and helped me forward during the thesis. I also would like to thank Pieter Fopma from KLM Cargo for supporting me during the thesis. His openness to new ideas and provision of the right resources was an extremely valuable contribution. His input allowed me to perform field research and visit different stakeholders, gaining many new insights and adding a great deal of value to the project. The project has been an ongoing process of learning and the input and feedback from these people would not have given the same result.

At last, I would like to thank my parents, sister and family for supporting me during the last few months of my life as a student. Your counsel motivated me to work effectively on my thesis and it helped to stay focused throughout.

Frank van der Voort, soon to be MSc
Delft, December 2016

SUMMARY

The flower market has become global in recent decades. A lot of developing countries have an increased export in horticulture and cut flowers form the greater part of that. One of the emerging countries is Kenya, which is the third largest exporter of flowers in the world. The climate and cost of labour are advantageous for the growth of flowers and for roses in particular. Kenyan flowers account for 35% of all flower sales in the European Union. The Netherlands plays a significant role in this, buying 67% of their export tonnage and 57% of their export value. Air France-KLM-Martinair Cargo is the biggest carrier on this pathway and it transports a lot of perishables. The main perishable shipped on this route are roses, which account for [redacted]. KLM Cargo is challenged by external as well as internal aspects. The first external aspect is fierce competition from the Gulf and the Far East. Carriers from this region are investing a significant amount of money in the cool chain to deliver a product with a high quality and to be competitive. Additionally, customers are becoming more demanding, asking questions about the handling of perishables and the temperature changes they have been exposed to. The internal challenge is to measure time and temperature and to optimise the performance of the cool chain.

The focus of this research is on redesigning the cool chain for air transport of perishable goods from Nairobi to Schiphol. The air cargo supply chain is defined over 5 actors: shipper, exporting forwarder, airline, importing forwarder and the consignee. The shipper is the origin of the supply chain and in this system, these are farms in Kenya which grow and harvest the roses. The forwarder is the architect of the air cargo supply chain. It handles the shipment and it organises export handling and air transport. The airline is responsible for transporting cargo from the origin airport to the destination airport. After that, the flowers arrive at the importing forwarder which clears the shipment for import. The process ends with the consignee who checks the quality of goods at final delivery. To determine the quality of the flowers, the rose is viewed as a system with input parameters and output parameters. The input parameters are time and temperature and the output parameter is vase life. Vase life is judged by the end customer to be the main criteria for quality of the flowers and a higher vase life is defined as a better quality of the flower. To determine the quality of the roses the linear Degree Days model is used which expresses vase life as a function of time and temperature.

Time and temperature are measured during the supply chain and the cool chain can be described by the multiplication of these parameters: degreehours. Time and temperature data of the supply chain is collected by data loggers and in total 30 shipments are logged from 2011 until 2015. Different farms in Kenya are the origin of the supply chain and various consignees in the Netherlands are the destination. For each of the shipments, one sensor is entered in the middle of the pallet and one sensor is entered at the side of the pallet. These shipments gave an average degreehours [redacted] which resulted in a vase life reduction of approximately one day. The vase life of a rose at the beginning of the supply chain is 13 days. After transport, this is reduced to [redacted]. The temperature measurements collected by the data loggers are considered as continuous data. This is because the data loggers can measure the temperature on a small time interval, every 6 minutes. To determine the accuracy of the measurements different time intervals are used for the measurements. From this, it follows that an increased time interval gives an increased error percentage for the degreehours. The Mean Absolute Percentage Error of the degreehours is 10% at a measurement with a time interval of 10 hours. When the time interval increases the error of the degreehours also increases.

Field research on the supply chain found six available measurement points where time and temperature are measured. Information regarding time and temperature is used by each actor to monitor the process. The six measurement points indicated are considered as discrete measurements. To get a time temperature graph from this data time and the temperature is determined at the six measurement points for the all the shipments tracked. Two processing methods for time and temperature are employed, one by assuming temperature constant until the next measurement point and one by doing a linear interpolation of the temperature between two measurement points. This approach is executed for 30 shipments and the results are compared to the reference data, which is the continuous data. The linear interpolation method gives the best approximation with an average degreehours of [redacted] and a Mean Absolute Percentage Error of the degreehours of 7.3%. For the calculation of the expected vase life after transport, the error percentage is much smaller and is below 1%. The error percentage on the quality of the flower is smaller since this gives the error on the total vase life and not the reduction in vase life as a result of transport.

To quantify the performance of the cool chain, the property 'degreehours' is used. Degreehours is the multiplication of time and temperature of the shipment from the begin until the end of the supply chain. For KLM Cargo the degreehours should be set to [redacted] as a maximum. Ensuring such a limit makes KLM competitive and satisfies the objective of improving the cool chain. For the supply chain seven design alternatives are considered which meet the following constraints. The design alternatives should be within the system defined, the design alternatives should be time or temperature related, and the design alternatives should be based on field research performed. The design alternatives considered are cooling steps at different parts of the supply chain, pre-cooling of the aircraft and shorter handling time. These design options are judged on costs and degreehours reduction. Within the scope of KLM Cargo pre-cooling of the aircraft is suggested because of the low costs and the high impact. It reduces the average degreehours from [redacted]. The maximum degreehours decreases from [redacted] which is equal to almost half a day of vase life. Outside the scope of KLM Cargo, the handling time at the consignee should be shortened. For the pre-cooling of the aircraft an external air conditioning unit is used. This device ensures that the cargo hold is cooled down to 5°C before cargo is loaded into the aircraft. The costs for using an air conditioning unit are [redacted] transported. In case the air conditioning unit is not available or out of order the auxiliary power unit of the aircraft should be switched on. This auxiliary power unit can also cool down the hold of the aircraft. However, this is not a preferred option since the costs are higher, [redacted], and it produces a lot of noise when it is turned on at the airport.

For the redesign of the cool chain for air transport of perishable goods discrete measurements should be done in combination with linear interpolation. This way of measuring determines the degreehours property of the cool chain and it allows to take measures at the measurement points if needed. To predict the quality of the flowers the Degree Days model is used. The pre-cooling of the aircraft ensures that the quality of the flowers at the end of the cool chain is higher. The redesign of the cool chain ensures that KLM Cargo remains in its current strong position within the market. Time and temperature can be measured by using the infrastructure of the supply chain which is already available. The simplification of the supply chain gives the opportunity to investigate design alternatives of the cool chain for perishable goods. Subsequently, the impact of the design alternative on the quality of the perishable transported can be determined.

Samenvatting

De sierteeltketen is de laatste jaren een mondiale markt geworden. De export van sierteelt en snijbloemen vanuit verschillende ontwikkelingslanden is de laatste jaren significant gegroeid. Een van deze landen is Kenia, wereldwijd op plaats drie qua export van bloemen. De weersomstandigheden en de arbeidskosten zijn gunstig voor het kweken van bloemen en voornamelijk rozen. Van de bloemen die verkocht worden in Europa zijn 35% van Keniaanse komaf. Nederland is een belangrijke speler hierin en koopt 67% van de export uit Kenia qua tonnage en 57% qua waarde. Air France-KLM-Martinair Cargo is de grootste transporteur op deze route en vanuit Nairobi worden veel verse producten vervoerd. Het grootste aandeel van deze bederfelijke goederen zijn rozen, deze vertegenwoordigen [redacted] KLM Cargo staat op dit moment onder druk door externe en interne uitdagingen. De eerste externe uitdaging is de hevige concurrentie met maatschappijen uit de Golfstaten en het verre Oosten. De maatschappijen uit deze landen investeren veel geld in de koelketen om een product van hoge kwaliteit te kunnen leveren. De tweede uitdaging is dat de klant steeds kritischer wordt op de luchtvaartmaatschappijen met betrekking tot de koelketen. Diverse vragen worden gesteld over hoe de goederen precies vervoerd zijn tijdens de keten en welke temperatuursveranderingen het heeft ondergaan. De interne uitdaging voor KLM Cargo is om de tijd en temperatuur te meten gedurende de keten en het niveau van de koelketen zo hoog mogelijk te houden.

Dit onderzoek richt zich op de herinrichting van de koelketen voor luchttransport van bederfelijke goederen vanuit Nairobi naar Schiphol. Deze keten is verdeeld over vijf blokken: shipper, exporting forwarder, airline, importing forwarder en de consignee. De shipper is het beginpunt van de keten en in dit systeem is de shipper de bloemenkwekerij in Kenya die de rozen kweekt. De exporting forwarder is de architect van de keten. Deze forwarder handelt de zending af en het organiseert het luchttransport. De airline is verantwoordelijk voor het vervoeren van de vracht van de luchthaven van oorsprong naar de luchthaven van bestemming. Hierna arriveren de bloemen bij de importing forwarder die zending accepteert en inklaart. Het proces eindigt met de consignee die de goederen keurt zodra deze binnen zijn gekomen. Om de kwaliteit te kunnen bepalen van de bloemen wordt de roos als een systeem gezien met input en output parameters. De input parameters zijn tijd en temperatuur en de output parameter is vaasleven. Het vaasleven van een bloem is een belangrijk aspect voor de klant, een langer vaasleven geldt hierbij als een hogere kwaliteit. Om deze kwaliteit te kunnen bepalen is het gradenuur model gebruikt. Dit is een lineair model om vaasleven uit te drukken als functie van tijd en temperatuur.

Voor het definiëren van de koelketen wordt gebruik gemaakt van tijd en temperatuur metingen. De kwaliteit van de koelketen wordt uitgedrukt in gradenuur. Het verzamelen van tijd en temperatuur data is gedaan door data loggers te gebruiken om zendingen te meten. In totaal zijn 30 zendingen gelogd van 2011 tot en met 2015. Het startpunt van deze zendingen zijn verschillende rozenkwekerijen in Kenya, het eindpunt van deze zendingen zijn verschillende importeurs in Nederland. Voor deze zendingen is er een sensor in het midden van de pallet en een sensor aan de zijkant van de pallet geplaatst. Deze zendingen geven een gemiddelde gradenuur van [redacted], dit resulteert in een gemiddelde afname van vaasleven van ongeveer een dag. Op het moment dat de bloemen worden gesneden is het vaasleven gemiddeld 13 dagen. Als gevolg van transport neemt dit af tot [redacted] De data loggers die de zendingen meten worden beschouwd als continue metingen omdat ze in staat zijn om op een klein tijdsinterval, elke 6 minuten, de temperatuur in de keten te meten. Om de nauwkeurigheid van de metingen te bepalen zijn de zendingen voor verschillende tijdsintervallen gecontroleerd. Hieruit blijkt dat bij het meten van de temperatuur elke 10 uur een Mean Absolute Percentage Error geeft van 10%. Als het tijdsinterval groter wordt, wordt de foutmarge van de gradenuur ook groter.

Voor dit project is veldonderzoek gedaan naar de keten om te zien op welke momenten er gemeten wordt. Over de gehele keten zijn er 6 meetpunten aanwezig waar de tijd en temperatuur wordt gemeten. Deze informatie wordt gebruikt voor ieder individueel blok in de keten om bijvoorbeeld de ingaande en uitgaande temperatuur te monitoren. Deze zes meetpunten in de keten worden beschouwd als discrete metingen. Om een soortgelijke tijd temperatuur curve te verkrijgen is de tijd en temperatuur op deze zes punten vastgelegd voor de 30 zendingen. Hierna kan op twee verschillende manieren het temperatuur verloop worden geïnterpreteerd. De eerste manier is om de temperatuur, gemeten op punt 1 constant te houden tot het volgende meetpunt, meetpunt 2. De tweede manier is om de temperatuur lineair te interpoleren tussen meetpunt 1 en 2. Deze twee methoden zijn uitgevoerd voor alle zendingen en resultaten zijn vergeleken met de continue

metingen. De lineare interpolatie geeft de beste benadering met een gemiddelde gradenuur van [redacted] en een Mean Absolute Error Percentage van 7.3%. Voor de berekening van het vaasleven is de foutmarge een stuk kleiner, de Mean Absolut Percentage Error is minder dan 1%. Dit komt omdat hier gekeken wordt naar de het totale vaasleven van de bloem in plaats van de afname ten gevolge van transport.

Om de prestatie van de koelketen te meten is de eigenschap gradenuur gebruikt. Deze eigenschap is de tijd maal temperatuur van het begin tot het einde in de keten. De limiet voor KLM Cargo is gezet op 600 gradenuur. Deze limiet zorgt ervoor dat KLM Cargo competetief blijft en hiermee kan tegelijkertijd de koelketen verbeterd worden. Voor het verbeteren van de koelketen zijn zeven ontwerpen overwogen die aan de volgende voorwaarden voldoen. Het ontwerp moet binnen het gedefinieerde systeem vallen, het ontwerp moet tijd of temperatuur gerelateerd zijn en het ontwerp moet voortkomen uit het veldonderzoek. De overwogen ontwerpen zijn: koelen bij verschillende delen van de keten, pre-cooling van het vliegtuig en een kortere doorlooptijd in een deel van de keten meegenomen. De kosten en gradenuur winst zijn voor deze ontwerpen berekend. Binnen het bereik van KLM Cargo is het pre-coolen van het vliegtuig de beste optie. Dit zorgt voor een gemiddelde gradenuur afname van [redacted] De maximale gradenuurwaarde gaat van [redacted], wat overeenkomt met bijna een halve dag aan vaasleven. Buiten de scope van KLM Cargo is de doorlooptijd bij de consignee de beste verbetering. Voor het pre-coolen van het vliegtuig een externe air conditioning unit is nodig. De air conditioning unit zorgt ervoor dat het ruim van het vliegtuig wordt afgekoeld tot 5°C. De kosten voor de externe air conditioning unit is [redacted] vervoerde bloemen. In het geval dat de air conditioning unit niet beschikbaar is of buiten gebruik is, dan kan het vliegtuig eerder aangezet worden. De auxiliary power unit van het vliegtuig zelf zorgt dan voor het koelen van het ruim. Dit is echter niet gewenst omdat dit voor hogere kosten zorgt, [redacted], en het produceert veel geluid op de luchthaven.

Voor de herinrichting van de koelketen kunnen discrete metingen toegepast worden in de huidige keten en een lineare interpolatie van de temperatuur kan gedaan worden tussen deze meetpunten. Op deze manier wordt de totale gradenuur van de koelketen berekend en dit zorgt ervoor dat maatregelen genomen kunnen worden bij ieder meetpunt indien nodig. Om de kwaliteit van de bloemen te kunnen voorspellen wordt het gradenuur model gebruikt. Het vooraf koelen van het ruim van het vliegtuig zorgt voor een betere kwaliteit van de bloemen aan het einde van de keten. Deze herinchting van de koelketen zorgt ervoor dat KLM Cargo de positie in de markt kan verstevigen. De vereenvoudingen aangebracht in de keten geven de mogelijkheid om verschillende ontwerpen te evalueren voor de koelketen van bederfelijke goederen. Daarnaast kan de impact van het ontwerp op de kwaliteit van de bederfelijke goederen worden bepaald.

Abbreviations

AAS Amsterdam Airport Schiphol. 3

ACU Air Conditioning Unit. 53

APU Auxiliary Power Unit. 53, 54

AWB Airwaybill. 24

BUP Build Up Pallet. 11, 13, 14, 19, 75, 77, 80

DD Degree Days. 26, 27, 34, 35

FOA First Order Arrhenius. 16, 26, 27, 35, 36

HWB House Airwaybill. 9

IATA International Air Transport Association. 9

JKIA Jomo Kenyatta International Airport. 9, 11, 37, 75, 79

K+N Kuehne + Nagel. 74

MAPE Mean Average Percentage Error. 34, 35, 38, 39

NOTOC Notification to Captain. 10, 54

POD Proof of Delivery. 11

RFC Ready For Carriage. 9

RFT Ready For Transport. 9, 10

RH Relative Humidity. 15

SLA Service Level Agreement. 54

SV Saudi Arabian Airlines. 24

TTI Time Temperature Integrator. 20, 21

ULD Unit Loading Device. 10

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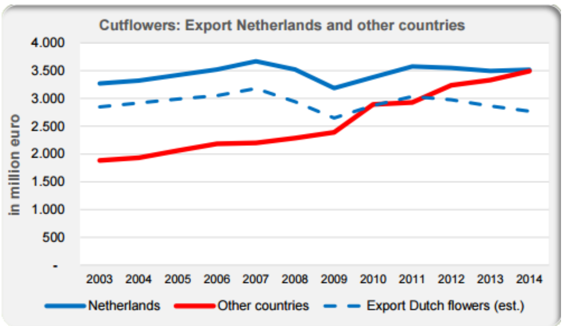
INTRODUCTION

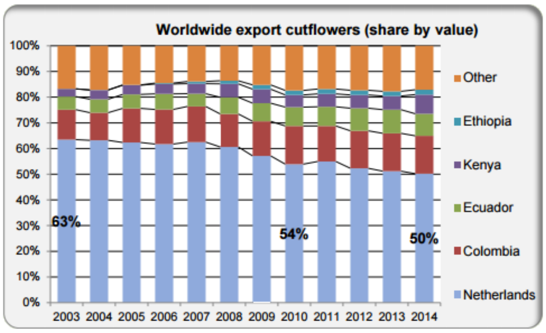
This chapter introduces the research. At first the flower market is explained in section 1.1. After this an introduction to KLM as a company is given in section 1.2. The problem is introduced in section 1.3. This section also includes the research questions, research scope and research goal. The chapter concludes with the outline of the report in section 1.4.

1.1. FLOWER MARKET

On a yearly basis cut flowers are traded internationally with a market value of 7 billion Euro, equal to 9.3 billion dollars. The Netherlands is the leader in export of cut flowers, as seen in Figure 1.1a. The export of cut flowers from the Netherlands has stayed at a constant level over the last years while that of other countries has increased. What also can be seen in this figure is that a part of the export from the Netherlands is not harvested in the Netherlands itself, the dotted line indicates the export of the Dutch flowers. The difference between the dotted and the solid line is flowers imported from one country and exported to another country. This commonly happens to Kenyan flowers. In the second graph, Figure 1.1b, the division of export per country can be seen. In this graph, it is visible that export share of the Netherlands is decreasing while developing countries' export increase. One of the trends which can be derived from this figure is the share of Kenyan export, this has increased from a few percent in 2003 to 7.5% in 2014.



(a) Value of worldwide export



(b) Shares of worldwide export

Figure 1.1: Worldwide flower export over the last years [1]

In the last thirty years the cut flower market has become global. Flowers and cut foliage are sourced from all over the world and are sold as bunches, used in bouquets or used in arrangements in the major destination markets [5]. Flowers are transported over ten thousand kilometres from harvesting until they arrive in the vase of the end customer. Significant destination markets are amongst others the European Union, North America, Russia and Japan. High export value has led to steep increases in production in many developing countries. One of these developing countries is Kenya. Flowers transported by air is one of Kenya's biggest export products. The flower trade between Kenya and the Netherlands is dynamic and vital for their horticulture. With the Netherlands buying 67% of their tonnage and 57% of their export value, Kenyan flower

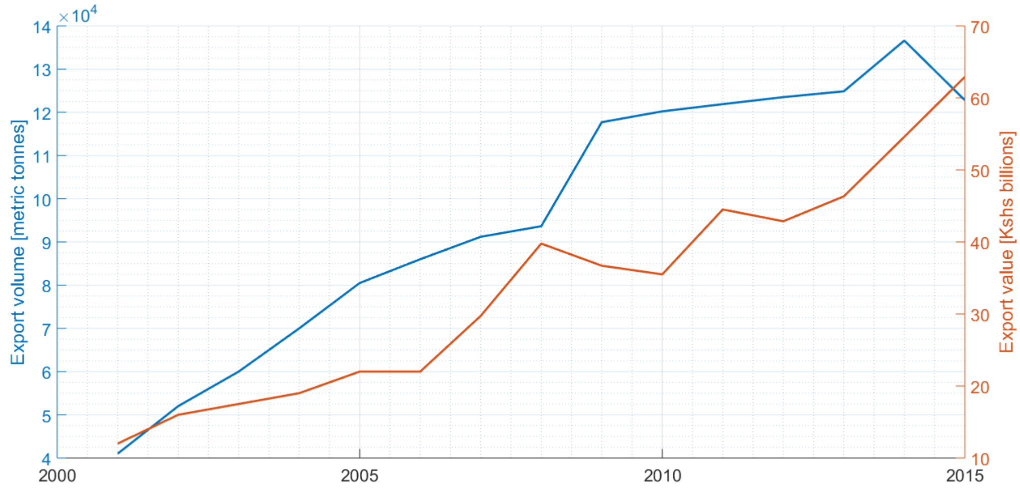


Figure 1.2: Kenyan horticultural export over the last years [2],[3]

growers have achieved tremendous export growth over the last decades [6]. This increase in export can also be seen in Figure 1.2. There was a slight decrease in the value of the export around the financial crisis in 2008. Afterwards, the value increased while the tonnage stayed more or less constant.

Air France-KLM-Martinair Cargo, hereinafter referred to as KLM Cargo, is one of the airlines which transports perishable cargo on this lane. Perishable cargo sent from Nairobi to Schiphol is an important lane for the carrier. Flowers transported from Nairobi to Schiphol, hereinafter referred to as the Nairobi-Schiphol lane, contributes for [redacted]. The main fresh commodity transported is roses, which count for [redacted] Roses are harvested in Kenya, mainly from the regions: Naivasha area, Mount Kenya, Nairobi and Nakuru. These regions all lay around the capital and all export goes via the airport in Nairobi. The customer, in this case the person who puts the roses in a vase, is located throughout and outside Europe, ranging from Russia to the United Kingdom.

Figure 1.3: Loading an aircraft with flowers

1.2. Company introduction

KLM is the oldest airline still operating under its original name. KLM, standing for Koninklijke Luchtvaartmaatschappij (in English Royal Dutch Airlines), was founded in 1919 by Albert Plesman. The main hub of KLM is Amsterdam Airport Schiphol (AAS) and the headquarters is located in Amstelveen. KLM transported 28,5 million passengers and 705 thousand tonnes of cargo last year [7]. In 2004 a merger took place between Air France and KLM and both of the airlines are subsidiaries of a holding company called Air France-KLM. Both of the companies still operate from their original home base, Air France from Charles de Gaulle Airport in Paris and KLM from Amsterdam Airport Schiphol in Amsterdam. For the holding company there are three core businesses:

- Passenger Business: The main area for KLM is the passenger business. At the moment KLM has 145 destinations worldwide of which 68 are intercontinental and 77 are European destinations.
- Engineering & Maintenance: At the Engineering & Maintenance department the aircraft are repaired and maintained. This is done for different airlines, not only KLM, and there are over 200 customers, international and regional.
- Cargo: The cargo department handles all shipments carried out by KLM. Last year 700 tonnes of cargo was transported. There are different kinds of cargo transported, ranging from live animals to secure goods. This is explained in section 1.2.1.

Air France-KLM is the holding company and the cargo section is a part of this company. In 2008 KLM bought all shares of Martinair which became a subsidiary of KLM. Air France-KLM-Martinair Cargo, also written as AFKLMP cargo has three different sections: Air France Cargo, KLM Cargo and Martinair Cargo. This project is executed for KLM Cargo and the structure of the company is explained below.

1.2.1. KLM Cargo

Within KLM Cargo there are four different groups distinguished. These groups are adjusted to specific cargo which have their requirements and priorities. These four groups are graphically represented in Figure 1.4. Explanation of these groups is given below.

Figure 1.4: Four different groups at KLM Cargo

Equation Equation cargo is the solution for fast transport. There is a high priority for loading the cargo and the shipment can be accepted just before the departure of the aircraft. For heavy cargo there is a separate choice 'Equation Heavy' for safe transport between two airports.

Cohesion Cohesion cargo is suitable for tailor-made solutions. In this category requirements and wishes of the customer are taken into account. This is communicated to the shipper, the forwarder and the airline.

Variation Variation cargo is the solution for specific commodities. These commodities have its logistical characteristics and special requirements. Within variation these groups are aerospace, art, extremely large or heavy shipments, dangerous goods, perishable goods, live animals, pharmaceuticals, valuable goods and all types of vehicles. In this research, the focus is on perishable goods.

Dimension The Dimension group is for general cargo. Different kinds of cargo are accepted and it is ideal for consolidated shipments. There are fixed drop-off and delivery times at each station, which makes it easy to plan ahead.

VARIATION-FRESH DEPARTMENT

Transport of perishables is done within the variation segment, which is also called Fresh. Variation Fresh is divided into three categories; Fresh 1, Fresh 2 and Fresh 3. Specifications of this categories and examples are given below.

Fresh 1: This solution is for perishables that require strict temperature control. The shipment is transported and stored in a temperature-controlled environment. Examples of products within Fresh 1 are frozen meat and frozen seafood. Products are shipped in temperature-controlled containers which can be between -20°C and +20°C.

Fresh 2: The Fresh 2 category is the greater part of the shipments concerning volume and tonnage. Shipments transported in this category are temperature sensitive perishables. The commodities transported have a desired temperature range which is between +2°C and +8°C. Examples are plant cuttings, fresh flowers, string beans, asparagus, cheese, species, live lobster, fresh fish, fresh meat and mushrooms.

Fresh 3: The last category is Variation Fresh 3. In this category, less sensitive perishables are transported. For these shipments the handling procedure is to protect from extreme temperature during transportation, like heat or frost. In practice this temperature range is between +2°C and +25°C. Examples are tropical flowers, wine, mangoes, tomatoes, melons, pineapple and chocolate.

1.2.2. CARGO FLEET

Perishables and other types of cargo can mainly be transported with three different types of flights. These type of flights are stated in Table 1.1. On the Nairobi-Schiphol lane most of the times a full freighter is used since these aircraft have the greatest capacity. KLM Cargo used to have a lot of combi aircraft but these aircraft will be phased out in the coming years.

Table 1.1: Three different ways of transporting perishables and other cargo

Flight	Explanation
Full freighters	Aircrafts dedicated to cargo transport; shipments carried on both upper (main) as well as lower deck.
Combi flights	Aircrafts carying both passengers as well as cargo.
Passenger flights	Aircrafts mainly for carrying passengers but with some lower deck capacity for cargo.

■

Kenya-to-Europe routes are served by different commercial Airlines, KLM Cargo being one of them. Three types of aircraft are used for this transport and these are stated in Table 1.2. At the moment the Boeing MD-11 is out phased. Many flowers are transported in a Boeing 747 which is owned by KLM Cargo but leased to Martinair. This aircraft has a load capacity of 110 to 120 tonnes, more details of this aircraft can be found in Appendix C.

Table 1.2: Different models of aircraft and their loading capacity [6]

Model	Capacity [tons]
Boeing 777	20-30
Boeing 747	110-120
Boeing MD-11	75-85

1.3. Problem introduction

KLM Cargo is a subsidiary of KLM and is responsible for all the cargo flights. There is a lot of interest from KLM Cargo in improving the supply chain and in particular the cool chain of the Nairobi-Schiphol lane. This is mainly for two reasons: on the one hand there are external factors which put a lot of pressure on KLM Cargo and on on the other hand there are also internal challenges. On the external side, customers are becoming more quality concious and demand higher quality products [8]. Next to that, the customer wants to have transparency. They are interested in what happens to their flowers during transit and ask questions to the airline about the handling of perishables and temperatures they have been exposed to. Next to the customer there is a lot of competition with other airlines. Airlines from the Gulf and the Far East are investing a significant amount of money in the cool chain which makes the market a competitive environment.

Internally, KLM Cargo is having trouble with the consolidation of the cool chain. Products are sold under certain conditions. This includes, for example, a temperature minimum, maximum and the delivery time. There are several moments in the chain where the boxes transported are exposed to high temperatures. These high temperatures increase the risk that flowers go bad or become diseased. These two aspects are combined into the initial problem definition stated below. The problem is analysed further in section 2.1.

> *"The problem of KLM Cargo is to measure time and temperature of perishable products and to keep the cool chain at a high level to ensure the right quality for the customer and to outperform the competition."*

1.3.1. Research questions

To solve the problem of KLM Cargo the research is guided by a research question and several sub-questions. The research questions is as stated below:

> *What design criteria can be determined for perishable goods transported from Nairobi to Schiphol from a quality perspective?*

(a) How is quality defined for roses and which parameters influence it?

(b) How to define the supply chain from a transport and logistics perspective?

(c) What is the performance of the cool chain from a time and temperature perspective?

(d) Which measurements are available in the current system?

(e) Which design alternatives are possible along the supply chain?

(f) What is the impact of the design alternative chosen on the quality of roses?

The sub-questions are answered in different chapters. Sub-question (a) and (b) are answered in Chapter 2. In Chapter 4 subquestion (c) is answered. Subquestion (d) is answered in Chapter 5. The last two subquestions, (e) and (f) are answered in Chapter 6.

1.3.2. Research scope

One of the biggest constraints for this project is time. The project is done over a period of 8 months which restricts the research to a single lane. The significance of the lane, available information and potential for redesigning the cool chain are three arguments taken into account choosing the lane. The most significant lane regarding quantity and price is considered which is the Nairobi-Schiphol lane, where the main commodity is roses. On this lane, research is already performed and the information is available to continue with. For redesigning the cool chain, there are many different lanes which have a challenging cool chain. For some of the lanes the cool chain can not perform in a stable way or can result in a lot of claims.

Judging these three aspects the research is solely focused on the Nairobi-Schiphol lane. However, the method used in this research can be applied to other supply chains and some of the conclusions are for KLM Cargo in general. The supply chain is analysed on a top level, from farm to importer, to get a complete overview of the chain.

1.3.3. RESEARCH GOAL

This research is initiated by KLM the Royal Dutch Airlines and aims at improving the cool chain to better preserve the quality of perishables transported. More specifically this research aims to improve the cool chain of the Nairobi-Schiphol lane to deliver higher quality perishables. This leads to an improved customer's satisfaction and a stable position of KLM Cargo within its competitive market. For Delft University of Technology the research goal is to develop a greater insight in the transport of perishables. The quality of perishables transported is defined and different measurement methods for the cool chain are research. This is eventually translated to design alternatives for KLM Cargo.

1.4. REPORT OUTLINE

The outline of the report is as follows. Chapter 2, defines the problem and system more extensively. Chapter 3 describes the way data is collected. The following chapter, Chapter 4 analyses this data and defines performance for the cool chain. The next chapter elaborates the analysis more by checking other measurement methods, see Chapter 5. After that design alternatives are discussed in Chapter 6. The next chapter, Chapter 7 contains the conclusion. The last chapter, Chapter 8, contains the recommendations given to Delft University of Technology and KLM Cargo. Five appendices are completing this research. The first appendix, Appendix A, includes a research paper about this project. Appendix B explains the field research which is done. Different facilities in and around Nairobi are described and visualised. The third appendix, Appendix C, specifies details of a Boeing 747-400 ERF which is mainly used for this transport. Appendix D contains handling manuals of the aircraft and cargo handling in general. The report is completed with Appendix E describing the blooming phase of a rose and the end of vase life is also explained.

2

Problem and System Definition

In this chapter the problem and the system are defined. The problem definition is given in 2.1. The second section, section 2.2, defines the system. Both for the problem definition and the system definition a seperation between the biological and logistical aspect is made.

2.1. Problem definition

The initial problem definition as stated by KLM Cargo is given in section 1.3. This problem definition states multiple sub-problems from which the following parts can be distinguished. The first part of the problem is about measuring time and temperature and redesigning the cool chain. The second part is about preserving the quality of perishables. In fact, two aspects of the problem can be differentiated. Since the product should be transported from origin to destination there is a logistical aspect. On the other side, the commodity transported are perishables and deteriorates over time which is a biological aspect.

The logistical aspect is the way it is transported, for example by air, road or sea, the way measurements are done but also which measures are taken to preserve the quality. When a product is perishing a lot, logistical actions can be taken by re-cooling the commodity. The biological aspect is describing the quality, how the product perishes over time and how the product behaves under different circumstances. The interplay between these two aspects makes this problem interesting and complex at the same time, this can be seen in Figure 2.1.

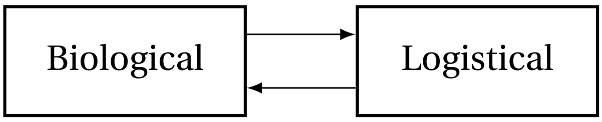


Figure 2.1: The interplay of two aspects within the problem and system

2.1.1. Logistical aspect

This research focuses on the transport of perishable goods. The commodity mainly transported from Nairobi to Schiphol are roses. Roses perish over time and therefore a consolidation of the cool chain is very important to preserve quality. The aim of KLM Cargo at the moment is to transport goods as fast as possible from the farm to the consignee and at a temperature as low as possible. The first part is the logistical aspect. From a logistical point of view, there are several problems which are: non-defined performance, exceeding temperature and no control on logistics. These three subjects are explained below.

1. **Performance not defined:** The first and most important aspect of the problem is the performance of the cool chain. The aim of KLM Cargo is to deliver roses with a higher quality but at this moment the cool chain and its performance are not defined. It is not known whether measurements are done along the chain and if information is collected. Before any design alternatives can be considered measurements and performance should be determined.

2. **Exceeding temperature:** Products like roses are sold in category Fresh 2, this category is explained in 1.2.1. The condition of Fresh 2 is that products are transported between +2 to +8°C. It regularly happens that, during transport, the commodity exceeds this temperature. This can happen for several reasons. For example, the aircraft pallet can be stored outside waiting for the aircraft which is delayed. There can be a priority of other cargo, for example, pharmaceuticals which are occupying cool room capacity during storage. A co-loading issue can happen where one pallet with fresh products and one pallet with live animals is stored in the same cargo hold in the aircraft. In this case the captain will set the temperature in that case to 15°C. These are some examples of the risks along the supply chain where the temperature exceeds the limit of +8°C.

3. **No control on logistics:** Perishables which are transported by KLM Cargo do not have any performance regarding the cool chain. For this reason, no measures are taken within the cool chain to make sure the output quality is as high as possible. For example, when boxes arrive at the forwarder having a too high temperature vacuum cooling can be done. With this measure, the boxes reach a temperature of 1.8°C. The disadvantage is that the forwarder does not put every shipment in the vacuum cooler so whether or not the shipment is cooled depends on capacity and if either party is willing to pay for cooling. There are no control actions which are can guarantee the performance of the cool chain or the quality of the flowers.

2.1.2. BIOLOGICAL ASPECT

For the biological aspect of the problem several sub-problems can also be defined. These problems are explained below.

1. **Lack of knowledge of commodity:** The moment a rose is harvested from the fields it is still alive and it deteriorates over during the post-harvest phase. There is very little knowledge about this deterioration processes. The moment KLM Cargo receives flowers, they are packed in boxes and can not be opened until they are delivered to the customer. The airline is a small part within the supply chain and their input is effectively to accept a cool box, maintain its temperature and deliver it to the customer.

2. **External parameters:** Roses are vulnerable commodities and need to be treated with care. The influence of external parameters like time and temperature on the behaviour of roses and its deterioration is not known. Therefore no cooling actions are taken to have a high quality output.

3. **Cultivars:** Roses are treated as one flower but actually, there are over hundreds of species and thousands of cultivars. Farms often grow more than one species and these species have different behaviour. They can differ in appearance but also in biological properties In the current situation, no distinction is made between different roses.

2.2. SYSTEM DEFINITION

In this section, the system and its boundaries are defined. The problem definition is given in the previous section and in the following subsections the system will be explained further. As in section 2.1 the logistical and biological part are discussed in different sections.

2.2.1. DEFINING LOGISTICAL SYSTEM

In this section, the logistical system is explained. First the air cargo supply chain is defined and afterwards there is a focus on the cool chain and examples of the current situation are given.

AIR CARGO SUPPLY CHAIN

The supply chain and the management of it is an important aspect of this system. The definition of supply chain management is given below.

> *Supply chain management is defined as a set of approaches utilized to efficiently integrate suppliers manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and the right time, in order to minimize the system-wide costs while satisfying service level requirements [9].*

Supply chain management is about integrating suppliers manufacturers, warehouses and stores. In this case, the manufacturers are the farms which harvest flowers. Every supplier in this system has its own warehouse. An overview of the air cargo supply chain is given in Figure 2.2. There are five actors in the system: the shipper, the forwarder, the airline, the second forwarder, the consignee. The airline is the responsible area for KLM Cargo and has a box around the block in the figure. The functions of the actors are explained below.

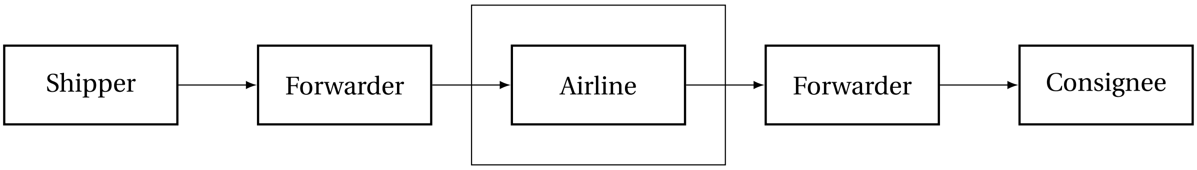


Figure 2.2: An air cargo supply chain with different actors

Shipper The first part of the supply chain is the shipper. In most of the cases, and especially on the Nairobi-Schiphol lane, the shipper is the farm. At the farm, the actual produce is grown and harvested. These farms can belong to small-scale growers or to large producers who may have invested in post-harvest cold chain facilities such as warehouses and refrigerated trucks. Farms which harvest for the Nairobi-Schiphol route all produce roses. There are, however, many different colours and cultivars and this can be one way for the farm to distinguish themselves.

In our scope there are around 80 farms which harvest flowers in different amount and these farms are spread all over Kenya. When the flowers are Ready For Transport (RFT) which means they are packed in a correct way and with the right documents, they go by truck to the forwarder. The length of this trip depends on the location of the farm and can range from [redacted] Depending on the situation, the truck can either be provided in-house by the shipper or forwarder or can be hired by either of them from a third-party.

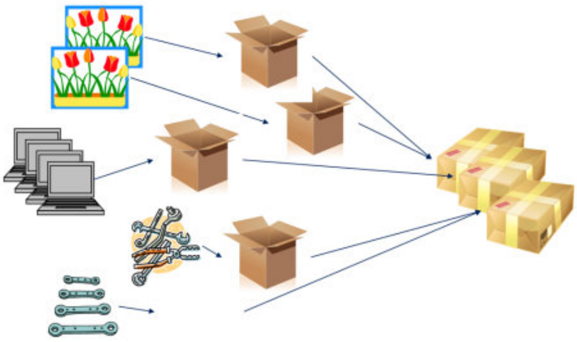


Figure 2.3: Harvesting and packing flowers at the shipper

Forwarder Perishable goods are delivered at the warehouse of the forwarder. The forwarder, also called expediter, is the ‘architect’ of the air cargo supply chain. A forwarder or expediter can be International Air Transport Association (IATA) certified, in that case, he is referred to as an agent. The forwarder’s responsibilities vary depending on agreements with the customer, but they typically organise:

1. Outgoing handling or export handling and customs clearance of the customer’s shipment. Export handling is the process of loading boxes onto the aircraft pallet.

2. Air transport from a nearby airport to an airport near the destination. In our case, the nearby airport is Nairobi Airport and Schiphol Airport is the airport near the destination.

To keep track of the different customer’s shipments from one exact address to another, the forwarder makes a House Airwaybill (HWB) for each shipment. The next step to take is to make the goods Ready For Carriage (RFC). The goods should be correctly packed and labelled and provided with the right documents and security checks. In the defined supply chain there are 4 or 5 different forwarders which are all located at Jomo Kenyatta International Airport (JKIA)

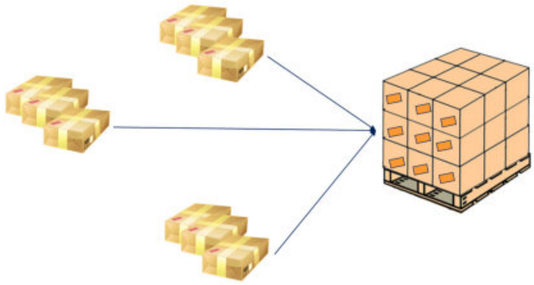


Figure 2.4: Boxes are received and consolidated at the exporting forwarder

Airline The goods are received at the airline's handling agent warehouse. The handling agent is often a separate company contracted by the airline, but cargo handling can also be an in-house function, especially at a major hub. Besides this handling other important functions are:

1. Controlling the overall weight and balance of the aircraft, make a load sheet and assure flight safety. The balance of the aircraft is to have more weight in the back of the aircraft so it is in a natural flight position.

2. To make a cargo manifest for the goods on board, for the airline's import and export declaration to customs.

3. To make a Notification to Captain (NOTOC) which informs the crew about the cargo on board. It can inform about the potential risk of emergencies (e.g. dangerous goods, live animals, valuables), as well as information for the right conditioning of the cargo holds.

4. To plan and control bookings, slot-times, goods flows in the warehouse to prevent delays and assure correct execution of the airline's timetable.

An important aspect is the incoming checks before the loading and the departure of the aircraft. These checks are commercial checks, logistics checks, flight safety checks and security checks. After the checks, the Unit Loading Device (ULD)s and documents are transported to the aircraft at the ramp. When the ULDs are loaded in the aircraft on the planned position the cargo doors are shut and the aircraft is ready to depart. During the flight, the crew is responsible for controlling the temperature of the cargo holds according to the NOTOC. At the airport of destination the cargo will go through the whole process again but then in reverse.

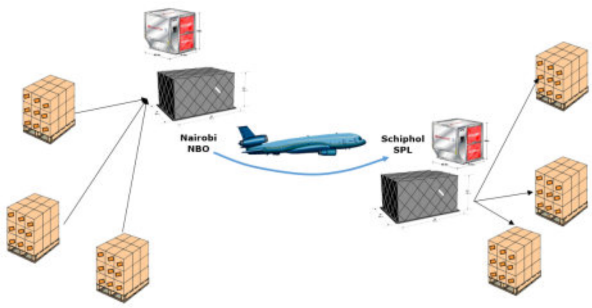


Figure 2.5: Flowers are transported from Nairobi to Schiphol by KLM Cargo

Forwarder When cargo arrives at the destination airport the receiving forwarder picks up the shipment documents at the handling agent. The forwarder prepares import documents and performs customs clearance for import. At this stage, customs can decide to release or hold the shipment for inspection. After approval by customs, the pick-up of the goods at the handling agent is ordered and the goods are delivered at the forwarder's warehouse. The forwarder splits the shipment and makes them RFT again.

- Further incoming handling or import handling and customs clearance near the destination. This import handling is breaking down the pallet and collecting the boxes for the same consignee.

- Delivery at the final destination, which is the consignee. This consignee is located in the Netherlands and especially around the area of Aalsmeer. From the consignee flowers are sent to retailers or wholesalers.

Goods are picked up by road transport for delivery to the consignee, which is the end point for the air cargo process. This road transport can be organised by either the forwarder or the consignee. Again, this transport can be arranged in-house or can be hired from a third-party.

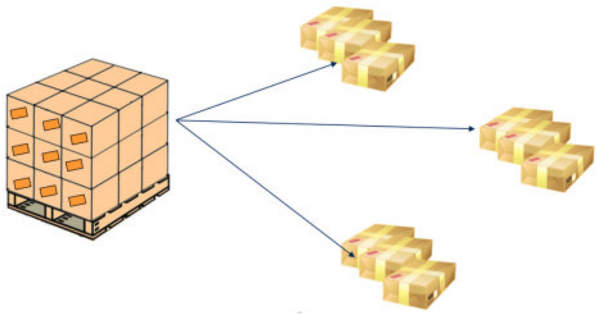


Figure 2.6: Boxes are approved at the importing forwarder and distributed to the consignee

Consignee The air cargo process ends with the consignee. This consignee is the person or company that is physically and administratively responsible for accepting the goods at final delivery. The consignee is in a lot of cases the customer of the forwarder but this is not necessarily so. The consignee will give a Proof of Delivery (POD) to the forwarder's transporter when the goods have arrived in a good state. The packages are opened and the contents are checked against the packing list and invoice.

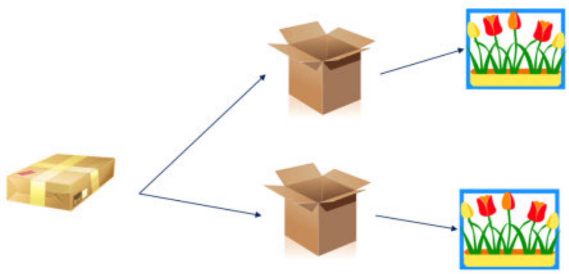


Figure 2.7: Consignee receives the flowers and checks the product

Two different pathways

The general supply chain for perishable goods can be seen in Figure 2.2. However, there are multiple pathways within the system which are explained in this section. Another figure of the supply chain can be seen in 2.8. A second pathway is added where the shipper sends perishables directly to the warehouse of the airline. These pathways are discussed below.

Pathway 1: With forwarder The first pathway is the supply chain explained in the previous section. A part of the incoming pallets come from a forwarder. In this case, the forwarder builds up the pallet and dispatches it to the airline. The Build Up Pallet (BUP)s arrive at the warehouse in JKIA and they are handled to be loaded on the aircraft. The airline's handling agent warehouse is called Triple FFF.

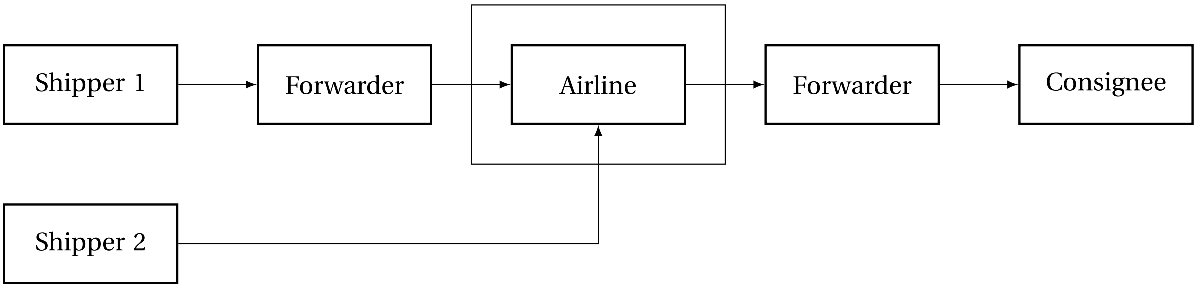


Figure 2.8: Two different flows on the Nairobi Schiphol chain

Pathway 2: Forwarder and airline combined The second pathway is where the shipper directly sends their flowers to Triple FFF. In this case, the airline acts as the forwarder and as the agent. Loose cargo is received from different farms and aircraft pallets are build up in the warehouse. The shipment is consolidated and loaded on the aircraft. From here on the steps in the original supply chain are followed.

TRANSPORT IN BOXES

Flowers are transported in standard boxes as seen in Figure 2.9. This box contains 13 bunches of 27 roses, which is equal to 351 stems in total. Most of the boxes with these dimensions have on average 350 stems in one box and have a maximum weight of 12 kilogrammes. Boxes have ventilation holes at the sides to allow convection and therefore improve the cooling of a box. Roses can be transported either dry or wet. In this case, roses are transported dry, which saves space and is also better for preserving the quality of the rose [10]. The quality of flowers transported dry is typically higher than that of those transported wet and this holds for a transport temperature below +10°C [5],[11].

Figure 2.9: Roses stored dry in a box ready to be transported

COOL CHAIN

The focus of this research is on redesigning the cool chain which is a temperature controlled supply chain. The definition of a cool chain and its management is given below.

> *Cool chain management is defined as the process of planning, implementing and controlling efficient, effective flow and storage of perishable goods, related services and information from one or more points of origin to the points of production, distribution and consumption in order to meet customers requirements [12].*

The definition covers different aspects of the cool chain. The cool chain is from the point of origin to, in our case, a point of distribution. The customer requirements which should be met are discussed in more detail in section 2.2.2. For the cool chain, an efficient and effective flow and storage of perishable goods is needed. To achieve this there are a lot of parts within the chain which are cooled. For example, perishables are stored in a cooled warehouse and they are driven around in temperature controlled trucks. These facilities should ensure the quality of the goods.

Ensuring that there are no breaks in the cool chain is vital for perishable products, as they require strict temperature control and monitoring to maintain their quality, safety and value [13]. Flowers from a well-managed cold chain are likely to have a longer vase life and also likely to attract higher prices [14].

Heat production by flowers

Since flowers are a living product after harvesting they keep generating heat. This continues during the post-harvest phase. In Figure 2.10 the generation of heat is represented by the time needed to increase the temperature of the box with 1°C. On the y-axis, the time is shown and on the x-axis the starting temperature. From the graph can be read that it takes 8 hours to go from 0 to +1°C. A box goes from +5 to +6°C in 4 hours, which is half of the time. This indicates the *'broei'* effect. Therefore it is dangerous to put boxes in a non-closed cool chain; this will result in boxes with high temperatures and increases the risk that flowers lose their quality.

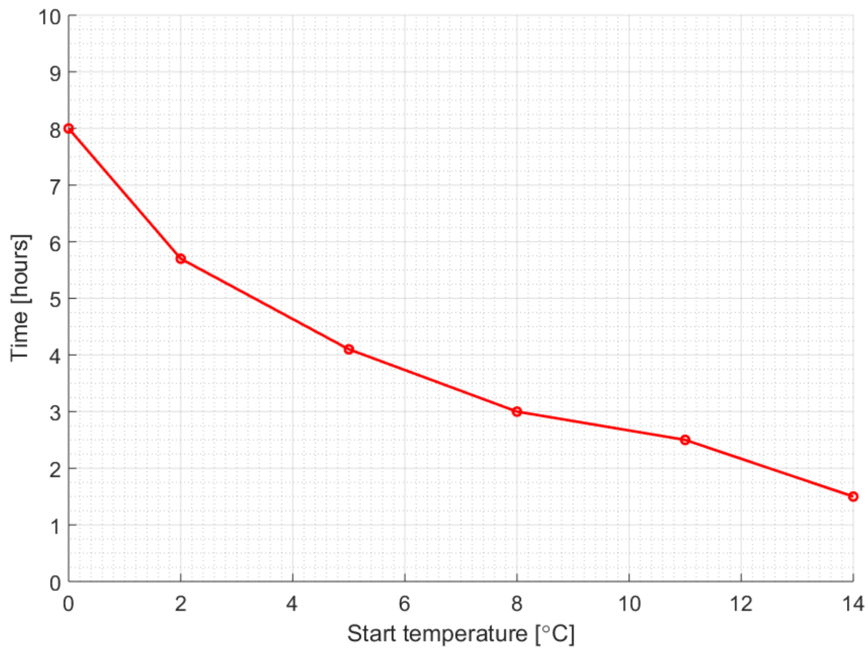


Figure 2.10: Time for a box of flowers to increase 1°C [4]

Re-cooling possibilities

As mentioned above there are many facilities to keep the perishables at a low temperature, between +2 and +8°C. However, it is hard to keep the cool chain closed from beginning till end. With a closed cool chain it is meant that goods are kept in a temperature controlled environment along the chain where the desired temperature depends on the specific requirements. A closed and unbroken cool chain is not always the case and it is possible that perishables reach a too high temperature as a result of that. There are several options to bring down the temperature of the boxes. These re-cooling options have different capacities regarding time and temperature and have different costs. Two examples which are currently used in the chain are given below; one is a vacuum cooler and the other one are insulating covers.

Vacuum cooling The first option for re-cooling is vacuum cooling. In Figure 2.11a an example of a vacuum cooler is seen, this picture is taken at one of the forwarders in Nairobi, Kenya. A BUP can be vacuum cooled if the temperature is not at the desired level. The pallet enters the machine and the output temperature is given. The doors are closed and the pressure drops until the point that water boils at 2°C. After that the cooling process starts and the temperature of the BUP drops. The maximum input temperature of the pallet is 15°C. A vacuum cooler can cool down the core of the aircraft pallet to 1.8°C within 45 minutes. This way of cooling is effective but also expensive.

(a) An aircraft pallet ready to be vacuum cooled

(b) Insulating cover to protect aircraft pallet

Figure 2.11: Current way of recooling flowers and keeping flowers cool

Insulating covers Along the chain, there are parts where flowers are outside. When they are exposed to sunlight, in Nairobi temperature easily reaches 25°C, the temperature of the boxes can increase very fast. To prevent the boxes from heating up an insulating cover can be placed over the BUP as soon as they get outside. An example of an insulating cover over a pallet is shown in Figure 2.11b.

2.2.2. DEFINING BIOLOGICAL SYSTEM

The biological aspect is the second aspect of the system. The quality of the rose is defined as well as two prediction models which can assist in choosing certain logistical actions.

QUALITY OF ROSES

The quality of a rose affects the price as well as customer satisfaction in perishable goods [15]. For the customer the quality of the roses they buy is essential. Buying a bouquet of flowers which are wilted after 5 days leaves the customer disappointed, and sees them less likely to buy the same flowers again. Some of the retailers even give a 7-day vase life guarantee. To achieve this a proper cool chain must be maintained. To get more insight into the behaviour of a rose it can be seen as a system with input parameters and output parameters. A function determines the output based on the input parameters; this is seen in Figure 2.12.

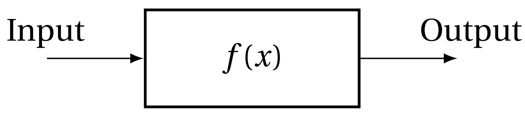


Figure 2.12: Viewing the rose as a system with input and output

Output parameter The most important aspects of quality are 'freshness' and vase life and these aspects depend on optimum postharvest handling [5]. The destination of cut roses is the end customer, everyone who buys roses. The roses are kept in the vase and subsequently, a certain vase life is expected. Vase life is, therefore, leading as a quality indicator and is defined as follows:

> *"The remaining vase life is defined as the time that flowers can be kept on the vase at room temperature, which is regularly assumed to be equal to 20° C." [16]*

There are several criteria on when the vase life of a flower ends. A regular quality criterion for cut roses is the wilting of the flower, which can be caused by bacteria [17], [18]. Other incidents which may happen to roses are the occurrence of petal browning due to severe *B. cinerea* infection and bent neck due to vascular blockage [19],[20]. An overview of this criteria can be found in Appendix E. In Figure 2.13 a Kenyan rose in blooming phase can be seen. It must be noted that the higher the ambient temperature the shorter the vase life of cut rose flowers [21].

Figure 2.13: A Kenyan rose in blooming phase

Input parameters The vase life of roses is determined by many different factors, which are the input parameters. There are two important parameters: temperature history and flow time through the supply chain [22],[23]. Humidity is not taken into account as an influencing parameter and is only affecting vase life of a flower at extremely high levels which are assumed not to be reached during transport.

Temperature Temperature history is seen as one of the most important aspects in transporting perishables [24],[25],[26] . Ideally, roses should be transported close to 0°C. This results in a minimum loss of quality. However, most of the guidelines in the transport chain aim at a range of 2 to 8°C. High temperature during transport increases the chance on diseases like Botrytis and also increases the chance a flower does not open at all. The effect of temperature on the rate of flower senescence is one of the most important parts of a model to simulate. A model can be used to see the effects of temperature during the post-harvest phase on flower quality for the final customer [27]. Temperature monitoring and control is judged to be the solution of 90% of the quality problems, starting when the product is harvested at the farm [28].

Time In combination with temperature, time is also important in transporting perishables and transport time should be kept as short as possible [29]. The aim is to keep the transport time from farm to the customer as low as possible. A long transport time can negatively affect vase life and can increase the chance on *'broei'*.

Humidity Relative Humidity (RH) is one of the parameters which can also have an effect on the vase life of roses. Literature states that high RH values can slightly affect the vase life of flowers. Flowers should be kept in greenhouses or in a room where the relative humidity is below 80-85% [30]. This parameter can have an influence on the quality of roses, however, the focus on the research is on a different aspect so this will not be taken into account.

PREDICTING QUALITY

Combining the input and output parameters Figure 2.12 can be extende to Figure 2.14. The input parameters are time and temperature and the output parameter is vase life.

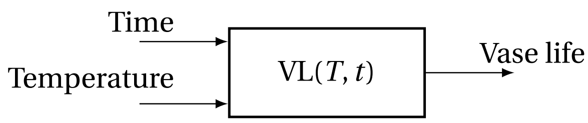


Figure 2.14: Viewing the rose as a system with input and output parameters defined

The rose is now viewed as a system with input parameters, mainly determined by logistics, and an output parameter, describing the quality of the flower. The black box represents a function which can predict the quality deterioration.

Literature on prediction models There is very few literature available on prediction models of the quality of roses. However, a prediction model can assist decision-making in the fresh produce business. One of the articles available is written by Tromp [16] which considered two different functions. The first function is a First Order Arrhenius function. This function is described more often in literature to calculate the shelf life of perishable products [31]. The First Order Arrhenius function is found suitable for predicting the quality of a rose. The second function is a linear function which predicts the quality of a rose. In this article temperature fluctuations along the storage are included in the graph. Other papers which describe the prediction of the vase life of roses assume a constant temperature along the storage and are therefore not used [32].

First Order Arrhenius The first function describing the quality of a rose is the First Order Arrhenius (FOA) function. The Arrhenius function is widely applied in modelling food quality and shelf life estimation [33],[34]. It appears that the first order function also fits the prediction of vase life of roses. The function is given below in Equation 2.1. The symbol A is the initial predicted vase life and the summation indicates the decrease in vase life. The reference temperature is set at 293.15 Kelvin.

$$\mathrm{VL} = A - \frac{1}{24} * \sum_{i=1}^{n-1} e^{B*\left(\frac{1}{T_{ref}} - \frac{1}{T_i}\right)} * (t_{i+1} - t_i) \tag{2.1}$$

Degree Days The second model is the degree days model. There are two other papers which base the vase life on a linear time temperature function [27], [35]. It has the same structure as the previous function where A is the initial predicted vase life and the summation indicates the decrease in vase life. For both of the formulas several symbols are used, these symbols with their meaning and unit are given in Table 2.1.

$$\mathrm{VL} = A - \frac{1}{24} * \sum_{i=1}^{n-1} \frac{1}{200} * (T_i - 273.15) * (t_{i+1} - t_i) \tag{2.2}$$

Table 2.1: Symbols of the functions and their explanation

Symbol	Parameter [unit]
VL	Actual expected vase life [days]
A	Initial expected vase life [days]
B	Experimentaly defined parameter [-]
i	Data point [#]
n	Total number of data points [#]
k	Increment step [-]
t_i	Time at point i [hours]
T_i	Temperature at point i [Kelvin]
T_{ref}	Storage temperature [Kelvin]

Different cultivars

As mentioned in the problem definition in Section 2.1 there are many different cultivars of roses. There are several references which are comparing the deterioration of roses with the prediction models and an overview of these are given in Table 2.2. In the first column the source is given and which paper is used as a reference. The second column states the cultivar tested and the third column states the simulation of transport. There are two ways of transporting roses, dry and wet. The last two columns are the prediction models, the values for the parameters, and the correlation with the actual vase life.

Table 2.2: Correlation for different cultivars of roses, rose used in this project is marked bold

Source	Cultivar	Storage	FOA Model			DD model	
			A	B	R^2	A	R^2
Celikel and Reid, 2005 [36]	First Red	Dry	9.1	5345	0.67	8.7	0.75
		Wet	9.5	5254	0.76	9.0	0.91
Pompodakis et al., 2005 [37]	First Red	Wet	13.0	2925	0.93	10.5	0.67
	Akito		14.1	2692	0.95	11.4	0.42
Goedendorp and Barendse, 2010 [38]	**Catch**	**Dry**	**12.8**	**8221**	**0.69**	**13.0**	**0.75**
	Red Horizon		13.2	4965	0.77	11.9	0.74
	Upper Gold		15.9	4213	0.57	14.2	0.65
	Valentino		11.7	5660	0.52	10.8	0.69

Choice of flower For the scoping of the project, one cultivar is taken and the 'Catch' rose is used throughout this research. On the Nairobi-Schiphol lane, the flowers are transported and stored 'Dry' so none of the correlations for wet stored flowers can be used. Furthermore, a flower which has a high correlation preferably with both of the prediction models is needed. Otherwise, the prediction model will not give an accurate result representing reality. The 'Catch' rose is chosen as the flower. The 'Red Horizon' cultivar also has high correlations for both models but the initial vase life differs more than one day.

3
DATA COLLECTION

In this chapter information about time and temperature is gathered. Data is collected to get more insight in the cool chain and the quality of perishables. The collected data is used in the next chapter to analyse the cool chain. In the first section, section 3.1, it is explained why the specified data is collected. In section 3.2 the way the data is collected is explained. The chapter finishes with the output of the data in section 3.3.

3.1. REASONS FOR COLLECTING DATA

In the previous chapter, the system is defined and several parameters are explained. To get a good overview of the system data is collected on the biological as well as the logistical side. These two sides and the data collected is explained below.

3.1.1. BIOLOGICAL POINT OF VIEW

As mentioned in section 2.2.2 vase life can be determined with time and temperature as input parameters. The importance of these two parameters is explained below.

TIME

For the performance of a supply chain time is a straightforward but crucial parameter within the chain. The time of the commodity from the beginning of the supply chain until the end is important to know. Within this supply chain there are different actors and they are all dependent on each other. The farm has to deliver to the forwarder, and the forwarder on his turn to the airport. The aim of the supply chain is to have a low throughput time at every part of the supply chain which results in an overall low throughput time. Late deliveries by one of the actors can result in a delayed delivery time at the subsequent actor or not even a delivery at all.

TEMPERATURE

The temperature of a rose is important from the moment it is harvested until the consignee has received the box with flowers. Flowers are sold in category Fresh 2, where the temperature should be maintained and controlled between 2 and 8°C. Various products are sold in this category which implies this category is not tailored for flower transport. The temperature of the box is important to know since a too high temperature can damage the flowers and reduce its quality. The boxes are transported on aircraft pallets and a distinction is made between the middle and the side of the pallet. An example of a BUP is seen in Figure 3.1.

- **Middle Pallet:** The temperature is measured in the middle of the pallet. At the forwarder stage or at Triple FFF the pallet is build up. The time boxes spent on the BUP has to be as short as possible since there is a chance on *'broei'*. This is a Dutch term describing the phenomenon that each stem generates or produces its own heat which increases the temperature of the box. Boxes stay cool because of convection but when the pallet is already build up the middle boxes do not have a chance to dissipate the generated heat. This can lead to an exponential increase of the temperature.
- **Side Pallet**: Another measurement is done at the side of the pallet. Boxes which are stacked at the side of the pallet show different behaviour in temperature and should, therefore, be analysed separately.

The side of the pallet is less sensitive for *'broei'* but can be more sensitive to other situations, such as exposure to sunlight or being in a warm environment. For example, when the BUPs are waiting on the TARMAC to be loaded in the aircraft they can be exposed to sunlight. The exposure to radiation can lead to an increased temperature of the boxes located at the side of the pallet.

Figure 3.1: Build up pallets waiting to be loaded on the aircraft

3.1.2. LOGISTICAL POINT OF VIEW

The air cargo supply chain is explained in section 2.2.1 and roses are transported from the farm to the consignee. The time and the temperature are measured by Time Temperature Integrator (TTI)s. These integrators are widely used within cold chain logistics and are a guideline for the time and temperature performance of the cool chain. The performance is discussed further in the analysis phase in the following chapter. The different parts of the supply chain are explained below.

- **Origin:** Roses are grown mainly in four different areas around Nairobi. These regions are Naivasha area, Mount Kenya, Nairobi area and Nakuru. Approximately a total of 80 farms export flowers from Kenya via the airport of Nairobi. Most of these farms emerged in the last decade with the increasing export of flowers. For a proper system analysis different farms should be analysed, this will equal out the differences between the more and less experienced and equipped farms.

- **Two pathways:** As discussed in section 2.2.1 there are two pathways a rose can follow. Time and temperature data on these two pathways should be collected and discussed separately. This gives insight in the different supply chains and results of these pathways can be compared.

- **Destination:** Similar to the origin there are various importers of flowers. In fact, there are even more importers than farms which grow the roses. Similar to the origin, different destinations should be considered. The destinations in this research are all located in the Netherlands.

3.2. DATA COLLECTION

The collection of the data is one of the most crucial parts within this research. KLM Cargo is not in the availability of data regarding time and temperature so external parties provided information needed. This data is therefore used as reference data since it can not be obtained by KLM Cargo itself. There are some possibilities to do measurements within the chain and these are discussed in Chapter 5.

3.2.1. REFERENCE DATA

The reference data is provided by FlowerWatch. FlowerWatch is a consultancy company specialised in improving the cool chain of perishable goods. They provide companies with advice and data about time and temperature along the supply chain.

TIME TEMPERATURE LOGGERS

The time temperature integrators are used for the measurement of the cool chain. Time temperature integrators are widely applied in perishable transport to measure the parameters along the supply chain [39]. The data loggers are entered at different farms in the boxes where flowers are transported in. A standard transport box is seen in Figure 3.2. At a certain point the boxes are build up on the aircraft pallet right before they are loaded in the aircraft, this can be seen in 3.1. There are different shipments tracked and each shipment contains three TTIs. There is one integrator which measures the air temperature, one which measures the temperature in the middle of the pallet and one which measures the side temperature of the pallet.

Specification of the loggers For the measurement a regular temperature logger is used. This data logger has an accuracy of 0.1°C. Measurements are done by the data loggers and values of time and temperature are stored in the memory. In this way, the data can be read out afterwards. The data loggers are also waterproof since the flowers can loose water during transport.

Instructions on usage The person handling the boxes should be able to allocate the box on the right position, in the middle of the pallet or at the side of the pallet. This is ensured by labelling the boxes with different colours. The box that should be located in the middle of the pallet has a pink sticker and the box that should be at the side of the pallet has a yellow sticker. The stickers on the boxes indicate where the boxes should be located during transport. During the build up boxes with pink stickers are located in the middle of the aircraft pallet, boxes with a yellow sticker are located at the side of the pallet.

Figure 3.2: Boxes where data loggers are put in

3.2.2. FLIGHTS MEASURED

For the analysis phase series of measurements needs to be collected. In this section the data collection is explained discussing the number of flights, the different origins and the different destinations. The data is collected over a time span of 5 years, from 2011 until 2015. In total, there are 40 flights measured containing in total 120 different sensors. Not every shipment is relevant for the research. Some of the flights had a stop between Schiphol and Nairobi at Jeddah Airport. The flights are provided by Saudia Cargo and are, therefore, not within the scope of the research. These flights are excluded from the analysis and 30 shipments remain.

ORIGIN

The origin of the supply chain is at different farms. In total, there are 80 different farms and for this research 11 different origin farms are used. This is done since some of the farms have advanced facilities while other farms have fewer resources. Next to the equipment the location of the farms differs resulting in a varying transport time from farm to airport. By using multiple farms differences in equipment and location are equalled out. The farms used are presented in Table 3.1. In the table there is one farm named 'Farm Kenya', for these shipments the origin farm is not defined. The shipments from Mount Meru Tanzania are two exceptions on the lane. These farms are located in Tanzania instead of Kenya but the distance from farm to airport is similar to the other farms.

Table 3.1: Exporting farms with the number of measurements

[redacted]

PATHWAYS

The two different pathways are analysed in section 2.2.1. For the first pathway, three shipments are tracked, these shipments have 'Farm Kenya' as the origin. Flowers transported on this pathway are going via a separate forwarder called Airflo/Panalpina. Flowers from the farms arrive at Airflo/Panalpina and after this step, they go to the warehouse of the airline. The other 27 shipments follow the second pathway and in this supply chain the flowers go from the farm directly to the warehouse of the airline which is Triple FFF. For this pathway there are multiple origins and multiple destinations.

Table 3.2: Two different pathways with the number of measurements

Specification of pathway	**Measurements [#]**
Pathway with separate forwarder	3
Pathway without separate forwarder	27

DESTINATION

The destination of the supply chain is the consignee. Similar to the origin there should be various consignees. There are 12 different consignees considered for this research and these are listed in Table 3.3. By analysing multiple consignees differences in facilities, location and storage time are equalled out.

Table 3.3: Importers with the number of measurements

[redacted]

3.3. Data output

For the collection of data, data loggers are entered at the farms mentioned. When the boxes arrive at the consignee the data loggers are removed. The information about time and temperature are retrieved by reading out the data loggers. An example of a time temperature graph obtained from the loggers is given in Figure 3.3. The data is processed by FlowerWatch and information can be retrieved from these graphs. The numbers indicated in the figure are explained below.

[redacted]

1. **Origin:** This indicates the farm where the flowers are harvested in Kenya. Flowers are grown and harvested on different locations. The farm is responsible for putting the data logger in the box and also putting a yellow or pink sticker on the box.

2. **Destination:** This indicates the consignee which receives the boxes with flowers. The data loggers are removed at this point in the supply chain and the consignee is responsible for reading out the data from the loggers and share the information with different companies.

3. **General information:** In this part general information is given. The client, report number, person who set up the report, date of execution and time zone is listed.

4. **Date shipment:** The date of the shipment is noted here. It says when the boxes with flowers are packed and when it arrives at the importer. The length of the supply chain varies and ranges from two up to five days.

5. **Flight number:** There are several possibilities for the air transport of perishables. Most of the times flowers are transported with a Martinair aircraft. In this case, this is noted with 'MP' and a full freighter is used. Sometimes the boxes are shipped in a passenger flight with a KLM plane; this is indicated by 'KL'. As mentioned before, there is also data collected on Saudi Arabian Airlines (SV) flights. These are not taken into account in this research.

6. **Airwaybill Number:** The Airwaybill (AWB) number is noted which indicates the shipment number. This Airwaybill number is used for different parties to trace the shipment.

7. **Different handlings:** On these graphs, pieces of information regarding the handling is written down. This information is used to see when the shipment is at a different part of the chain. At some of the shipments, the way of cooling is also explained but in general the level of detail is limited.

8. **Temperature variation:** There are three sensors which measure the temperature of the shipment. The blue, pink and yellow line indicates the air temperature, the middle of the pallet the side of the pallet respectively.

4

System Analysis

In this chapter the system is analysed from a time and temperature perspective. Measured data from the previous chapter is used for the analysis. In the first section, section 4.1, one specific flight is analysed. Section 4.2 analyses data of all the shipments. The performance of the cool chain regarding time and temperature is explained in section 4.3. The chapter ends with conclusions in section 4.4.

4.1. Example flight

As indicated in Chapter 3 shipments are tracked and data concerning time and temperature is collected. This section takes out one specific flight and analyses it. The flight analysed is from the farm Bilashaka located in Kenya with the destination Zuurbier International located in the Netherlands. The shipment started at 24th of April in 2013 and ended at 27th of April 2013.

4.1.1. Time temperature graph

The time temperature graph of the shipment is shown in Figure 4.1. The graph shows the same information as Figure 3.3 in the previous chapter except the fact that it is converted to usable data. From this graph data can be retrieved. The supply chain length and temperature over time is shown in this graph. The additional comments provided by FlowerWatch gives information about the location of the shipment at that moment. It must be noted that these comments are limited to the location of the box and no further information is provided about the exact handling actions during shipment. However, for analysing the system on a supply chain level the given information is sufficient. Time and temperature taken from this figure act as a basis for the prediction models explained in the following sections.

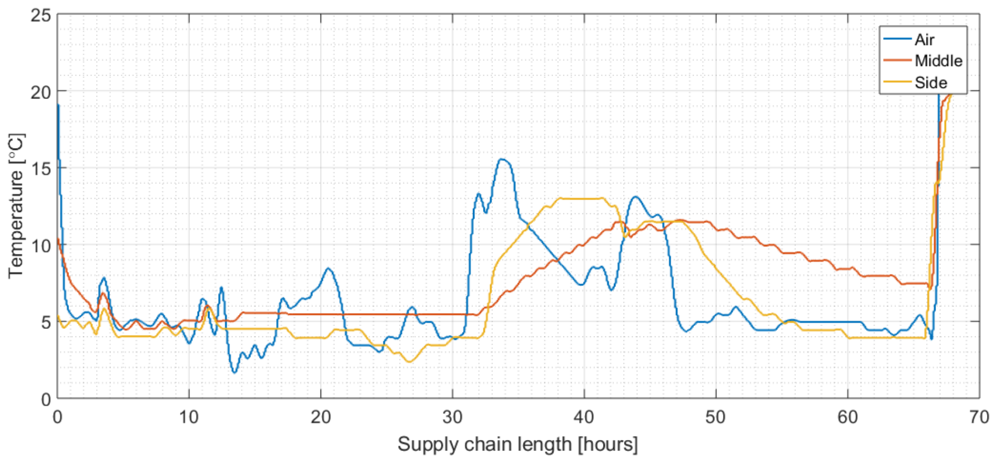


Figure 4.1: Time temperature graph of a shipment from Bilashaka Kenya in April 2013

4.1.2. IMPACT ON VASE LIFE

For further analysis on the quality of the rose the prediction models explained in section 2.2.2 are used. The Degree Days and First Order Arrhenius models are used to see the impact of the time and temperature on the quality of a rose. Next to that, results of these two models can be compared. The temperature over time and its impact on the quality of a flower can be seen. This impact can support in decisions for redesigning the cool chain. For both the equations, the increment step is set to 1/10 hour being equal to 6 minutes. The temperature is assumed to be constant during this time step. Other parameters and their values are taken from Table 2.2.

DEGREE DAYS MODEL

The Degree Days model uses a linear equation to express vase life as a result of time and temperature. At every time step, the vase life reduction is calculated and is subtracted from the initial expected vase life. This leads to Figure 4.2 where time in hours is presented on the x-axis. This is the time that a shipment takes and at 0 hours the shipment starts. On the y-axis is the expected vase life of the flower in days. The initial vase life, denoted by A, is set to 13.0 days. For the two loggers located in the middle and at the side of the pallet the expected vase life is calculated. In this graph, the sensor of the air temperature is not given since it is not useful to calculate the remaining vase life of an empty box. The graph shows various decrease rates because of the different temperatures at every time step. A higher temperature in the cool chain leads to a higher vase life reduction. This phenomenon is seen between 35 and 45 hours for the side logger. On this time span, the expected vase life decreases faster than in the previous hours. The output of our system is the expected vase life at the end of the shipment. In this graph this is the expected vase life after 69 hours which is 12.06 days for roses transported at the side of the pallet and 11.97 for roses in the middle of the pallet.

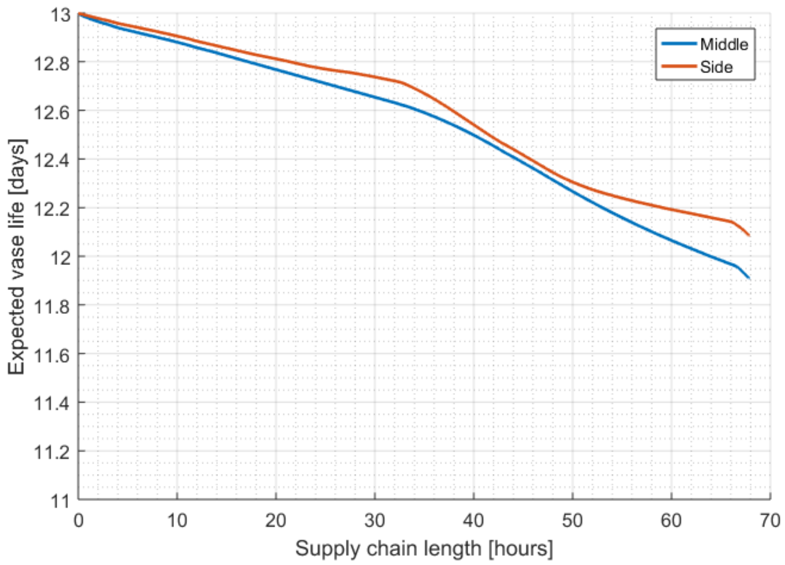


Figure 4.2: Deterioration of roses for Degree Days prediction model

FIRST ORDER ARRHENIUS MODEL

The next model used is the First Order Arrhenius function which slightly differs from the Degree Days function. For this function, there are several symbols used which are explained in Table 2.1. Where the initial expected vase life, denoted by A, is 13 days for the Degree Days (DD) model , the initial expected vase life is 12.8 days for the FOA model. The dimensionless parameter B is set to 8221 which is retrieved from literature. Similar to the Degree Days model the vase life reduction is calculated per time step. The expected vase life as a function of time is given in Figure 4.3. The trend of the graph is similar to Figure 4.2, for the logger in the middle of the pallet as well as for the side of the pallet. The expected vase life at the end of the shipment is 12.01 days for boxes at the side of the pallet and 11.95 for boxes in the middle of the pallet. This result is in line with the Degree Days model.

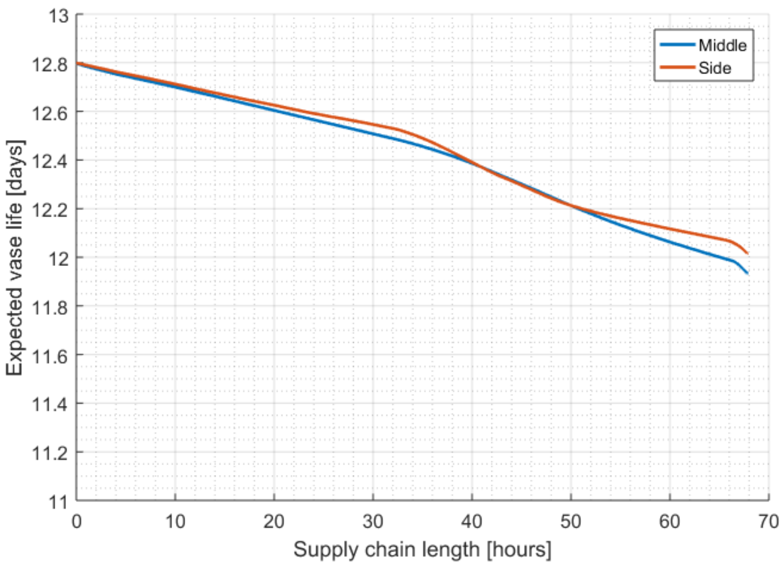


Figure 4.3: Deterioration of roses for First Order Arrhenius prediction model

4.2. All shipments

The analysis showed in section 4.1 is for one shipment. By doing the same analysis for 30 shipments more information can be obtained regarding the time and temperature in the supply chain. The result of this analysis is showed in the upcoming sections. The time, temperature and the impact on the quality are discussed for the Degree Days model as well as for the First Order Arrhenius model.

4.2.1. Degreehours versus vase life

The degreehours is used as a property of performance since this combines two parameters which are influencing the quality of perishables. The degreehours is calculated by multiplying the time with the temperature. For all the shipments the average degreehours, FOA predicted vase life and DD predicted vase life is given in Table 4.1. The number of sensors in the middle and at the side of the pallet is 26, which is lower than the 27 shipments indicated before. For this shipment the sensors gave inaccurate data or the sensor got lost during transport, this data is ignored.

There is a slight difference in degreehours between the middle and side of the pallet. This can be explained by the fact that the middle of the pallet has an increased heat build up. The side of the pallet can have more benefit from cooling by convection than the middle of the pallet. The expected vase life by FOA model after transport is [redacted]. This means that there is a reduction of almost one day of vase life. The expected vase life by DD after transport is [redacted] which is a reduction of more t[redacted]. The results between the two prediction models are similar.

Table 4.1: Expected vase life of middle and side box after transport for both prediction models

[redacted]

Degree Days model

The first prediction model analysed is the Degree Days model. This Degree Days model is based on a linear function where a multiplication of time and temperature results in the degreehours. For the degreehours calculation it takes the surface of the time temperature graph in Figure 4.1. The result of the predicted vase life versus the degreehours obtained is shown in Figure 4.4. As expected the figure gives a perfect linear correlation between degreehours and expected vase life. The obtained degreehours ranges from b[redacted]

[redacted]. The expected vase life ranges from [redacted]. The middle and side data loggers are shown respectively as blue and red dots and these points are equally distributed along the x-axis.

[redacted]

Figure 4.4: Time temperature sum versus expected vase life for Degree Days model

FIRST ORDER ARRHENIUS MODEL

The second prediction model used is the First Order Arrhenius model. The degreehours versus predicted vase life is seen in Figure 4.5. The degreehours points are the same as in the previous graph since the data is taken from the same measurements. The resulting expected vase life is slightly different and range from [redacted]. However, the scatter plot is a bit more divided than the linear Degree Days model. In this case, an exponential function is expected since the First Order Arrhenius calculates the vase life with an exponential function. This is not the case in Figure 4.5 where there seems to be a strong linear correlation between degreehours and expected vase life.

[redacted]

Figure 4.5: Time temperature sum versus expected vase life for First Order Arrhenius model

4.3. Performance

One of the guidelines for the performance of the cool chain is degreehours. Having a cool chain with a degree-hours of 500 is seen as the industry standard. [redacted]%. The distribution of degreehours of all shipments is given in a bar chart in Figure 4.6. From this graph, it can be seen that there is no normal distribution for the shipments tracked. Reason for that could be that the number of measurements is not sufficient. To have a normal distribution for degreehours, possibly more measurements are needed.

[redacted]

Figure 4.6: Distribution of degreehours for all shipments

The performance of the cool chain is given in Figure 4.7. The number of shipments and their degreehours is accumulated and given in the bar chart. On the y-axis, the performance of all the shipments can be seen. This performance is expressed in a percentage and should be interpreted as the percentage of shipments which is below the threshold.

[redacted]

Figure 4.7: Performance of shipments for different thresholds

4.3.1. SUPPLY CHAIN LENGTH

Roses harvested in Kenya are transported for thousand of kilometres before they arrive at the customer and along this way, several modes of shipments are used. The boxes are transported by air, by truck and are also handled in several warehouses. The length of the example shipment is 69 hours which means that the flowers are at the importer three days after harvesting. There are different origins and different destinations in the supply chain. Therefore, one would expect a varying duration of the supply chain. The duration of all shipments is presented in a bar chart in Figure 4.8. The bar chart shows a random distribution of the supply chain duration. The 40-50 hours block is the range with the most shipments. The random distribution of the length of the supply chain could be caused by the different origins and destination. The average supply chain duration is 54.4 hours, the minimum is 29.9 hours and the maximum is 128 hours. There are two measurements which are at the far right, between 120 and 130 hours. These two measurements are from the same importer and this importer is keeping the boxes longer in the warehouse than others do.

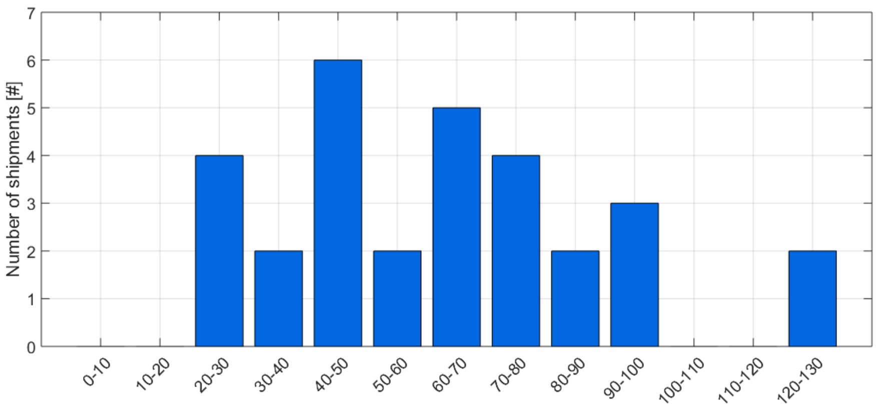


Figure 4.8: Duration of supply chain for all shipments

4.3.2. INCREASE IN TEMPERATURE

The analysis so far was on a supply chain level where the degreehours property is analysed. The temperature deviations where a shipment is exposed to is important. In Table 4.2 the average maximum and minimum temperature is given for both data loggers. [redacted] This temperature is very high and if this temperature is maintained for a longer time it affects the quality of the flowers. The average temperature is for both of the boxes above 8°C, which is above the specifications of category Fresh 2. Flowers transported in this category should be transported in the temperature range of 2 and 8°C.

Table 4.2: Temperature maxima and minima for different boxes

[redacted]

During the supply chain, temperature deviations can happen and boxes can reach a peak temperature. These temperature spikes are indicated in Table 4.3. Each of the shipment is checked whether the temperature was above 8°C at each part of the supply chain. The total amount of boxes with a temperature measured above 8°C is given for each part of the supply chain. From this table, it follows that at the airline and at the consignee the most temperature peaks occur. However, there is no information on the length of the peaks so no conclusions can be drawn about the quality that is lost.

Table 4.3: Number of shipments with temperature above 8°C at each part of the supply chain

[redacted]

4.4. Introduction to discrete measurements

So far it is assumed that for each shipment information regarding time and temperature from data loggers is available. This continuous data is collected by a data logger which is entered at the beginning of the shipment. During the supply chain, the temperature is measured at a small time interval of 6 minutes. The question arises what happens to the accuracy of the measurement if the time interval where the temperature is measured is changed. In this scenario the data logger would measure the temperature on a larger time interval. If the time interval increases the error concerning degreehours can increase. This error also has an influence on the prediction of the quality of a flower. On top of that, the data used is provided by an external company. For every shipment tracked the customer, in this case another company, has to pay to get information from three data loggers. The next chapter focuses on increasing the time interval and puts a connection between increasing the time interval and actual measurements during the chain.

5

Discrete Measurements

This chapter is an extension of Chapter 4 where the focus is on the increment steps of the measurements. In section 5.1 the measurement plan is explained. This is followed by the error from continuous data in section 5.2. Section 5.3 puts a link between discrete measurements and the current infrastructure available in the supply chain for KLM Cargo. The last section, section 5.4, analyses the performance from a time and temperature perspective.

5.1. Measurement plan

In Chapter 3 it is explained how data is supplied by FlowerWatch. From this data graphs with temperature measured at a six minute time interval is created. This increment step assumes an ideal case where the temperature of the box can be measured throughout the supply chain. From this follows the question below.

What happens to the accuracy of the measurements when the increment step is increased? Is it still possible to predict the quality of a flower accurately?

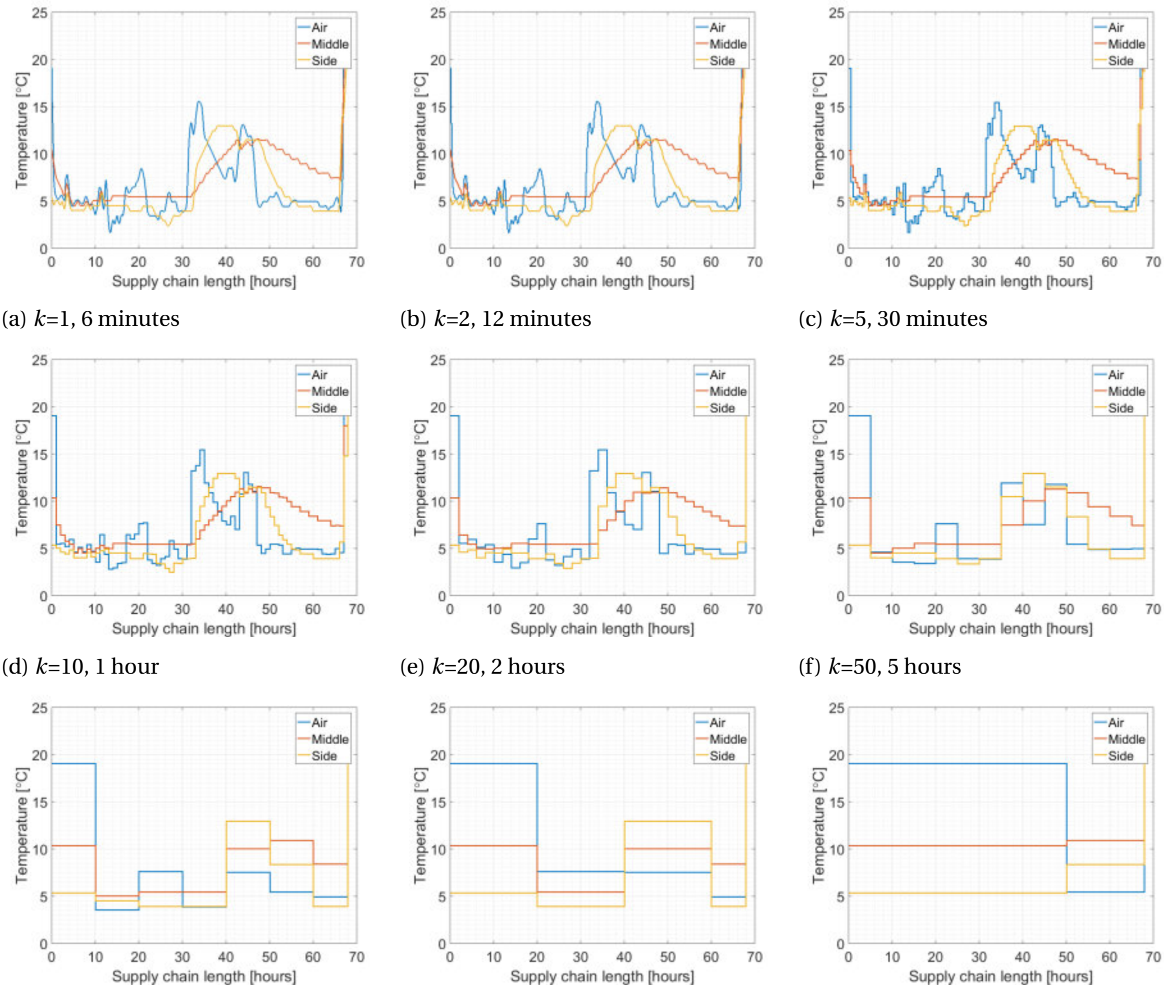
To answer this question a measurement plan is needed. Calculations should be done with various increment steps to see the difference between discrete and continuous data. Data which is processed in the previous chapter is used as reference data and is referred to as continuous data. First, the different increment steps are discussed. After that, the impact of changing the increment step of measurements on the cool chain is discussed.

5.1.1. Increment steps

To see the difference between continuous and discrete data various increment steps are considered. An overview of the increment steps are given in Table 5.1. The increment step k is shown in the first column and the actual time step of the measurement is given in the second column. The smallest increment step is 1, which is equal to the continuous. The largest increment step taken is 1000 which equals 100 hours.

Table 5.1: Different increment steps and the actual time step of the measurement

Increment step k	**Time step [hours]**
1 (continuous)	1/10
2	1/5
5	1/2
10	1
20	2
50	5
100	10
500	50
1000	100



(a) k=1, 6 minutes (b) k=2, 12 minutes (c) k=5, 30 minutes

(d) k=10, 1 hour (e) k=20, 2 hours (f) k=50, 5 hours

(g) k=100, 10 hours (h) k=200, 20 hours (i) k=500, 50 hours

Figure 5.1: Time temperature graphs of one shipment for different increment steps

5.1.2. RESULTS ON MEASUREMENTS

To gain more understanding on how these increments affect the time temperature graphs images are shown where the increment step is increased. Different plots are generated for the time steps mentioned in Table 5.1 and these plots are shown in Figure 5.1. In Figure 5.1a the continuous data is shown for the same shipment used in the previous chapters. In other figures, the increments are step by step increased. This can be interpreted as a data logger reading out temperature every increment step k. The graphs follow the original time temperature graph accurately until k=20 and after that, inaccuracies seem to occur. With this increment step there are temperature increases which can not be measured by the data loggers.

5.2. ERROR FROM CONTINUOUS DATA

From Figure 5.1 it seems that as the increment step increases the error concerning the temperature increases as well. Logging the temperature on a large time interval results in an overshoot or an undershoot in temperature. To quantify this, the error of the different increment sizes with respect to the continuous data is calculated. For the quantification, the Mean Average Percentage Error (MAPE) is calculated. This error is calculated as a percentage of the original value and the mean is calculated afterwards. In Table 5.2 the results are given of this error percentage for different increment steps. In the first column, the different increment steps are given as time intervals. The two following columns give the degreehours average and MAPE respectively. After that two columns represents the average and MAPE of the FOA model respectively. The last two columns represent the same but then for the DD model.

Table 5.2: Different increment steps and their error of degreehours and vase life

[redacted]

The results of the error percentage are given graphically in Figure 5.2. The x-axis represents one divided by the increment step on a logarithmic scale. The y-axis gives the MAPE of degreehours. It is seen that for until a time interval of 5 hours, k=50, the error is not very high. [redacted]

[redacted]

Figure 5.2: Increment step versus percentage error of time temperature sum

5.2.1. DEGREEHOURS VERSUS VASE LIFE

For the discrete measurements the same approach as in section 4.2.1 is used. When the increment step increases the degreehours change. As a result of this, the predicted vase life also changes for both the FOA and DD model. In this case, the degree days versus predicted vase life is shown for the case with the largest increment step where k=1000, equal to a time interval of 100 hours. The differences between these graphs and the graphs from continuous data are explained below.

DEGREE DAYS MODEL

The degreehours versus the predicted vase life according to the Degree Days model is seen in Figure 5.3. Similar to the scatter plot for the continuous measurements there is a perfect linear correlation between degreehours and expected vase life. Contrarily to the continuous measurements, the range of the x and y-axis are larger. [redacted] The locations of the data points differ from the continuous data; this is also seen in the error percentages in Table 5.2.

[redacted]

Figure 5.3: Time temperature sum versus expected vase life for Degree Days model and k=1000

FIRST ORDER ARRHENIUS MODEL

For the First Order Arrhenius model the scatter plot is shown in Figure 5.4. In line with the model above the range for the FOA model is also extended. [redacted]. The scatter plot in Figure 5.3 has a perfect linear correlation between the two variables but for this graph the correlation is very weak.

[redacted]

Figure 5.4: Time temperature sum versus expected vase life for First Order Arrhenius model and k=1000

5.3. Current measurement infrastructure

In the previous section, the error for different increment steps is calculated. With this knowledge, a transition can be made. When the increment step of the data logger is higher this is interpreted as measuring temperature at a larger time interval. When this time interval is not fixed, this can also be understood as doing measurements along the supply chain. Collecting the data in such a way is referred to as discrete measurements.

In the current state it is not known which measurement points are available and which data regarding time and temperature is collected. Field research is performed and the facilities in Nairobi and Kenya are visited on the 10th and 11th of October. This visit gave insight on how each of the actors operates within the supply chain. More information about their guidelines and pictures of the handling of the flowers can be found in Appendix B. From this visit, it became clear that each of the actors within the chain is doing measurements but the information about time and temperature is not shared with other parties. An overview of the measurement points for the second pathway is given in Figure 5.5.

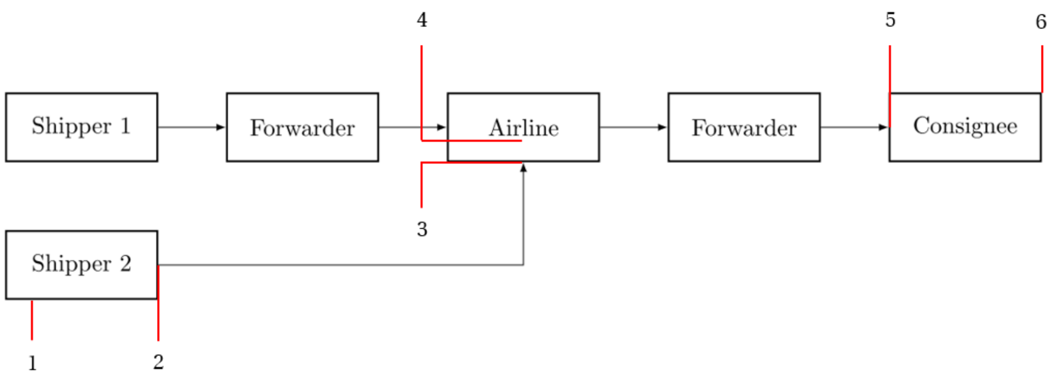


Figure 5.5: Location of current measurement points in the supply chain

1. **Measurement 1:** The first measurement point is when the data loggers are entered in the box at the farm. When the flowers are harvested, they are graded and the stems are cut to the selected length. After this step, the flowers are ready to be packed into a box. Most of the times this happens in a cooled environment. This is the moment of the first measurement.

2. **Measurement 2:** The second measurement point is when the boxes leave the farm. At this moment boxes are cool and should be stored in a cool room ready to be dispatched. The boxes are picked up by truck to be transported to the forwarder. This truck is most of the times arranged by the forwarder. When the boxes are loaded into the truck the temperature is measured.

3. **Measurement 3:** Farms are in a range of 2 up to 4 hours driving from Nairobi. When they have covered this distance they arrive at the airport in Nairobi, JKIA. As soon as a truck arrives the boxes are checked on temperature. This is done during acceptance of the goods. At this stage temperature measurements are performed at 10% of the boxes.

4. **Measurement 4:** The fourth measurement point is when boxes leave the airlines' warehouse, Triple FFF. At the previous measurement point boxes arrive from different farms at Triple FFF warehouse. These boxes are checked at measurement point 3 and are handled in the warehouse. The schedule of the flight is tracked and as soon as it is scheduled on time the build up pallets are prepared. This is the moment the fourth temperature measurement is performed.

5. **Measurement 5:** The fifth measurement is after the aircraft is unloaded at Schiphol Airport and when the boxes arrive at the importer. The importer is located in the Netherlands and in this part of the chain the boxes are also transported by truck. Again the temperature of the boxes is checked while the boxes are unloaded from the truck.

6. **Measurement 6:** The sixth and last measurement is when the boxes are stored at the warehouse for a certain amount of time. In that case, the data logger is removed after storage. The last temperature measurement is performed at this point.

An example of the temperature measurement is given in Figure 5.6. A temperature sensor is inserted in the box and the temperature can be read out with an accuracy of 0.1°C. After a while, the temperature stabilises and it can be read out. To make sure that the measurement is a good representation of the box measurements are done multiple times to see if there are any deviations regarding temperature.

Figure 5.6: Temperature sensor showing measured temperature of a box

5.3.1. CONSTANT FUNCTION

The measurement points are defined in the section above. Having the temperature on these data points several functions for the temperature path can be plotted in between. The first function discussed is the constant function. The constant function works the same as the function for continuous data. Temperature is measured at a certain point and is assumed to be constant until the next measurement. The difference between measurements by a data logger with a large time interval and these measurements is the time interval which is not constant. The measurement points can be seen in Figure 5.5. Taking the temperature constant between these intervals results in Figure 5.7. The starting temperature at these points is measured and this temperature is taken constantly until the next measurement is done. In the graph it is seen that the temperature starts around 5 degrees. The second measurement point is at 16 hours. At the second last measurement, the temperature increases a lot which is the measurement point at the importer.

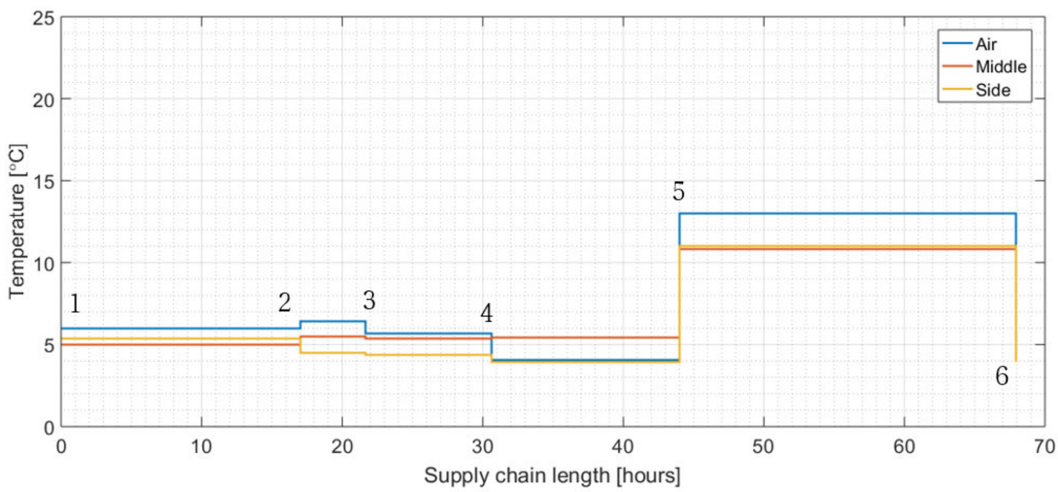


Figure 5.7: Time temperature graph showing constant function between measurement points

Compared to the original graph, there seems to be some overshoot in the temperature but this can also be compensated by the undershoot. In Table 5.3 the error of this constant function with respect to the continuous data is given. [redacted] This seems like a good prediction model but this is the average of all shipments tracked. The MAPE gives the average absolute error in percentage and this is 16.18%. The effect on the predicted vase life is around 1% where the First Order Arrhenius seems to be more accurate than the Degree Days model.

Table 5.3: Error of degreehours and vase life prediction for constant function

[redacted]

5.3.2. Linear interpolation

The second model analysed is the linear interpolation model. For this model, the same measurement points as for the constant function are used, and also the same data regarding temperature. Instead of assuming a constant temperature linear interpolation is done between two data points to retrieve the temperature curve. This function is showed in Figure 5.8. For the First Order Arrhenius the linearised function is divided into a time interval of 6 minutes. By doing that this model can be used to determine the quality of the roses. Again for the linear interpolation the error is also calculated, this is shown in Table 5.4. The degreehours sum of the linear interpolation is close to the average of the reference temperature. The MAPE is lower than for the constant function, in this case 7.27%. Therefore the linear interpolation gives a more accurate approximation to the continuous data. This is also seen in the error percentages of the two prediction models, both are below 1%.

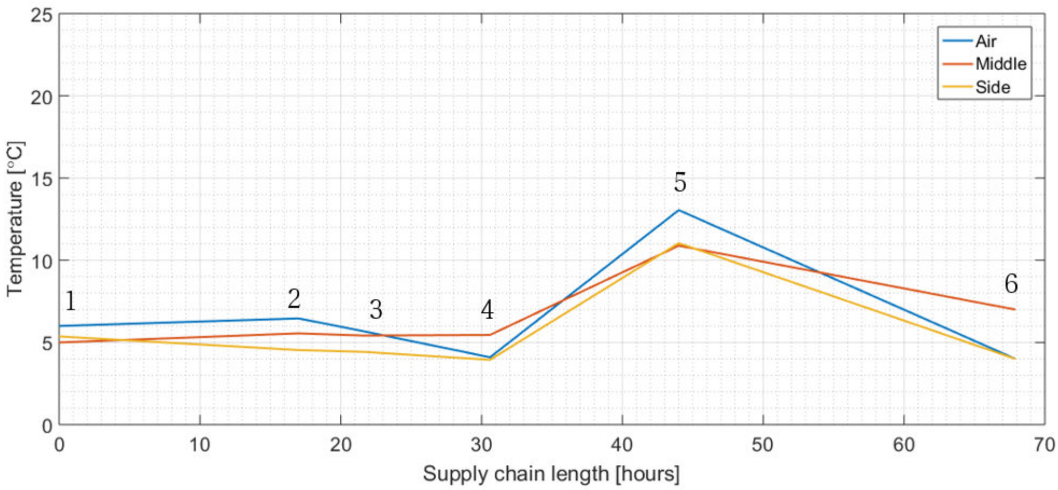


Figure 5.8: Time temperature graph showing linear interpolation between measurement points

Table 5.4: Error of degreehours and vase life prediction for linear interpolation

[redacted]

5.3.3. MEASUREMENT LEFT OUT

When discrete measurements are taken there is a chance that the temperature at one of the measurement points will not be done. The temperature sensor can be broken, the person who is handling the boxes can forget to measure the temperature or forget to write it down on the Airway bill. In that case, the accuracy of our degreehours is expected to decrease. For the calculations, it is assumed that the begin and end measurement are registered and in between one random measurement is taken out. This is done for all 26 shipments and the results are given in Table 5.5.

Table 5.5: Error of degreehours and vase life prediction if one measurement is left out

[redacted]

From this Table, it can be derived that for both of the functions the error percentage increase. [redacted] for the linear interpolation and the constant function respectively. The Mean Absolute Percentage Error on [redacted] This is slightly higher than the original measurements. The linear interpolation is a more accurate way of approximating degreehours for the cool chain. Even if one measurement is left out, it approximates the degreehours closely.

5.4. PERFORMANCE

Different measurement points are indicated and a comparison between continuous and discrete measurements is done. From this comparison, it follows that linear interpolation is the most accurate way to calculate the degreehours of a shipment. The measurement points help to indicate the different parts of the supply chain and more information of the cool chain can be retrieved. Each of the measurement points is analysed and the different parts of the supply chain can also be analysed. These aspects will be analysed on time, temperature and on degreehours.

Building blocks The average time between each measurement point is given in Figure 5.10. In the continuous data section, the average length of the supply chain was given. This supply chain length is, in fact, build up in different blocks. The first blue block is the from measurement point 1 to measurement point 2. This block is indicated with the Roman number I and indicates the time spent at the farm. This is done for all the blocks and these are specified below.

I Farm: The first block is where the flowers are at the farm. After harvesting the flowers are cooled, graded and stored in the cool room. At a set time the boxes are picked up by truck. At this moment the Farm phase ends.

II Truck: The truck picks up the flowers and delivers them to Triple FFF, the warehouse of the airline. The warehouse of the airline is located at the airport of Nairobi and when the flowers are delivered the trucking phase is finished.

III Triple FFF: The third block is where the boxes are at Triple FFF, the warehouse of the airline. At the warehouse the boxes are scanned, accepted and stored in a cool room. The boxes exit the warehouse to be loaded into the aircraft. At this moment the Triple FFF phase ends.

IV Airline: After the dispatch from this warehouse the boxes are loaded into the aircraft and transported by air from Kenya to the Netherlands. At the warehouse in Schiphol Airport, boxes are transported by truck to the consignee. The airline phase ends when the boxes arrive at the consignee.

V Consignee: The last part of the chain is when boxes are trucked to the consignee. This consignee is located in the Netherlands and receives the boxes. After checking the boxes are stored in a cooled warehouse for a certain time. Roses leave the warehouse when they go the retailer or wholesaler.

Temperature At each measurement point the temperature of the boxes is measured. The average temperature at each of these points is seen in Figure 5.9. This average is a combination of boxes located at the side of the pallet and boxes located in the middle of the pallet. The first measurement point is when the roses are harvested. [redacted].

[redacted]

Figure 5.9: Average temperature at each measurement point

Time Next to the temperature, time is a key parameter influencing the quality of the flowers. The average time spent at each of the blocks as defined above is given in Figure 5.9. There is a short time when the boxes are at the farm and trucked to Triple FFF warehouse. [redacted] Within this time the boxes are accepted checked and cooled. The airline part and the consignee part are the greatest part of the supply chain which are taking [redacted]. This means that boxes are at the airline or the consignee more than half of the time of the total supply chain.

[redacted]

Figure 5.10: Average time at different parts of the chain

Degreehours Considering that time and temperature are both important for preserving the freshness of flowers a graph can be made with the average temperature and average time at each measurement point. This is given in Figure 5.11. The surface of each of the areas indicate the obtained degreehours. As expected the latter two parts are the greatest contributor to the degreehours the time is long and the temperatures are high. From this graph, it is expected that most of the degreehours win can be decreased by making these surfaces smaller. This can be done by either lower the temperature or lower the time.

[redacted]

Figure 5.11: Time temperature graph for an average shipment

The degreehours for every part is given in Table 5.6. Roses obtain between 40 and 60 degreehours at the first three parts. At the Farm, Trucking and Triple FFF phase the temperature is low and the throughput time is short. The greater amount of degreehours is obtained at the last two parts of the supply chain. Both the airline and the consignee have a great share in the total amount of degreehours.

Table 5.6: Average degreehour per part of supply chain

[redacted]

The previous figure and table can be translated to a pie diagram where the share of each of the blocks is expressed in percentage of the total degreehours. This pie diagram is shown in Figure 5.12. Due to the increase in temperature and the long storage times the airline and both have a share of 34% of the total degreehours. Overview of degreehours in percentage. This translates Figure 5.11 to Figure 5.12.

[redacted]

Figure 5.12: Average degreehour share for each part of the supply chain

5.4.1. INTRODUCTION TO DESIGN ALTERNATIVES

In Chapter 4 and Chapter 5 the supply chain is analysed from begin until the end. At some points of the cool chain the temperature can not be maintained and at some points, the time spent is relatively long. Based on that design alternatives are possible throughout the supply chain. In the next chapter, the concepts are discussed more extensively. Additional to the analysis of the cool chain, two ways of measuring have been considered. A choice between them can be made in the next chapter.

6
Design Alternatives

In this chapter measurement methods and design alternatives are discussed. First, the measurement methods are evaluated and the performance for the cool chain is defined in section 6.1. The second section, section 6.2 evaluates different design alternatives. The chosen design alternative is described more extensively in section 6.3. The chapter is concluded with section 6.4 where future developmments are discussed.

6.1. Applying measurements and performance

In the previous chapters, the system and its measurement points have been analysed. Based on these findings a decision can be made concerning the way of measuring and setting a threshold for the degreehours. This is discussed in two different sections, section 6.1.1 and section 6.1.2.

6.1.1. Type of measurement

In this report, two ways of measuring time and temperature are discussed. Continuous measurements are discussed in chapter 4 and discrete measurements are discussed in Chapter 5. A short recap for both of the measurement methods is done below.

Continuous measurements

With continuous measurements it is understood that data loggers are used to measure the time and temperature. The data loggers are passive and information regarding time and temperature is stored in the logger and can be read afterwards. The data loggers are entered at the begin of the supply chain, at the farm, and are removed at the end of the supply chain, at the importer.

Advantages	Disadvantages
+ Accurate degreehours for a shipment	- No intervention based on data possible
+ Technology available	- Implementation of system

Discrete measurements

Discrete measurements can be done at any points within the supply chain. These measurements are done by a person who is handling the boxes. The temperature is measured with a probe and it is written down on the Airwaybill at which time this temperature is measured. The measurements are done at the indicated points within the chain and information regarding time and temperature can be obtained at these measurement points.

Advantages	Disadvantages
+ Interventions based on data possible	- Less accurate degreehours for a shipment
+ Make use of current infrastructure	- Sensitive for mistakes

6.1.2. SETTING THE THRESHOLD

The time and temperature can be measured throughout the supply chain. The parameters are used as an input for the prediction model. With the prediction model the quality of the flowers as a consequence of air transport can be calculated. The property degreehours of the cool chain is related to the quality and, therefore, should be as low as possible. At the moment the aim of each of the actors in the supply chain is to keep the temperature as low and the time as short as possible. This is important for preserving the quality of the flowers. However, the measurement data is not shared and therefore not known to other actors in the supply chain. To investigate the design alternatives the degreehours is used as a performance indicator of the supply chain and a limit should be set. By assigning the degreehours property, the current cool chain and the design alternatives can be evaluated. T[redacted]

[redacted]

Figure 6.1: Cool chain performance for different thresholds

6.1.3. DECISION MATRIX

Combining the performance and the measurements there are four situations possible. This is presented in Figure 6.2. On the horizontal axis is the performance limit, where the limit can be set at 800 degreehours or below 800 degreehours. On the vertical axis, there two measurement methods. The four situations are explained below.

	Below 800 degree hours	800 degree hours
Continuous	A	B
Discrete	C	D

Figure 6.2: Decision matrix for the performance setting and the measurement method

(A) **Continuous + Redesign** The way of measuring is continuous, and the performance is set to below 800 degreehours. This means that, first of all, a continuous measurement system should be set up. With the farm and the importer, an arrangement should be made that they put data loggers in the boxes and to also extract the data afterwards. T[redacted] the cool chain needs to be redesigned. This can be done based on this data provided and on the new measurements.

(B) **Continuous + No Redesign** [redacted]. In this situation, no redesign is needed but the measurement system should be set up. This can be done by KLM Cargo or in collaboration with one of the customers. When KLM Cargo is setting up such a system a farm should be contacted to enter the data loggers in the boxes. One of the importers should be contacted to take out the data loggers and to share the time temperature measurements. The second option is done to request from another actor in the supply chain to share data.

(C) **Discrete + Redesign** In this situation discrete measurements should be done and a redesign of the cool chain is needed. By measuring the temperature on the indicated points a less accurate degreehours is predicted. The advantage of measuring in the chain is that time and temperature history can be included while making decisions. Based on that, measures can be taken throughout the supply chain.

(D) **Discrete + No Redesign** The last option is to perform discrete measurements and have a degreehours limit of 800. In this situation, a redesign of the cool chain is not needed but the temperature measurements should be shared. By sharing the data the degreehours can be calculated by using the linear interpolation method. In this way the tperformance of the cool chain can be calculated.

Discrete + Redesign

Option C, *Discrete + Redesign*, is considered as the most feasible option and this option is chosen in agreement with KLM Cargo. By doing discrete measurements time and temperature at each part of the supply chain is known. The linear interpolation the degreehours of the cool chain can be calculated. The current measurement infrastructure is used and at each measurement point, time and temperature are written down. [redacted].

6.2. Redesigning the cool chain

The current performance of the cool chain is not sufficient for KLM Cargo. By redesigning the cool chain the competitive position in the market can be kept and eventually be strengthened. In this section, design alternatives are proposed and judged on different criteria. To judge the alternatives, they are split in alternatives which are inside the scope of KLM Cargo and alternatives which are outside the scope of KLM Cargo.

Constraints for design alternatives

Redesigning the cool chain can be done at many different steps and in many different ways. For this research, restrictions for design alternatives are set. These constraints are given and explained below.

- Within system: The concepts suggested should fall within the scope of the system as defined in Chapter 2. This means that design alternatives along the whole supply chain can be considered. However, a separation is made between design alternatives applied inside the scope of KLM Cargo and outside the scope of KLM Cargo.
- Time or temperature constrained: There are two components important for maintaining the quality of roses. A short time and a low temperature contribute to the freshness of flowers. The design alternative can be done based on one of those two aspects.
- Based on field research: For this project field research is done which gave insight into the supply chain. The observations act as a basis for design changes. Next to the field research several stakeholders are considered. From these stakeholders, the input is generated for redesigning the cool chain. A list of the stakeholders is given in Appendix B.

CRITERIA SELECTION

To judge the concepts several criteria are considered. For this research, most of the criteria used are quantitative and therefore the concepts can be compared to each other. The criteria involved in the selection procedure are stated below.

- DH Average: For the shipments, the average degreehours is calculated. This average is compared to the original degreehours.
- [redacted]: The first criteria is the degreehours average. Redesigning the cool chain should lead to a lower degreehours and a higher performance. The degreehours performance is expressed as the amount of shipments that obtained less than [redacted] by the total amount of shipments
- Costs: Costs are one of the key aspects in redesigning the cool chain and an investment can be needed to apply changes. The costs for a concept are expressed in dollar per tonne and can be build up by the following costs.
  - Operational costs: Operational costs are used for every time a box gets cooled.
  - Investment costs: Investment costs are needed when a cooling device is not available at the specific place. In this case, the investment costs are amortised over a certain period.
  - Maintenance costs: These costs are devoted for maintenance. When the cooling system breaks down it needs to be repaired and for that, maintenance costs are reserved.
- Capacity: Cooling a box can be done in several ways and these different devices have a different capacity. Some of the cooling actions can be done on one pallet and some of them affect more boxes. The capacity of the cooling device is expressed in boxes/hour.

6.2.1. OVERVIEW DESIGN ALTERNATIVES

In this section, an overview of design alternatives suggested is given. These alternatives can be time or temperature based. Statements are used to calculate the new degreehours of the shipments. In Table 6.1 the values for the example shipment from Bilashaka are given. The time and temperature at the indicated points of the supply chain are used as an input for the statements. For the calculation, every flight 70 tonnes of flowers are shipped at a frequency of 5 times a week.

Table 6.1: Time and temperature of Bilashaka shipment for middle box

Point [#]	Time [hours]	Temperature[°C]
1	$t(1)$=0.0	$T(1)$=5.07
2	$t(2)$=17.0	$T(2)$=5.55
3	$t(3)$=21.6	$T(3)$=5.41
4	$t(4)$=30.6	$T(4)$=5.45
5	$t(5)$=44.0	$T(5)$=10.88
6	$t(6)$=67.9	$T(6)$=7.20

1: COOL AT TRIPLE FFF

In this situation, a cooling step is added at the warehouse of the airline, Triple FFF. When boxes arrive at this warehouse, all the incoming boxes are checked for temperature. In case the boxes are above a certain temperature a cooling step is done. The cooling of these boxes is done by a pre-cool unit which uses forced air to cool down the boxes. An example of the pre-cool unit is given in Figure 6.3, further explanation is given in Appendix B.

- For this situation, the threshold is set at 4°C. In case boxes arrive above this temperature, they are recooled to 4°C. Boxes are kept at this temperature until leaving the warehouse since they are stored in a cool and isolated room. This results in the following equation.

  if $T(3) > 4$, then $T(3) = 4$ and $T(4) = 4$

- The second threshold applies when boxes arrive above 100 degreehours, this is above the average of time and temperature combination a the farm. In this case, extra cooling is applied and boxes are cooled down to 2°C. The boxes are kept at this temperature until leaving the warehouse. This results in the following equation

  $$DH(3) = \frac{T(2)+T(1)}{2} * (t(2)-t(1)) + \frac{T(3)+T(2)}{2} * (t(3)-t(2))$$
  $$\text{if } DH(3) > 100, \text{ then } T(3) = 2$$

- At the warehouse of Triple FFF six pre-cool units are available. At the pre-cool unit there are two lanes for 8 boxes each and this results in 16 boxes per cooling unit. As a maximum, 96 boxes can be cooled at the same time. For cooling down the boxes one hour is required. This results in a total capacity of 96 boxes/hour.

Figure 6.3: Pre-cooling a box at Triple FFF

2: Pre-cool aircraft

In this situation, the aircraft is pre-cooled so the warm air is removed from the aircraft. This results in a lower starting temperature of the hold at the beginning of the flight. At this moment the starting temperature of the aircraft hold ranges from 10 up to 20 degrees. Because of this, temperatures of the boxes increases fast and heat can not easily be dissipated from the aircraft. According to the regulations the hold temperature needs to be 5°C, see the first section of Appendix D. This temperature is most of the times only reached 5 hours after the flight started. By pre-cooling the aircraft the hold temperature is decreased to 5°C before pallets are loaded into the aircraft.

- For calculating the degreehours the following formulas are used. In this case, the middle and side box are separated. The middle box has an extra temperature factor because of heat generated by the boxes. The side does not have this factor since these boxes can dissipate their heat. This results in the following equations.

  $$T_{middle}(5) = \frac{T_{middle}(5)+5}{2} + 2$$
  $$T_{side}(5) = \frac{T_{side}(5)+5}{2}$$

- To cool the complete aircraft the air conditioning unit is turned on 1.5 hours before the flight departs. One air conditioning unit can cool down the complete hold of the aircraft.

3: Blankets at TARMAC

For this concept, blankets are used to cover the aircraft pallets when they are waiting to be loaded into the aircraft. These blankets are applied when the aircraft pallets are in the cool room of the warehouse. They are taken of just before they are loaded on the high loader. This prevents the boxes from heating up while they are waiting on the TARMAC.

- At the moment there are no blankets available at Triple FFF. To cover all the pallets 50 blankets are needed. The lifetime of one blanket is assumed to be five years and every year 10 blankets get lost or break. An example of such a cover is given in Figure 6.4, the cost for one cover is assumed to be $150. An extra factor is added since the loading of the aircraft will take half an hour longer. The costs for an aircraft on the ground is 1000$ per hour.
- In this situation the pallet is assumed to heat up less than in the initial situation. The pallet is on average 2°C lower at measurement point five. This is derived from the temperature increase at the 30 shipments analysed. This results in the following equations.

$$T_{middle}(5) = T_{middle}(5) - 2$$

$$T_{side}(5) = T_{side}(5) - 2$$

- One blanket can cover one aircraft pallet. On one aircraft pallet there are 250 boxes with flowers, this gives a capacity of 250 boxes per cover.

Figure 6.4: A build up pallet with an insulating cover

4: Shorter storage time at Triple FFF

For concept 4 a shorter time at the Triple FFF warehouse is assumed. In the current situation, boxes are received, scanned and stored in the cool room. It is possible that trucks deliver the boxes at a later moment to Triple FFF, this results in saving time in the cool chain.

- Trucks will deliver the boxes 2 hours later. Boxes are expected to be at Triple FFF8 hours before the flight departs. In case the boxes are delivered more than 10 hours before departure of the flight, this is assumed to be 2 hours less. This results in the following equation.

$$\text{if } t(4) - t(3) > 10 \text{ then } t(4) = t(4) - 2, t(5) = t(5) - 2, t(6) = t(6) - 2$$

5: Cool at farm

The first temperature measurement is done at the farm. In case this temperature measurement shows that the temperature is above a certain threshold, the boxes are re-cooled using a pre-cool unit. For this concept, the same pre-cool unit is used as in design alternative 1, see Figure 6.5.

- In case the temperature of the flowers is not below 4°C, the flowers must be cooled. The flowers are kept in a cool room until measurement 2 is done so the flowers stay at 4°C. This results in the following equation.

  if $T(1) > 4$, then $T(1) = 4$ and $T(2) = 4$

- At the farm five pre-cool units are available. At the pre-cool unit there are two lanes for 8 boxes each and this results in 16 boxes per cooling unit. For cooling down the boxes one hour is required. This results in a capacity of 80 boxes/hour.

Figure 6.5: Pre-cool units at the Nini farm

6: Cool at consignee

Flowers arrive at the consignee after air transport to Schiphol airport. Boxes are delivered to the consignee and are the temperature is checked. When the boxes arrive above a certain temperature they are re-cooled.

- For this situation, the threshold is set at 4°C. In case boxes arrive with this temperature, they are re-cooled to 4°C. They are kept on this temperature until they leave the warehouse of the consignee. This results in the following equation

  if $T(5) > 4$, then $T(5) = 4$ and $T(6) = 4$

- At this moment there are no cooling units available at the consignee. In total 6 of these pre-cool units will be installed at the cost of 10,000$ each. The pre-cooling units are amortised over 10 years. The capacity of the pre-cooling units is 96 boxes per hour, equal to the capacity at Triple FFF. There are 30 consignees in total dividing the 70 tonnes of flowers shipped per flight. The aircraft flies from Nairobi to Schiphol five times a week, 52 weeks a year.

7: Shorter handling time consignee

Flowers arrive at the consignee and in Chapter 5 it is established that boxes stay on average long at the consignee. For this concept, it is assumed that the throughput time of the boxes at the consignee is reduced to a maximum.

- The storage time at the consignee is set to 24 hours maximum. When flowers arrive at the consignee they should leave the next day. For that the following equation is used.

  if $t(6) - t(5) > 24$ then $t(6) = t(5) + 24$

6.2.2. DECISION MAKING

The concepts are calculated and results of the impact of each design are given regarding costs, capacity and degreehours. To decide which concept is the most feasible one to apply they are split into two sections. The first section is regarding design alternatives within the scope of KLM Cargo. In this section KLM Cargo has direct influence and a change in the cool chain can be applied faster. The second section is regarding design alternatives outside the scope of KLM Cargo. To apply changes on this part of the supply chain more time is needed since the influence on it is lower.

INSIDE THE SCOPE OF KLM CARGO

The first decision is made for design alternatives that are inside the scope of KLM Cargo. The first four concepts belong within this scope and are given in Table 6.2.

Table 6.2: Design alternatives with criteria inside scope KLM Cargo

Criteria	**1: Cool at Triple FFF**	**2: Pre-cool aircraft**	**3: Blankets at TARMAC**	**4: Shorter storage time Triple FFF**
DH Average	[redacted]			
600 DH Performance				
DH max				
Costs				
Capacity				

For the different concepts the costs, capacity and degreehours are calculated. Shorter storage time at Triple FFF does not decrease the degreehours average a lot, the degreehours for the original shipments is 506 on average. Between the first three concepts pre-cooling of the aircraft has the highest ratio of degreehours win versus costs per tonne. There is also no limit on the capacity since the hold is completely cooled with one air conditioning unit. From the other two options applying blankets has a better degreehours win versus costs per tonne ratio. Inside the scope of KLM Cargo is the preferred design alternative to pre-cool the aircraft.

OUTSIDE THE SCOPE OF KLM CARGO

For changes in the complete supply chain, there are three other concepts considered. The three concepts with the criteria are given in Table 6.3.

Table 6.3: Design alternatives with criteria outside scope KLM Cargo

Criteria	**5: Cool at farm**	**6: Cool at consignee**	**7: Shorter time consignee**
DH Average	[redacted]		
DH Max			
600 DH Performance			
Costs			
Capacity			

The concept with the most effect on the degreehours is shortening the time at the consignee. Adding an extra cool step at the consignee also decreases the degreehours but costs are involved for this. For shortening the time at the consignee no costs are directly involved. However, it probably requires resources to ensure that the throughput time at the warehouse is shortened. Cooling the boxes at the farm gives a slight decrease in the degreehours average. This is a cheaper option than cooling at the consignee, but it has a smaller effect on the degreehours. Outside the scope of KLM Cargo it is preferred to shorten the time at the consignee.

6.3. Pre-cooling aircraft

From the analysis it follows that pre-cooling the aircraft is the best design alternative for KLM Cargo to apply. In this section, the concept will be further explained and how to implement this at KLM Cargo. The technical aspect, the cost aspect, and the regulations aspect are discussed subsequent.

Technical aspect

The aircraft is pre-cooled by an external air conditioning unit which blows cold air inside the hold of the aircraft. An example of an air conditioning unit is given in Figure 6.6. The aircraft arrives at the airport in Nairobi and when it is waiting on the TARMAC the air conditioning unit is attached. A yellow tube is connected to the aircraft between the main wheels, this is done when the aircraft is at the ground. When the two tubes are connected the air conditioning unit is switched on and it cools down the complete cargo hold. For a Boeing 747-400, it takes around 1.5 hours to cool down the cargo hold to 5°C.

Figure 6.6: Example of an air conditioning unit pre-cooling the aircraft

There is a chance that the air conditioning unit is not available or not working. In that case, the cargo hold can not be pre-cooled by the air conditioning unit and the Auxiliary Power Unit (APU) needs to be used. The auxiliary power unit is turned on by the flight crew or by a ground engineer. The disadvantage of using the APU is that it produces a lot of noise and there is an increased chance that it breaks down. Therefore, this option is used as a backup solution to be able to cool down the cargo hold every flight.

In Nairobi the flowers are loaded into the aircraft. This takes approximately 2 hours and at first, the lower deck is loaded. Afterwards, the main deck is loaded with the aircraft pallets. Specifications of these decks are given in Appendix C. For the lower deck, the lower hold loader is used and for the main deck the main deck loader is used. These loaders are attached at the back of the plane. It should be noted that the cargo doors only are opened when the loading takes place. Otherwise, there is a chance that the hold increases in temperature and pre-cooling will not have effect. When the aircraft takes off the hold reaches the specified temperature of 5°C faster. In case the door at the nose is opened and at the same time the door at the side of the aircraft the temperature of the hold can increase fast. To prevent the heat exchanges during the loading phase a strip curtain can be used at the door of the main deck. The plastic strip curtain separates the cold air of the aircraft from the warm outside air. The loading of the pallets is not interfered because the pallets can move through the curtain. A second option is to use an air curtain. An air conditioning unit creates an air curtain between the inside and outside are and because of that the heat exchange is limited. In this way the hold of the aircraft is protected from the outside temperature during the loading phase.

Costs

Redesigning the cool chain is inherent to costs and also pre-cooling the aircraft costs money. The air conditioning unit is available at the airport in Nairobi but at the moment it is not used. There is a contract which allows KLM Cargo using the Air Conditioning Unit (ACU) for a flight. The costs for using it are [redacted]. The total loading capacity of a Boeing 747-400 ERF is 110 tonnes, see Appendix C for the loading details. [redacted] aircraft is not completely filled with flowers but every flight there is 70 tonnes of roses in it. In this way the costs per kilogramme of transported flowers can be calculated and are [redacted].

For the auxiliary power unit the engine of the plane needs to be turned on by the flight crew or ground personnel. T[redacted] When using the APU the same amount of flowers is cooled as in the situation with the air conditioning unit. The calculation of the costs for both the options are showed below

[redacted]

[redacted]

REGULATIONS AND PRACTICAL ASPECT

[redacted]

[redacted].

[redacted]

Figure 6.7: Time temperature graph for an average shipment

IMPACT ON COOL CHAIN

At every flight the aircraft is pre-cooled which has an impact on the cool chain. The temperature at measurement point 5 changes as a result of the pre-cooled aircraft. Th[redacted] A graph is showed with the new time temperature curve in Figure 6.7. The yellow line indicates the new temperature when pre-cooling of the aircraft is done. The blue line indicates the original situation. The surface under the blue line gives the degreehours for the original situation. The surface under the yellow line gives the degreehours when pre-cooling of the aircraft is applied. The surface of this is smaller and this explains de decrease in average degreehours. The average degreehours decreases from [redacted].

For all the shipments a distribution of degreehours is made. The performance of the cool chain can be checked in this way. In Figure 6.8 the yellow bars indicate the new cool chain and the blue bars indicate the original situation. [redacted]

[redacted]

Figure 6.8: Distribution of degreehours for original situation and pre cooling the aircraft

6.4. Future prospect

This research has given insight about redesigning the cool chain. In the future the transport of perishables will become more advanced. Some views on the future prospect of KLM Cargo and of perishable transport in general are given.

6.4.1. KLM Cargo

For KLM Cargo the transport of perishables is important and the volumes and tonnage shipped are vital for their income. Trends are spotted in the market where information sharing becomes important and there is a high attention on the quality delivered by the airline. Changes are needed in the cool chain to stay ahead of competitors and the design of the cool chain is important. Information about time and temperature is vital for the transport of perishables and the focus of KLM Cargo should be on this the coming years. The data can be collected by the company themselves but it can also be shared between actors in the supply chain. Active data loggers can not be used during air transport right now. If the regulations allows the usage active data loggers the time and temperature can be read out during the supply chain. In that case no measurements on the indicated points are needed. When this information comes available measures can be taken on historical data of time and temperature.

6.4.2. Perishable transport in general

For the transport of perishables in general there is a strong focus on quality oriented transport. More and more information about time and temperature becomes available and this information will be used by buyers to see which flowers have had the best cool chain. When the time temperature history of a flower is known, it can assist in the decision-making. Flowers which obtained few degreehours can attract higher prices since they last longer on the vase. Airlines and other companies involved in the cool chain who invest in managing time and temperature can be awarded through better prices on their roses. Besides that, it would be beneficial if the actors work together more closely in the future. In the current situation each actor of the supply chain operates on its own. By collaborating, information can be shared and the cool chain can be further redesigned.

7
Conclusion

This research has given new information about measuring the time and temperature and about design alternatives for the cool chain. The conclusions are summed up in this chapter and the research question is as follows:

> *What design criteria can be determined for the transport of perishables from Nairobi to Schiphol from a quality perspective?*

There are several design criteria for the air transport of perishables from Nairobi to Schiphol. To determine the quality of the roses transported, the rose is modelled as a system with input parameters and an output parameter. Time and temperature are the input parameters and the output parameter is vase life. For the cool chain performance of a shipment, the property degreehours is assigned and can be calculated by multiplying time and temperature. There are six points available in the cool chain measuring the time and temperature. Two processing methods for time and temperature are employed, one by assuming temperature constant between two measurement points and one by doing a linear interpolation of the temperature between two measurement points. The linear interpolation method is the most accurate method and predicts the degreehours of the shipment within an error percentage of 7.3% and the vase life with an error percentage of 0.6%.

Seven design alternatives for this cool chain are evaluated to deliver flowers with a longer vase life at the end of the chain. The design alternatives are cooling steps at different parts of the cool chain, pre-cooling of the aircraft and shortening the handling time. The design alternatives are judged on costs and vase life win. Pre-cooling the aircraft is the best option to preserve the quality of the flowers during the cool chain. This design alternative results in a lower temperature on the cool chain and it decreases the degreehours from [redacted]

From the research it can be concluded that the design criteria for the transport of perishable goods in general are as follows.

- Define the perishable transported. The quality of the perishable and the parameters influencing the quality needs to be determined.
- Model the perishable transported. The perishable can be modelled with input parameters affecting vase life and the output parameter is the defined quality.
- Define the cool chain. The cool chain of the perishable transported needs to be defined with the different actors.
- Indicate measurement points in the cool chain. Along the cool chain points should be indicated where the input parameters can be measured.
- Generate design alternatives. Based on the desired quality output the design alternatives can be judged and applied.

8
Recommendations

Several recommendations can be made following this study. These recommendations are split into recommendations for TU Delft in 8.1 and recommendations for KLM Cargo in section 8.2

8.1. Recommendations for TU Delft

There are several recommendations for TU Delft. Most of these recommendations are based around the theory of perishable logistics. These recommendations follow from literature research and by applying this research to practice.

1. **Humidity** The first recommendation is to also include humidity in a prediction model. Research has shown that humidity can be an influencing factor in vase life, however, this data is not quantified. Including this parameter into the prediction model will give more accurate results.

2. **Measurements** More measurements should be done on the Nairobi Schiphol route. With the current data, only one sensor at the side of the pallet is considered. This can be extended to multiple measurements at the side of the pallet. With that, the temperature at each side of the pallet can be determined.

3. **Compare cool chains** This research can be extended to other cool chains to compare differences in time and temperature. Other lanes can be considered, for example perishable transport from Quito or Bogota to Schiphol and on these flows also flowers are transported.

4. **Other perishables** In this research one cultivar for the rose is considered. The methodology can also be applied to other perishables which are transported by air. These perishables can have different prediction models for quality.

5. **Different functions** The two functions used in discrete measurements are the constant function and linear interpolation. It is possible that there are more functions which can describe the original temperature curve better.

6. **Smaller increment steps** For this research just one time temperature indicator is used with minimum step size of 6 minutes. Other indicators can be used to see if smaller increments give an even more accurate result.

8.2. Recommendations for KLM Cargo

Recommendations for KLM Cargo have a slightly different angle. These recommendations are more practically oriented and follow from observations made during the research and analysis.

1. **Information sharing** The supply chain involves multiple actors all of whom have the knowledge and the power to make changes. The information they gather should be shared with other actors in the chain. In this way the cool chain can be redesigned by collaboration and transparency.

2. **Analyse first pathway** For this research only the second pathway is considered and data can be obtained from the first pathway which includes the forwarder on land side. This cool chain has an extra step which allows more measurements and design alternatives.

3. **Design alternatives** In this research design alternatives are discussed on a general level. Based on this study design alternatives can be worked out in more detail. The technical aspect and the cost aspect can be worked out more extensively.

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A

Research Paper

Redesign the cool chain for air transport of perishable goods by KLM Cargo

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***Abstract*— This research paper is on redesigning the cool chain of perishables transported by air from Kenya to the Netherlands. Roses are transported from Kenya to and via the Netherlands to be consumed in Europe. To preserve quality and freshness of the roses time and temperature should be controlled throughout the supply chain. Time and temperature are considered as the important parameters influencing the vase life. Vase life is defined by the end customer as an important quality aspect for flowers. To control quality these two parameters should be measured along the supply chain. Two ways of measuring time and temperature are discussed. A distinction is made between continuous and discrete measurements. Continuous measurements are performed using data loggers, and discrete measurements are done by measuring at certain points. Discrete measurements appear to be a good approximation of the temperature during the supply chain and of the degreehours total, it has an error percentage of just seven percent. By measuring at six points in the supply chain different design alternatives can be investigated to see on which part of the cool chain a redesign is needed.**

***Index Terms*— Roses, quality, measuring, cool chain, vase life, redesign**

I. Introduction

THE flower market has become global in the last decades. The Netherlands, used to be the biggest harvester in flowers, has a decreased share in the world production. This place is overtaken by developing countries. These developing countries have an increased export in horticulture and cut flowers are vital for their export shares. One of the emerging countries is Kenya, which are the third largest flower exporter in the world. The climate and cost of labour in Kenya are advantageous for the growth of flowers and roses in particular. Kenyan flowers account for 35% of all flower sales in the European Union. The Netherlands plays an important role in this by buying 67% of their export tonnage and 57% of their export value [1]. Flowers are transported by air from Nairobi to Schiphol and KLM Cargo is one of the carriers flying this route. Measuring and controlling the time and temperature has become a vital part for the cool chain to preserve quality of perishable goods. The focus of this paper is on redesigning the cool chain from a quality perspective. The impact of time and temperature on the quality of flowers is analysed and way time and temperature are measured is evaluated. Afterwards, several design alternatives are investigated and one alternative is chosen.

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II. System definition

For the air transport of perishable goods two parts are identified. The first part of the system is the logistics part and the second part is the biological part. These parts are discussed separately in the following sections.

A. Logistical aspect

Roses are harvested at a farm in Kenya and after transport they end up in a vase of the end customer. The supply chain for perishable transport consists of different actors which can be seen in Figure 1. There are five actors in the system and these actors with its functions are described below.

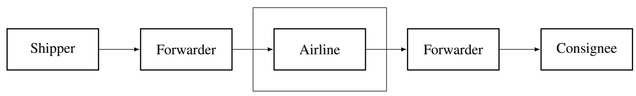


Fig. 1: The supply chain of the Nairobi Schiphol flow with different actors

1) Shipper: The first part of the supply chain is the shipper which is in this case the farm.At the farm the roses are grown and harvested. There are around 80 farms delivering to Nairobi for export purposes. At the farm these roses are packed into boxes and delivered to the forwarder. This is done by trucking and it can take from 1 up to 5 hours, depending on the location of the farm.
2) Exporting forwarder: The exporting forwarder is the expediter of the air cargo supply chain. The roses arrive from different farms at the forwarders' warehouse and here they are made ready for transport.
3) Airline: The airline arranges air transport from Nairobi to Schiphol. The aircraft used for this rout is a Boeing 747-400 ERF which is a full freighter. For loading the cargo into the aircraft the weight and balance should be taken into account.
4) Importing forwarder: Flowers arrive at Schiphol airport and the importing forwarder receives the goods. The forwardar performs customs clearance for import. The goods are picked up by truck and are delivered to the consignee.
5) Consignee: The consignee is the last part of the air cargo supply chain and receives cargo from the forwarder. The boxes are opened at this stage and flowers are checked against the packing list and for quality.

B. Biological aspect

The quality of a rose affects the price as well as customer satisfaction in perishable goods [2]. For the customer the quality of the roses they buy is essential. Buying a bouquet of flowers which are wilted after 5 days leaves the customer dissapointed, and sees them less likely to buy the same flowers again. Some of the retailers even give a 7-day vase life guarantee. To achieve this a proper cool chain must be maintained. To get more insight in the behaviour of a rose we it can be seen as a system with input parameters and output parameters. A function determines the output based on the input variables, this is seen in Figure 2.

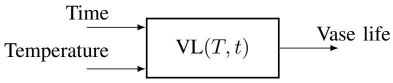


Fig. 2: Viewing the rose as a system with input and output parameters defined

1) Input parameters: The quality of a rose is affected by various external factors. From the external factors two parameters are important: temperature history of the flower and flow time through the supply chain [3], [4]. In the current situation flowers are transported within a temperature range of +2 to +8°C. Humidity is not taken into account since this is onnly affecting quality at extreme heights, which are not reach during the air transport[5].

a) Temperature: Temperature history is seen as one of the most important aspects in transporting perishables [6],[7],[8] . Ideally roses should be transported close to 0 degrees Celsius. Transporting roses at this temperature results in a minimum loss of quality. However, the current air transport has a temperature range of +2 to 8°C. When flowers are transported at high temperatures there is an increased chance they get diseased or that the flower does not open at all. The effect of temperature on the rate of flower senescence is one of the most important parts of a model to simulate during the post-harvest phase on flower [9]. Temperature monitoring and control is judged to be the solution of 90% of the quality problems, starting when the product is harvested on farm [10].

b) Time: In combination with the temperature time is an important parameter in transporting perishables and transport time should be kept as short as possible [11]. The aim is to keep the transport time from beginning to end as low as possible. A higher transport time affects the quality of the flowers and also increases the chance of heat generated by a flower.

2) Output parameters: The most important aspects of quality are 'freshness' and vase life and these should be controlled for an optimum post-harvest handling [12].

a) Vase Life: The destination of cut roses is the end customer, everyone who buys roses. The roses are kept in the vase and subsequently a certain vase life is expected. Vase life is leading as a quality indicator and is defined as follows:

> *"The remaining vase life is defined as the time that flowers can be kept on the vase at room temperature, which is regularly assumed to be equal to 20°C." [13]*

For this definition the storage temperature is set at 20°C, it must be noted that the higher the ambient temperature the shorter the vase life of cut rose flowers [14]. There are several criteria at which point vase life ends. A regular quality criterion for cut roses is the wilting of the flower, which can be caused by bacteria [15], [16]. Other incidents which may happen to roses are the occurence of petal browning due to severe *B. cinerea* infection and bent neck due to vascular blockage [17], [18].

3) Prediction models: The rose is viewed as a system with input parameters, mainly determined by logistics, and an output parameter, describing the quality of the flower. The box represents a function which determines the quality of the flower. There is very few literature available on models describing the quality of a rose as a function of input parameters. Two functions describing this are written by Tromp [13], one of them is the the First Order Arrhenius. The second one is the degree days model.

a) First Order Arrhenius: The First Order Arrhenius (FOA) function is widely applied in modeling food quality and shelf life estimation [19], [20]. There are several orders in this function and the first order function is used to determine the quality of the rose. The function is presented in Equation 1. The symbol A denotes the initial vase life of a rose and the summation indicates the decrease in vase life. This function uses an exponential function to describe the quality deterioration based on the reference and current temperature. The reference temperature is set at 293.15 Kelvin. Other symbols and their explanation are given in Table I.

$$\text{VL} = A - \frac{1}{24} * \sum_{i=1}^{n-1} e^{B*(\frac{1}{T_{ref}} - \frac{1}{T_i})} * (t_{i+1} - t_i) \tag{1}$$

b) Degree Days: The second model used is the Degree Days (DD) model. There are two other paper which base the vase life of a rose on a linear function [9],[21]. This function has the same structure as the previous function where A is the initial predicted vase life and the summation indicates the decrease in vase life. This function uses a linear relation between time and temperature and the affected quality. The list of symbols are given in Table I.

$$\text{VL} = A - \frac{1}{24} * \sum_{i=1}^{n-1} \frac{1}{200} * (T_i - 273.15) * (t_{i+1} - t_i) \tag{2}$$

TABLE I: Symbols of the functions and their explanation

Symbol	Parameter [unit]
VL	Actual expected vase life [days]
A	Initial expected vase life [days]
B	Experimentaly defined parameter [-]
i	Data point
n	Number of data points [#]
k	Increment step [-]
t_i	Time at point i [hours]
T_i	Temperature at point i [Kelvin]
T_{ref}	Storage temperature [Kelvin]

III. System analysis

For the analysis of the system the impact of time and temperature on the quality of flowers is determined. A separation is made between collecting the data with continuous measurements and with discrete measurements. These are discussed in separate sections

A. Continuous measurements

The first way of measuring is by doing continuous measurements. Continuous measurements are done by tracking 30 shipments with three data loggers. Information about time and temperature is collected from 2011 until 2015 and these are all flights from Nairobi to Schiphol. Data loggers measure temperature at a time interval of 6 minutes and this data can be read out afterwards.

1) One shipment: For one shipment a time temperature graph can be created based on the data from the logger. An example of a time temperature graph is given in Figure 3. Time is on the x-axis where 0 hours indicates the start of the shipment. On the y-axis the temperature over time is seen for three different sensors. Temperature is measured at the side of the pallet, in the middle of the pallet and the last sensor measures the air temperature.

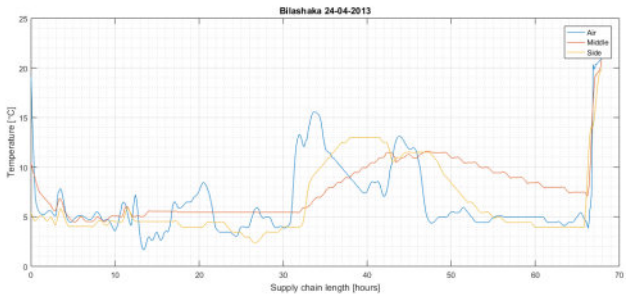


Fig. 3: Time temperature graph of a shipment

For the quality of roses time and temperature are used as input variables in the function. By using the FOA or the DD function the vase life of the shipment can be calculated. In Figure 4 the deterioration of roses over time is shown for boxes in the middle and at side of the pallet. Within the interval of 35 up to 45 hours the deterioration rate is higher for the side box. After 35 hours the air temperature increases because the pallets are loaded into the aircraft. As a result of that, the temperature of both boxes increases. [redacted]

2) All shipments: Multiple shipments are tracked and the time and temperature is used as an input to calculate the degreehours sum and the predicted vase life. The degreehours is a property of the cool chain and is the surface of the time temperature graph. The vase life of roses is predicted by two equations, the First Order Arrhenius and Degree Days equation. The results of this is given in Table II. Of the 30 shipments tracked 4 of them are not used in this research. This is because some of the shipment tracked are transported by another airline and from some of the sensors the data could not be read out.

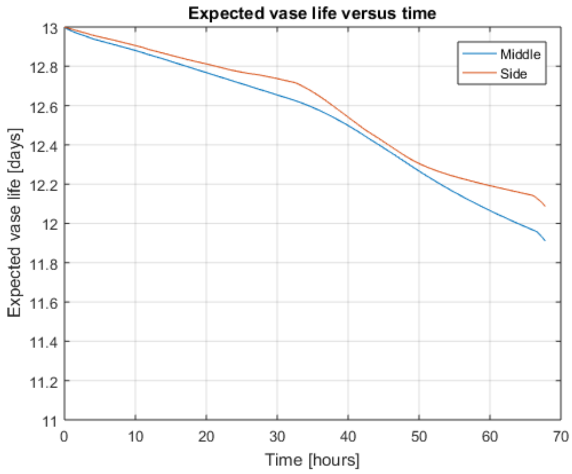


Fig. 4: Deterioration of roses over time

TABLE II: Predicted vase life middle and side pallet for both prediction models

[redacted]

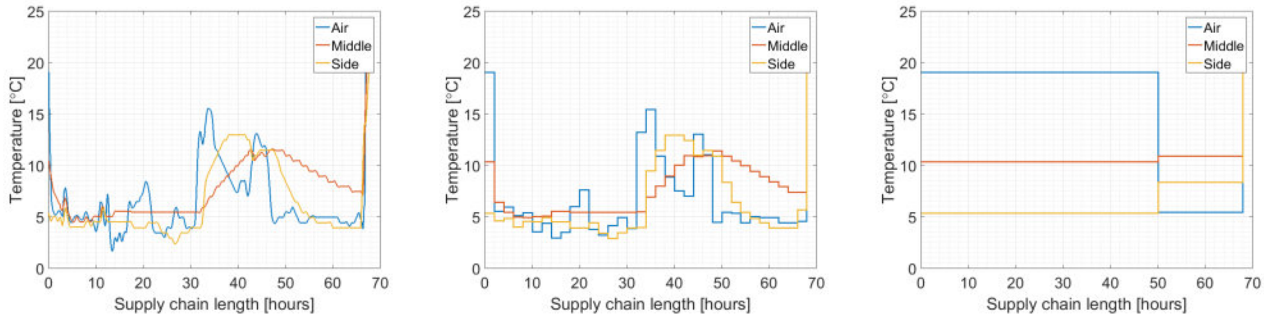
The results of the FOA and DD model are similar . An overview of all the shipments are given in Figure 5. On the x-axis the different time temperature sums are given. The expected vase life after transport is given in the y-axis. The [redacted] correlation between the time temperature sum and the expected vase life.

[redacted]

Fig. 5: Degreehours versus expected vase life

B. Discrete Measurements

The second part of the analysis is done for discrete measurements. Discrete measurements are defined as measuring



(a) k=1, 6 minutes (b) k=20, 2 hours (c) k=500, 50 hours

Fig. 6: Different step sizes

temperature at certain moments in the supply chain. At first, the increment step of the continuous measurements are increased.

1) Increasing Increment Steps: Data analysed in the previous section made use of measurements at a time interval of 6 minutes. When this time interval is increased the difference in temperature can be checked. There are 10 different increment steps k taken and the tie interval for k=1 is 6 minutes, for k=2 12 minutes and so forth. Three examples of this increased time interva is given in Figure 6. The first graph, Figure 6a, gives the continuous function with a time interval of 6 minutes. The second graph has an step of 2 hours and this graph still follows the original one. The last figure barely approximates the first one since the increment step is set to 50 hours.

[redacted]

Fig. 7: Error for different time intervals

For the different increment steps the Mean Absolute Percentage Error (MAPE) is calculated for the degreehours. It takes the absolute error between the degreehours of the specified time interval and of the reference value. An overview for the different increment steps and their error percentages is given in Figure 7. [redacted] When the increment step of the measurement increases the error percentage also increases. The largest increment step is k=1000 which is equal to a time interval of 100 hours. For some of the shipments this results in one measurement only.

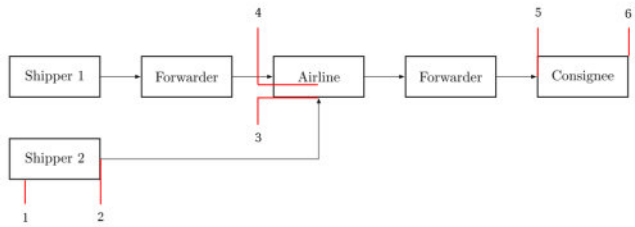


Fig. 8: Location of current measurement points in the supply chain

2) Measurement Infrastructure: The analysis for different increment steps can also be used for varying time intervals which could be compared with the current situation. Field research resulted in 6 measurement points on the route from Nairobi to Schiphol. The location of these measurement points are given in Figure 8. These measurement points are used for the discrete measurement analysis. The time and temperature logged during the shipment acts as an input for the two functions described below.

a) Constant Function: The first function assumes the temperature measured at a certain point to be constant until the next measurement point. An example of such a graph is given in Figure 9. The same shipment is used as in Figure 3 and temperature data of six measurement points are used as an input for the constant function.

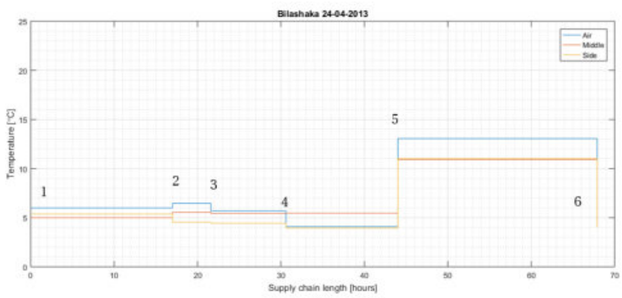


Fig. 9: Time temperature graph with a constant function

When the temperature is assumed constant the function is sensitive for an error since the temperature can have an overshoot or an undershoot. Similar to the error percentage for the different increment steps, the MAPE is calculated for the degreehours, vase life according to FOA and vase life according to DD. These results are showed in Table III. [redacted] approximates the continuous data.

TABLE III: Error for constant function

[redacted]

b) Linear Function: The second function used is the linear interpolation. For this function it is assumed that the temperature linearly increases or decreases between two measurement points. In this case a linear interpolation is done between two temperatures. A graph visualizing this is given in Figure 10.

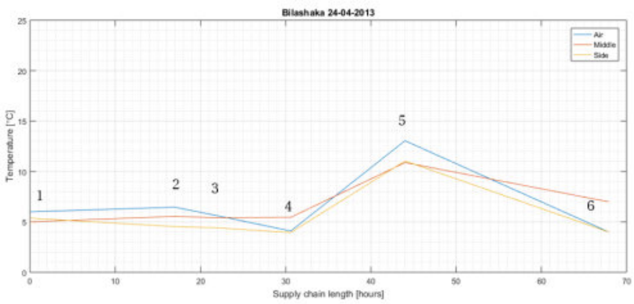


Fig. 10: Time temperature graph with linear interpolation

The error percentages for the linear interpolation are given in Tabel IV. [redacted]

TABLE IV: Error for linear interpolation

[redacted]

Comparing a constant function with linear interpolation the latter one is the best approximation according to degreehours. Doing discrete measurements instead of continuous measurements gives the advantage that measures can be taken to be able to control the cool chain. The results for both of the prediction models are similar when a linear interpolation is done. Because of its simplicity the Degree Days model is used in the rest of the paper to determine quality of the roses

IV. Design alternatives

In the current situation there are parts within the cool chain which could be designed in a different way. The cool chain is not closed at the moment and opportunities are there to change the cool chain. Several design alternatives are considered and compared on costs and degreehours win.

A. *Overview of alternatives*

Along the supply chain there are several design alternatives possible. These alternatives are checked on degreehours average, costs in dollar per tonne and on capacity in boxes per hour. Based on these three criteria it is decided which design alternative is the most suitable. For each of the alternative the formula to calculate the new temperature is given.

1) Cool at warehouse airline: A cooling situation is added at the warehouse of the airline. When boxes with flowers arrive at the warehouse they are checked for temperature. If they are above a certain threshold the boxes are re-cooled.

$$\text{if } T(3) > 4, \text{ then } T(3) = 4 \text{ and } T(4) = 4 \tag{3}$$

2) Pre-cool aircraft: The aircraft can be pre-cooled to remove the warm air from the hold. This results at a lower starting temperature of the hold.

$$T_{mid}(5) = \frac{T_{mid}(5) + 5}{2} + 2,\ T_{side}(5) = \frac{T_{side}(5) + 5}{2} \tag{4}$$

3) Blankets at TARMAC: For this design alternative, blankets are used to cover the aircraft pallets when they are waiting at the TARMAC. In that case they are protected from temperature extremes during the loading phase.

$$T_{mid}(5) = T_{mid}(5) - 2,\ T_{side}(5) = T_{side}(5) - 2 \tag{5}$$

4) Shorter handling time airline: A shorter handling time at the warehouse of the airline is assumed. To achieve this, farms should deliver the boxes with flowers later to the airport. Trucks should pick up the boxes later at the farm, in this way the supply chain is shortened.

$$\text{if } t(4) - t(3) > 10 \text{ then } t(4) = t(4) - 2 \tag{6}$$

5) Cool at farm: The first temperature measurement is done at the farm. In case the boxes are not cooled at this stage they should be re-cooled by using a pre-cool unit. After that it stays in a cool room until they are picked up by truck.

$$\text{if } T(1) > 4, \text{ then } T(1) = 4 \text{ and } T(2) = 4 \tag{7}$$

6) Cool at consignee: At the end of the supply chain the consignee receives the flowers. At this stage they can be heated up considerably and there is a possibility to do a re-cool step. After this re-cooling boxes are stored in a cool room.

$$\text{if } T(5) > 4, \text{ then } T(5) = 4 \text{ and } T(6) = 4 \tag{8}$$

7) Shorter time at consignee: The last design alternative is a shortened time at the consignee. It appears that flowers stay long at the consignee and therefore the throughput time should be decreased to maximum a day.

$$\text{if } t(6) - t(5) > 24 \text{ then } t(6) = t(5) + 24 \tag{9}$$

The suggested design alternative have an impact on the time or the temperature of the cool chain. As a result of that, the quality of the flower at the end of transport can be improved. To compare these design alternatives several parameters are calculated. These parameters are criteria for the supply chain and are: the new degreehour average, the costs and the capacity are calculated. Results of this are given in Table V.

TABLE V: Design alternatives with criteria

[redacted]

In total seven design alternatives are proposed and in this case the suggestion is towards the airline. This eliminates alternatives 5, 6 and 7 since they do not lay within the scope of KLM Cargo. From the first four options pre-cooling the aircraft is the best alternative. It has a high degreehours win and the costs per tonne are low. Next to that, there is no limitation in capacity since this alternative cools down the complete aircraft hold. The pre-cooling of an aircraft is done by an external air conditioning unit. This device is connected when the aircraft is at the ground in Nairobi. The air conditioning unit cools down the cargo hold before the boxes with flowers are loaded into the aircraft. As a result of this the temperature of the boxes does not increase during the flight. [redacted]

V. Conclusion

From this research it can be concluded that the cool chain of the Nairobi Schiphol route can be redesign by changing the measurement infrastructure and applying an extra cool step. Six points where temperature is measured in the supply chain is sufficient to approximate the original temperature curve. Linear interpolation is used to determine the temperature path in between two measurements. The degree days model is used to determine the quality of the flowers as a result of time and temperature. [redacted] This gives opportunities to sell the product at a higher price.

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B

Nairobi Visit

For this assignment the supply chain of perishable goods is analysed. To get more understanding of how the supply chain works different facilities are visited in Kenya. From 9th until the 11th of October Nairobi and the rural area was visited to see the farm, forwarder and airport facilities. On the October 10 a farm was visited, this is discussed in section B.1. The October 11 the forwarder and airport facilities were visited, these are discussed respectively in section B.2 and B.3. An overview of the stakeholders consulted is given in Table B.1.

Table B.1: Overview of stakeholders consulted

Stakeholder	**Company**	**Function**
Billy Coulsoun	Nini Farm	Director
Charles Njonjo	Airflo/Panalpina	Operations Manager
Harry Prins	Martinair	Project Engineer
Stephen Ngingo	KLM Cargo - Nairobi	Regional Operations Manager Eastern & Southern Africa
Nixon Luane	KLM Cargo - Nairobi	Quality Manager Eastern & Southern Africa
Walter Ongany	Triple FFF	Duty Manager Operations

B.1. Farm

The first visi was to one of the farms which is supplying flowers to a forwarder. The farm visited was the Nini farm located in Naivasha and is one of the bigger farms in this area. The farm originates from the year 2001 and it produces every week 2 million stems of roses. The farm grows 15 different types of cultivars. These cultivars are harvested from different fields some years after planting. The different steps of the farm are explained in the subsections supported by images taken at the farm.

Step 0: Fields

The first step is the flowers fields, in Figure B.1 a field of flowers can be seen. In this field the rose 'Akito' is grown. There are 15 different cultivar harvested at the Nini farm and the farm covers an area of 44 hectare. When the day and night are warm, the roses are harvested three times a day. One shift is in the morning, one in the afternoon, and one in the evening. From the farm it takes maximum 40 minutes to transport the flowers in buckets to the warehouse where the pre-cooling is done. The flowers are putted in buckets with a post-harvest solution. The post-harvest solution prevents the bacteria from going into the flower. According to the customer the flower is harvested on a certain length. The flowers are harvested based on the blooming phase and are cut along the requirements of the customer.

Figure B.1: A field of Akito roses at the Nini farm

STEP 1: PRE-COOLING

When the flowers arrive at the warehouse the first step is to pre-cool the flowers. They are stored for 4 hours up to 24 hours in a room where it is 5 to 10°C. The flowers are cooled and the post-harvest solution can take effect. Flowers which are cold are less likely to take up bacteria and be affected by for example Botrytis.

Figure B.2: Precooling area for flowers after harvesting

STEP 2: GRADING

At the grading phase the flowers are de-leaved and packed into bunches to prepare them to be packed in the box. This grading is done in an area where it is 20 to 25°C. The flowers increase in temperature a bit and therefore the grading process should be done fast. In Figure B.3 a table is seen where the flowers are graded. The ruler at the left indicates the length in centimetres and stems are cut according to this length.

Figure B.3: Table where rose is graded, ruler at the left indicates stem length

Step 3: Packing

After the grading the flowers are ready to be packed into boxes. In Figure B.4 boxes can be seen with roses packed in it. The cotton covers around the petals protect the flower from damaging. Depending on the length of the stem the amount of flowers is putted into the boxes. On average there are 360 stems in one box. For packing there are strict requirements. The boxes have ventilation holes at the side and if the box is too full the box can not close completely and the ventilation holes are blocked. The packing area is 1 to 3°C and is also used to cool the flowers before they leave by truck.

Figure B.4: Packing a box with flowers

Step 4: Storage

The flowers are now in boxes in the cool room and ready to be picked up by truck. A thermometer is used to randomly check boxes if they have the right temperature. If it happens that a box is not at the correct temperature, 2 to 3°C there are blazers which use forced air to cool down the boxes. The storage room with pre-cooling units in the background is seen in Figure B.5. On average the boxes stay 2 hours in the storage room waiting to be picked up by truck.

Figure B.5: Storage room with precooling units in the background

STEP 5: TRUCKING

The boxes are ready to be transported and are picked up by truck. The flowers are between 2 and 3°C when they enter the truck. Driving from this farm to the airport takes approximately 2 to 3 hours, depending on the weather and traffic. When the flowers are unloaded from the truck at the airport they are around 5°C. The truck is set at 1°C but because of the heat production of the roses and the way of stacking of the boxes the flowers increase in temperature. Trucks are owned by Kuehne + Nagel (K+N) which guarantees cooled transport.

Figure B.6: Quality center showing roses during different days of vase life

Quality center

The quality center, also called the vase life room is used to see the development of the vase life of flowers. Bunches of roses are taken and are exposed to room temperature which is in this case 20°C. Every day the blooming of the rose is checked to see how they perform in the vase. The vase life room is seen in Figure B.6 where each of the tables represents a different day in vase life. The quality of the flowers is also checked with the customer, in this case Bloom to see if the vase life is sufficient. Next to that the transport is also simulated by having the flowers in boxes for 3 days on a temperature for 4 to 8°C. After that the stems are cut and again simulated in a box for one day on 4 to 8°C. In this way the farm can see performance of their flowers in the vase.

B.2. Forwarder

The second visit was to Airflo/Panalpina which is one of the forwarders supplying to KLM Cargo. Airflo/-Panalpina is located at JKIA around 1 kilometre away from the warehouse of the airline. The forwarder accepts boxes from different farms, checks them and prepares the build up pallet. These BUPs are delivered to the air side where the pallets are loaded into the aircraft. The throughput volume for Airflo/Panalpina is 1000 ton per week.

Step 0: Delivery by truck

The flowers arrive from different farms by truck to the forwarder, this is seen in Figure B.7. These trucks are owned by the forwarder and are also cooled. Flowers arrive in the morning between 10pm and 2am. This arrival slot can cause collision since each of the trucks needs to be unloaded.

Figure B.7: Unloading boxes from truck at Airflo/Panalpina

Step 1: Acceptance and X-Ray

The flowers are accepted and checked with an X-ray scanner as shown in Figure B.8. The scanner checks if the boxes do not contain dangerous goods, explosives drugs or anything else. This step can lead to congestion since every box takes 20 seconds to scan and one truck can contain up to 700 boxes. There are 5 receiving areas around 20 trucks can arrive in the morning. This can lead to delay in acceptance. During this acceptance temperature is checked by putting a probe in a box for multiple times.

Figure B.8: X-Ray scanner checking incoming boxes

STEP 2: QUALITY CHECK

After acceptance there is a quality check for the incoming flowers and around 10% of the boxes are checked. These boxes are opened, as seen in Figure B.9, to see if they are according to several regulations. Thickness of stems, opening of buds, quality of packing should be okay to assure the quality of flowers. When the flowers are checked three colors are applied.

- **Green:** quality is OK, flowers can continue transport
- **Orange:** quality is just above required level. Warming that quality level can go to the red label further along the chain
- **Red:** quality is not OK. Flowers will be returned to the farm. Costs for this transport are for the farm.

Figure B.9: Box is opened for a quality check

Step 3: Storage room 1

The storage room, seen in Figure B.10, has a temperature of 3 to 5°C. The flowers are stored in this room until there is a confirmation that the aircraft arrives on time. After this sign the boxes can be pushed through to the build up area where the aircraft pallets are build up.

Figure B.10: Storage of the boxes before build up phase

Step 4: Build up pallet

The aircraft pallets are build up as soon as every box is inside the system and the flight is confirmed. An example of a BUP is shown in Figure B.11. In this figure the supporting corners are shown which should decrease the pressure on the bottom box. A net is tightened around the pallet to prevent boxes from falling of during transport.

Figure B.11: A build up pallet going towards storage room 2

STEP 5: COOLING

Cooling is done when the boxes are above 6°C. At that moment vacuum cooling is done, an example of such a vacuum cooler is seen in Figure B.12. Vacuum cooling takes 40 minutes for one BUP and it can decrease the core temperature of the pallet to 1.8°C. The maximum input temperature is 15°C.

Figure B.12: A build up pallet inside the vacuum cooler

STEP 6: STORAGE ROOM 2

The pallets are finally stored in a cool room where the temperature is 3 to 5°C. The pallets are stored in this dispatch room waiting to be transported to the aircraft. A couple of hours before the flight leaves the pallets are transported to the next warehouse.

Figure B.13: Build up pallets waiting to be dispatched

Step 7: Dispatch

When the pallets are ready to be dispatched they are driven by a tractor to the handling at the airside, this is seen in Figure B.14. The exit temperature of a pallet is maximum 6°C, otherwise a disclaimer is put on the pallet. The responsibility of the shipment is taken by Airflo/Panalpina when the boxes arrive from the farm at a correct temperature. In case the farm has delivered the boxes at a too high temperature, it is the responsibility of the farm to receive any claims.

Figure B.14: Dispatch of build up pallets to the next warehouse

B.3. Airline

The last visit was to the warehouse of the Airline, which is called KQ warehouse. This KQ warehouse receives already build up pallets from different forwarders. In the first subsection, subsection B.3.1 this process is explained. The second option is that KQ warehouse acts as a forwarder by accepting boxes from different farms, that part of the warehouse is owned by Triple FFF. This is explained in subsection B.3.2. The boxes are build up and both of the pallets go by aircraft to Schiphol Airport. These pallets are flying with an aircraft of KLM or Martinair. It is also possible that pallets have another destination, in this research only pallets transported with a Martinair aircraft are considered.

B.3.1. Arrival Build Up Pallets

The first flow discussed is the flow where build up pallets arrive from diffeent forwarders, Airflo/Panalpina, discussed in the previous section, is one of them. Several other forwarders are also located at the airport in Nairobi, JKIA,and deliver according to the same procedure.

Step 0: Delivery by truck

The aircraft pallets arrive at KQ warehouse at the lane which is seen in Figure B.15. At the left side of the fence there are two unloading slots for the pallets. Loose boxes are delivered at the other side of the fence, this is discussed in the next part. The full pallets arrive from different forwarders and most of the forwarders are in the proximity of the KQ warehouse. In communication with KQ warehouse the time of delivery is discussed.

Figure B.15: Two unloading slots for build up pallets at arrival section

STEP 1: ACCEPTANCE

The BUPs arrive and the shipment is checked and weighed. For the acceptance no X-ray scanning is done since this is action is already done at the forwarder. In this case there are temperature checks performed at the side of the pallet.

STEP 2: STORAGE

Build up pallets are stored in the throughput lane where the temperature is 4 to 8°C. In this throughput lane the BUPs wait until the aircraft is ready to be loaded. This lane is seen in Figure B.16.

Figure B.16: Throughput lane for build up pallets

Step 3: Loading in the plane

The last step to take is for the pallets to be loaded on the plane. In Figure B.17 the place where the aircraft normally lands is shown. The high loader in front is used to load the pallets into the aircraft.

Figure B.17: Loading area with high loader in front

B.3.2. Arrival boxes

This section describes the flow of loose boxes which arrive at Triple FFF. The loose boxes arrive from different farms around Nairobi which is similar to the arrival at Airflo/Panalpina. In this case KQ warehouse acts also as a forwarder. This process is a more extensive and each of the steps are explained below.

Step 0: Arrive by truck

The other side of the arrival section is shown in Figure B.18. One truck which is unloading is shown in the front.

Figure B.18: Unloading area for loose cargo

Step 1: Acceptance

The second step is the acceptance of loose cargo. Contrarily to the previous flow a dedicated check is needed. In Figure B.19 it is shown that the boxes are going through an X-ray scanner. Before going through this scanner the boxes are weighed to see if they are confirming the loading limits.

Figure B.19: Acceptance area for loose cargo with X-ray scanners in the back

Step 2: Cool room 1

After the perishables are checked they move to the first cool room. Here the boxes are stacked in such a way that they have funnels in between. This is done so the boxes can release their generated heat. This is seen in Figure B.20. Ventilation units which ensure forced convection can be seen in the background, these are located at the roof. In this room also blazers are available to cool the boxes if needed. These blazers are located in the back of this section and are used in case boxes arrive at a too high temperature.

Figure B.20: First cool room where boxes are stapled in such a way to create funnels

Step 3: Cool room 2

The second cool room is the cool room where aircraft pallets are build up and waiting to be dispatched. The build up is done as late as possible to prevent heat generation in the middle of the pallet. This cool room is shown in Figure B.21. At the moment this picture was taken there was just on build up pallet waiting. This was because of the time of the day, since these pallets are build up in a later stage.

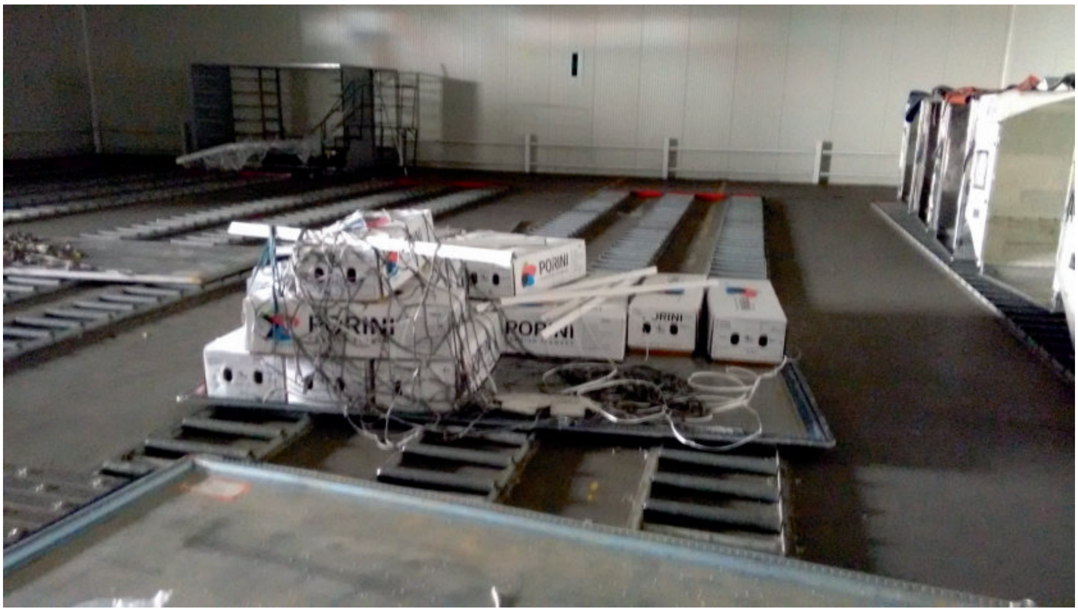

Figure B.21: Second cool room where build up pallets wait to be loaded into the aircraft

Step 4: Loading in the plane

The last phase of this flow is the loading of the aircraft. The Martinair aircraft parks in from of the door and the pallets can be loaded one by one into the aircraft. This is seen in Figure B.22.

Figure B.22: Area where aircraft is loaded with loading vehicle in front

C

BOEING 747 ERF

As mentioned in the report the aircraft used for the air transport of perishables is a Boeing 747-400 ER Freighter. In this appendix specifications of this aircraft are explained and several images are shown. The specifications of this aircraft are given in Table C.1.

Table C.1: Specifications of a Boeing 747 ER Freighter

Specification	Amount
Operating empty weight	164 tonne
Maximum take-off weight	413 tonne
Maximum payload	113 tonne
Maximum range	9,200 km

The dimensions of the aircraft used in the air cargo supply chain are given in Figure C.1.

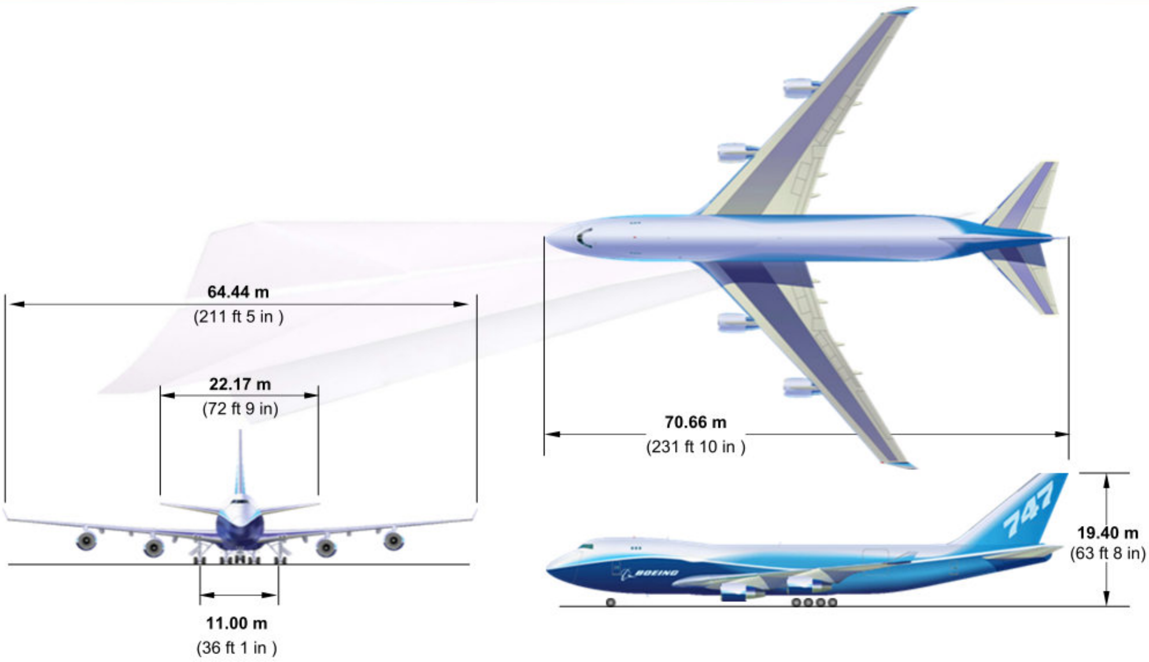

Figure C.1: Dimensions of a Boeing 747-400 ER Freighter

For the servicing arrangement there are several applications, these are given in Figure C.2. The air conditioning unit can be connected between the two main wheels. The connection point is denoted by AC in the figure.

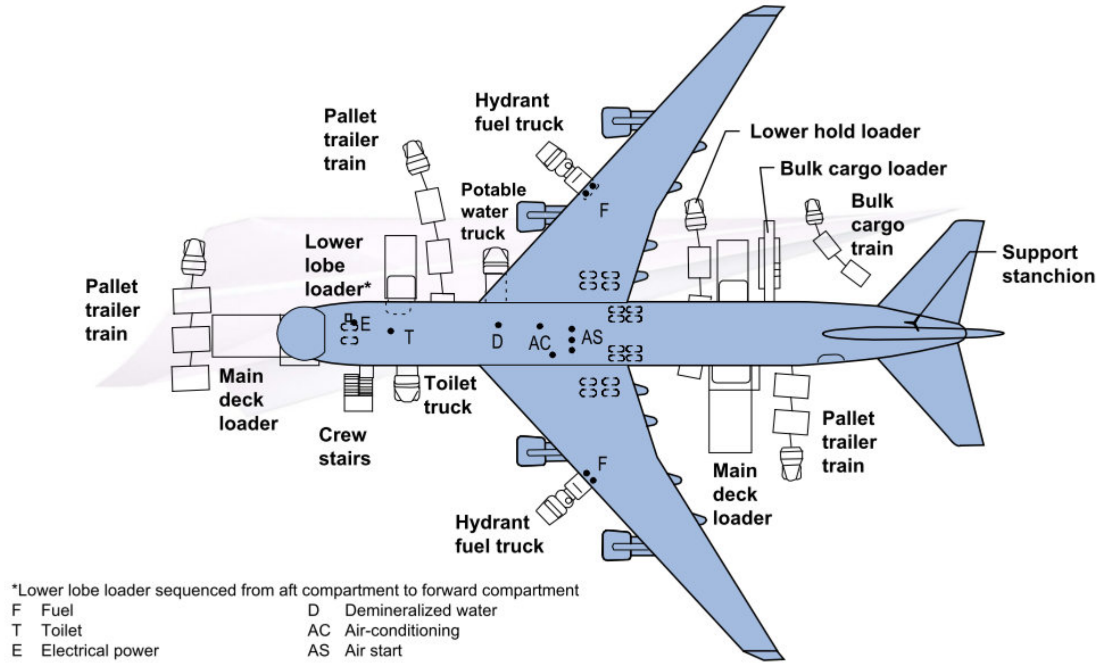

Figure C.2: Servicing arrangement with loading locations and AC location

The aircraft pallet used in the supply chain is given in Figure C.3. The dimensions are given in this figure and the height of this pallet can vary.

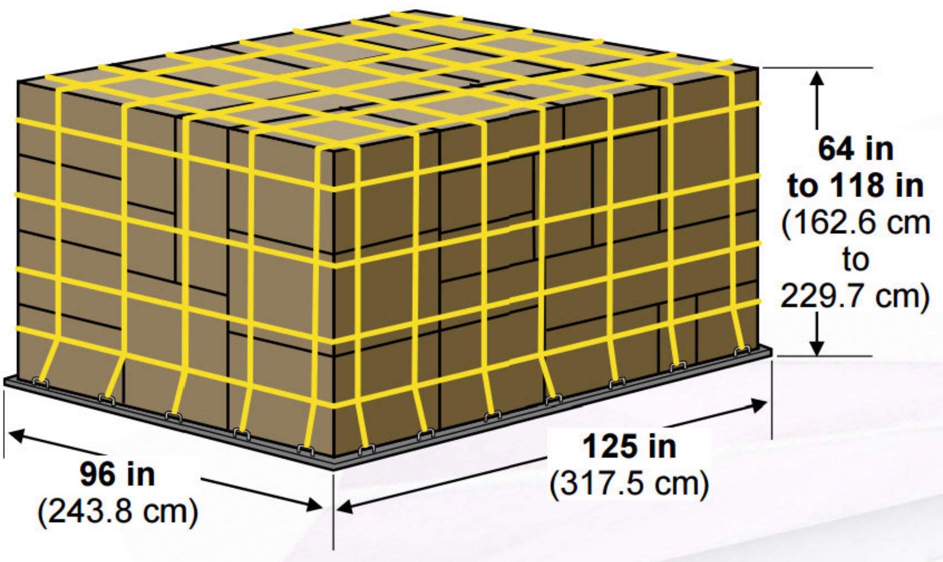

Figure C.3: Dimensions of an aircraft pallet

A cross section of the aircraft is given in Figure C.4. The height of the main deck and lower deck is different. When the aircraft pallet is build up, the height must be adjusted to where the pallet is loaded.

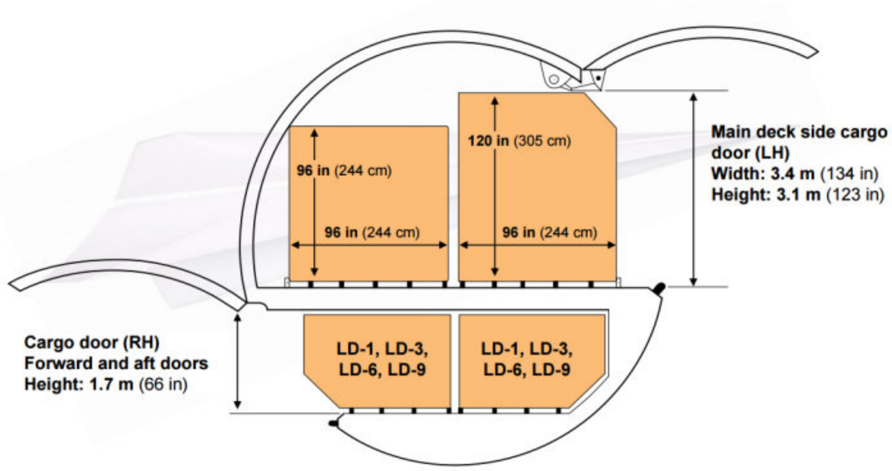

Figure C.4: Cross section of a Boeing 747 ER Freighter cargo hold

In the hold of the aircraft there are 30 positions available on the main deck. The arrangement of the pallets on the main deck is seen in Figure C.5. There are 9 positions available on the lowerdeck. The arrangement of the pallets on the lowerdeck is given in Figure C.6.

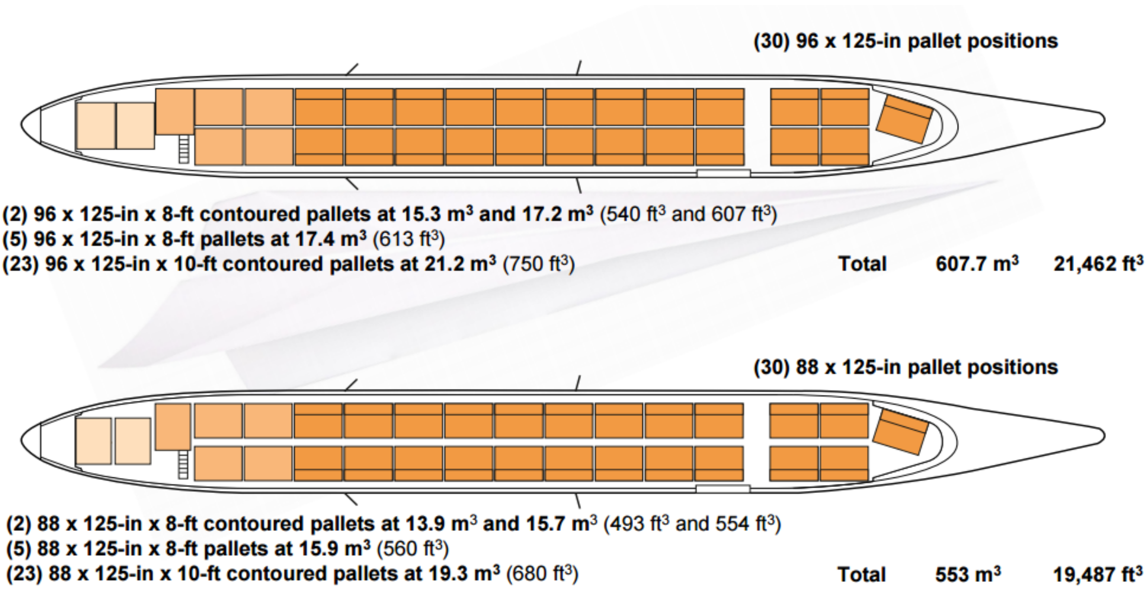

Figure C.5: Cargo arrangement for main deck

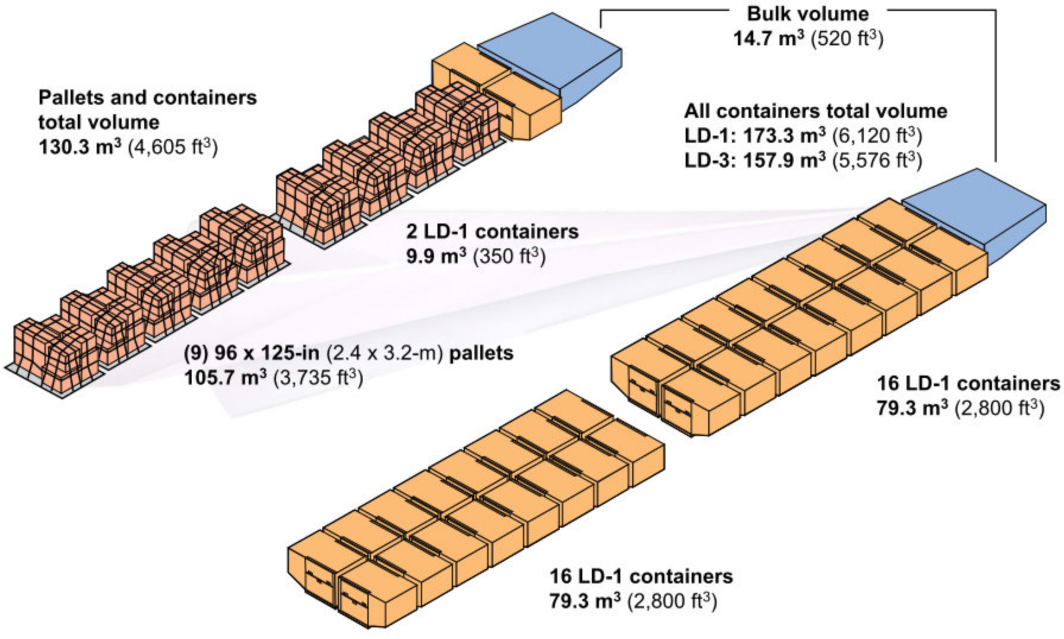

Figure C.6: Cargo arrangement for lower deck

The aircraft has loading limits throughout the hold. These loading limits are considered when the weight plan is made.

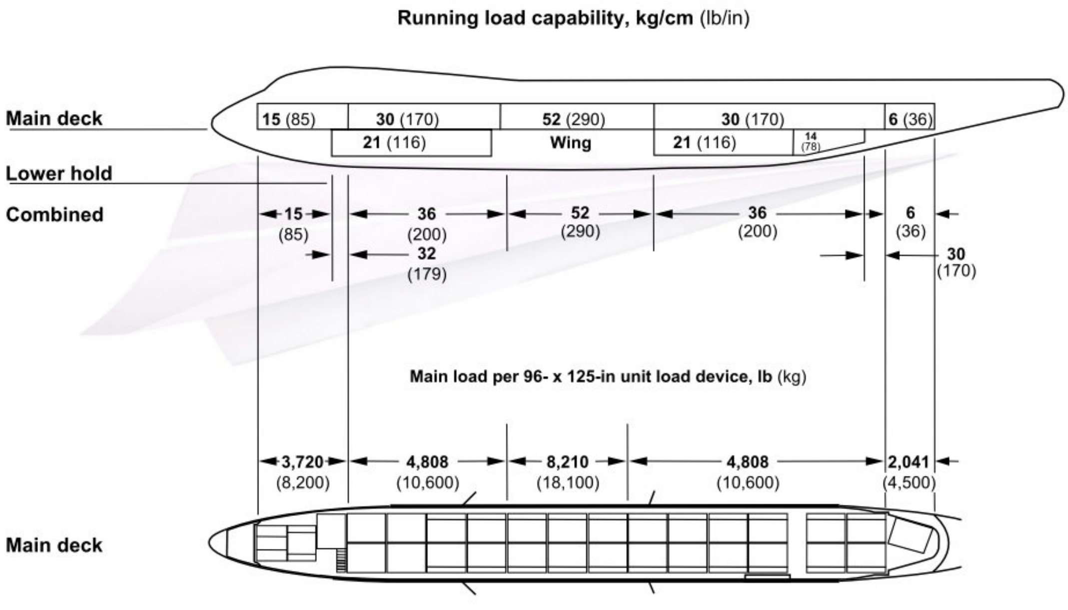

Figure C.7: Structural loading limits

D

HANDLING MANUALS

This chapter contains

- Aircraft Handling Manual for a Boeing 747-400 ERF
- Cargo Handling Manual for perishable shipments at KLM Cargo

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E

Characteristics of a Rose

For this project roses transported from Kenya are analysed. These roses have characteristics regarding the blooming phase and the end of vase life. These aspects are discussed in section E.1 and in section E.2 respectively.

E.1. Blooming phase of a rose

The perishable transported is a flower which has a limited shelf life. This shelf life is expressed as vase life, which is an important parameter for the customer. For a rose different blooming phases can be described, these phases are given in Figure E.1 for the Akito and Aqua rose. When harvesting the flowers the are checked on their blooming phase. Flowers that have reached blooming phase 2 are cut and are ready to be transported.

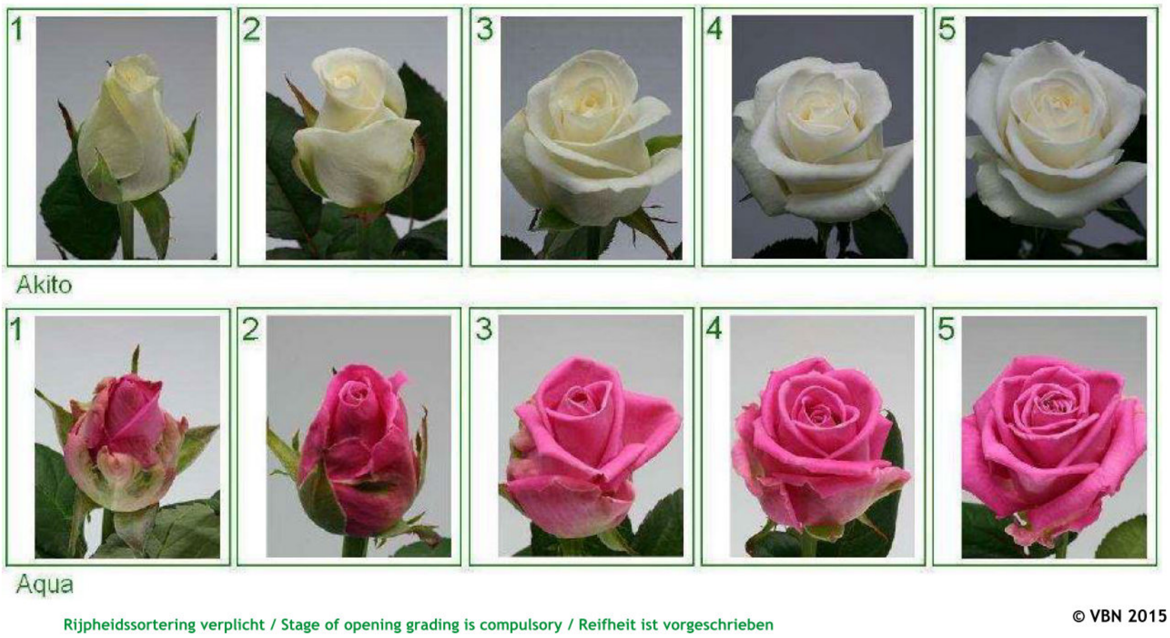

Figure E.1: Different blooming phases for the Akito and Aqua rose

E.2. End of vase life

The vase life is important for the end customer and there are several criteria when roses have reached the end of vase life. These criteria can be caused by several reasons and are explained below.

- **Bent neck:** A bent neck happens when the flower makes an angle bigger than 90 degrees. When a flower dries the peduncle can buckle.

- **Botrytis:** Botrytis, also written as *B. cinerea*, is a fungus that affects the flowers. The vase life ends when five or more petals are heavily affected by Botrytis. This leaves brown stems on the petals
- **Brown flower:** The petals of the rose can turn brown, not as a result of Botrytis. The vase life ends when five or more petals turned brown.
- **Blown roses:** A blown rose can occur when blooming phase 4 or 5 is reached. After this blooming phase petals will fall out or change color. The vase life ends when 2 petals have fallen out or when the flower is bent.
- **Wilting:** Wilting of the flower happens when the flower has reached blooming phase 3 as a maximum. As a result of wilting the flower stems are bent or petals are wrinkled.

An example of the fungus Botrytis is given in Figure E.2. In this figure it can be seen that the petals have turned brown. Flowers can get Botrytis after the harvesting phase. At this phase the stems are cut and roses are sensible to take up bacteria. To prevent this, roses are put in a post-harvest solution to prevent them from getting diseased.

Figure E.2: An example of a rose affected by Botrytis

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