A-pier Clean VOP:

Developing a strategy for on-time cargo delivery to the aircraft under clean apron conditions.

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Challenge the future

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by

T.M. van Rugge

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This thesis is confidential and cannot be made public until January 1, 2022.

Preface

This report is the result of my graduate internship at KLM Cargo at their hub at Amsterdam Airport Schiphol. It represents the final project to complete my Master's in Transport, Infrastructure and Logistics at the Delft University of Technology. During my internship I have been given the chance to discover the world of air cargo and to get involved in a number of projects, the largest of which was the A-pier project. The aim of my internship was to design new cargo handling strategies that would take into account the restrictions of the new regulations at the A-pier, and simulate their behaviour in order to identify the best strategy to implement.

My internship has been anything but ordinary and I am very grateful to those with whom I have worked together. I want to especially thank Drs. Bernard Holsboer for the opportunity to conduct my research at KLM Cargo and to explore the KLM organisation as an intern, as well as for his continued interest in my work and research even after his move to KLM Engineering & Maintenance. I would also like to thank Wim Kuipers for the support and guidance whenever needed, and for asking the right questions to keep me on my toes.

I would also like to take this opportunity to express my gratitude to my graduation committee from the Delft University of Technology: Dr. J.M. Vleugel, Dr. W.W.A Beelaerts van Blokland and Prof. dr. R.R. Negenborn. Their help, feedback and critical questions challenged me to think about the scientific relevance of my research and forced me to think broader than just KLM. Finally, I would like to thank my family and friends for their support, encouragement and understanding during all phases of my studies. Without them, I would not be in the privileged position I am today.

Enjoy,

Tim van Rugge
Schiphol, June 2019

Executive Summary

The aviation industry is growing. While airports are trying to increase their traffic numbers, they must often do so without increasing the size of the airport. This has led to airports finding ways to make optimal use of the space they have available, to maximise the number of flights they can accommodate.

Multiaircraft Ramping System (MARS) aircraft stands accommodate either one wide-body or two narrow-body aircraft at a time. This flexibility is beneficial to the airport as it allows for more aircraft at a given pier. However, due to the fact that the configuration of the MARS stand can change at any time, the stand must be clear of any cargo or baggage when there is no aircraft parked. This is referred to as the *Clean VOP* policy, and it means that cargo handlers may have to redesign their cargo handling procedures to ensure that cargo is not placed on a vacant MARS stand. Cargo handlers typically place cargo on the aircraft stand up to five hours prior to the aircraft's departure which, in some cases, is before the aircraft has arrived and has started its turnaround process. This would be considered a *Clean VOP* violation, which may lead to sanctions from the airport authority and must therefore be avoided.

At Amsterdam Airport Schiphol, the construction of the A-pier has commenced and is due to be completed by the end of 2020. The pier will feature five narrow-body aircraft stands and three MARS stands. The airport has decided it will introduce the *Clean VOP* policy at all aircraft stands of the A-pier. A centralised cargo buffer space will be provided directly underneath the pier to allow cargo handling agents to position their cargo in the buffer when the aircraft stand is vacant. The main cargo handler to be operating at the future A-pier will be KLM Cargo.

Since KLM Cargo regularly positions cargo on the aircraft stand prior to an aircraft's arrival, the introduction of the *Clean VOP* policy means current procedures will lead to many *Clean VOP* violations if left unchanged. This research explores a number of alternative cargo handling strategies for KLM Cargo in order to identify the optimal strategy to employ at the A-pier. The objective is to find a handling strategy which meets the *Clean VOP* requirements as well as the procedures laid out in the IATA Ground Operations Manual, and does not lead to a deterioration of the on-time performance. The DMADE process is used to define the problem, measure the current procedure, analyse the performance, design new handling strategies and evaluate their effectiveness. Discrete Event Simulation (DES) is used to model the system and test the effects of these different cargo handling strategies. The system performance in measured by the expected number of *Clean VOP* violations, the on-time performance, the maximum utilisation of the cargo buffer, the total distance driven by the cargo tugs, and the space required on the cargo premises for the handling of the cargo bound by to the *Clean VOP* regulations.

The strategies testing using the DES model consisted of a strategy using a pull system, one using a push system, another using a push-pull system, and two using a combination of either push and pull, or a combination of pull and push-pull. Input data consisted of the actual flight schedule along with a synthesised dataset for the cargo, specifying the amount of cargo assigned to each flight, as well as the time at which the ULDs would become available prior to the aircraft's departure. Each strategy was run 25 times for a simulated duration of one month. The results were averaged and analysed using the Analytical Hierarchy Process with weights assigned by KLM Cargo employees.

Results of the Analytic Hierarchy Process indicate that the optimal strategy to implement is a combination of push logic and pull logic; cargo made available before a flight's arrival is delivered to Apron Services (the ground handling agent) in the cargo buffer underneath the A-pier. Cargo made available *after* an aircraft's arrival is delivered to Apron Services directly at the aircraft stand. The strategy minimises the use of space on the shunting area on the cargo premises, while maintaining a high on-time performance and avoiding *Clean VOP* violations. The strategy does, however, require that KLM Cargo

and Apron Services improve their communication and collaboration, to ensure that no cargo is misplaced or forgotten, as rebooking cargo is costly and should be avoided.

The DES model and AHP was also used to measure the effect of moving the cargo delivery deadlines closer to the time of departure. The deadlines, currently at eighty minutes for intercontinental cargo and sixty minutes for European cargo, were shifted in increments of ten minutes until a minimum of fifty and thirty minutes was reached. Analysis pointed out that while the combination of push logic and pull logic is the optimal strategy to employ even if delivery deadlines are shifted twenty minutes closer to departure, moving the deadlines thirty minutes closer to departure led to a change in the strategy ranking. When cargo deadlines are fifty minutes for intercontinental cargo and thirty minutes for European cargo, the optimal strategy to follow is one utilising only pull logic. This would mean cargo is to be held on the cargo premises until the aircraft's arrival, at which point the cargo should be sent to Apron Services at the aircraft stand.

The proposed strategy has demonstrated to be the optimal strategy to employ at Schiphol's A-pier. However, at other piers and even at other airports, a different cargo handling strategy may lead to a better operational performance given the distance of the pier from the warehouse, the size of the shunting area, the number of aircraft stands, the number of buffer lanes, the flight schedule, etc.

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List of Abbreviations

AAS	Amsterdam Airport Schiphol
AGV	Automated Guided Vehicle
AHP	Analytical Hierarchy Process
AS	KLM Apron Services
DES	Discrete Event Simulation
ERA	Equipment Restraint Area
EUR	European (flight)
FB1/2/3	Freight Building 1, 2 and 3
GOMS	Ground Operating Manual Schiphol
GS	KLM Ground Services
GSE	Ground Support Equipment
IATA	International Air Transport Association
ICA	Intercontinental (flight)
IGOM	IATA Ground Operations Manual
KLM	KLM Royal Dutch Airlines *(Koninklijke Luchtvaart Maatschappij)*
KPI	Key Performance Indicator
MARS	Multiaircraft Ramping System
NB	Narrow-body (aircraft)
OTP	On-time Performance
PCHS	Pallet and Container Handling System
RTP	Real-time Planning
STD	Scheduled Time of Departure
UFT	Undisturbed Freight Transport
ULD	Unit Load Device
VOP	Aircraft Stand *(Vliegtuigopstelplaats)*
WB	Wide-body (aircraft)

Part I

Define

1

Introduction

In this chapter, the research performed for KLM Cargo is introduced. First the context will be described, followed by the future developments at Amsterdam Airport Schiphol which will lead to new rules and regulations. Next, the research problem will be defined, followed by the research objective, the research scope and the research questions. Finally, an overview of the approach and methodologies used for this research will be given.

1.1. Schiphol and KLM

The demand for air travel has been growing steadily over the last few years [2], along with the demand for air cargo [3]. Meanwhile, carriers are innovating to reduce costs or increase their competitive advantage, while airports compete with each other by increasing their capacity, facilities and passenger traffic [4][5]. Among them is Amsterdam Airport Schiphol (AAS), the third busiest airport in Europe [6]. With over 68 million passengers and nearly half a million aircraft movements in 2017, this major European hub airport is looking for ways to expand its business without increasing its footprint [7]. Cargo is also a crucial part of Schiphol's business; in 2016 AAS was the seventeenth busiest airport worldwide in terms of transported cargo tonnage [8].

In order to facilitate even more aircraft movements on a yearly basis, AAS has already started construction of a new pier; the so called *A-pier*. The new pier's purpose is to further increase the airport's capacity by adding five narrow-body (NB) gates on the north side, and three MARS[1] stands on the south side which can each be used as a gate for a wide-body (WB) aircraft, or *two* NB aircraft [9][10]. This means the pier can accommodate anywhere from eight to eleven aircraft at any time. Construction commenced in 2017 and the pier is due to be operational by December 2020 [11]. At a later stage, the pier will be expanded in order to accommodate two additional wide-body aircraft (or four narrow-body aircraft) on the south side. This research, however, assumes the former variant.

KLM Royal Dutch Airlines (KLM) was founded in 1919 and is based at Schiphol. Since its founding, the airline has grown and has expanded its network tremendously. Now that KLM is a part of the Air France–KLM Group, the global network has over 450 destinations in 157 countries [12]. The group's dedicated air cargo branch, Air France KLM Martinair Cargo (KLM Cargo), operates from both Paris Charles de Gaulle and AAS, transporting over one million tons of freight on a yearly basis [13]. Besides full freighters, KLM Cargo also handles freight in the belly of passenger flights or, in the case of the 747 Combi fleet, on the main deck behind the passenger cabin[2]. The A-pier will be predominantly used to serve KLM and other Skyteam partner airlines, meaning that ground (and cargo) handling will be done almost exclusively by KLM.

At present, outbound freight which has been processed by the *pallet and container handling system* (PCHS) in the cargo warehouse is placed onto a dolly, whereas mail and express parcels processed by the sorter are placed on a bulk cart. The dollies and carts are then placed outside on the shunting area on the airside of the warehouse in order to form a train with up to four other dollies and/or carts

[1] Multiaircraft Ramping System

[2] KLM will retire its 747 passenger and combi fleet by the end of 2021 and operate single-deck passenger aircraft and three 747-400 ERF full-freighter aircraft. [14]

destined for the same aircraft. Once a tug has picked up the train, the freight is typically delivered to the apron one to five hours prior to the aircraft's scheduled time of departure (STD). Special cargo, such as live animals or valuable goods, are only brought to the aircraft when it is due to be loaded, and is thus never brought to the apron ahead of time. In all cases, cargo is delivered to the aircraft stand and responsibility over the cargo is transferred to Apron Services. No communication is required between the departments for this step, since all cargo is placed on the aircraft stand. Although delivering the vast majority of cargo to the aircraft stand well ahead of the STD is something which has proven to be effective for many years, Schiphol wishes to explore the possibilities of an alternative.

Silo Mentality

The silo mentality occurs when there is a lack of communication between various departments within an organisation. When departments share no (or limited) information with each other, this may lead to redundancies, inefficiencies, a lack of transparency and/or departments pushing responsibilities onto other departments [15].

At a large organisation such as KLM, with over thirty thousand employees, silos form naturally. Departments make decisions and create systems and programs to manage their own processes as efficiently as possible, but may not always communicate and/or share information with other relevant departments. One such an example is the (lack of) collaboration between KLM Cargo and Apron Services. These departments can be seen as two separate silos within the KLM organisation. Although Apron Services is an internal customer of KLM Cargo, very little information is shared between the two departments. Generally, communication between the departments is only established in the case of irregularities. In order to optimise processes within the supply chain and improve the efficiency of both departments, a constant exchange of information would be required.

In order to rid the company of the silo mentality, communication must be restored between the departments. One way of achieving this is to create a unified vision for both departments. This vision provides a common goal to work towards, and allows for the departments to work together to form a plan on how to achieve this goal [16]. This may also require an investment to create an interface for seamless automated communication, but by finding win-win situations which benefit both departments, the advantage of working together can be felt. This is expected to stimulate the departments to continue communicating and working with each other, avoiding the silo mentality altogether.

1.2. Clean VOP

At the new A-pier, AAS is implementing the so-called *Clean VOP* principle. This means that the aircraft stand (vliegtuigopstelplaats; VOP) must be clear of any rolling stock (carts and dollies) whenever there is no aircraft present. This policy will allow the airport to be more flexible in its gate usage at the A-pier, while avoiding unsafe situations of rolling stock colliding with an aircraft due to cargo being placed incorrectly on the aircraft stand. While the increased safety and orderliness of the platform is a clear benefit, the downside to the *Clean VOP* regulation lies in the fact that some cargo must be delivered to the aircraft stand later than is currently done, while the delivery deadlines remain unchanged. This means the time window for cargo delivery to the aircraft stand is reduced. Since Schiphol is KLM's hub, there are a number of arrival and departure banks throughout the day in which many aircraft arrive or depart simultaneously. This maximises the number of (short) connections between flights, but has the consequence that there are numerous daily outbound peaks meaning much of the cargo has delivery deadlines very close to each other [17]. Delivering the cargo to the aircraft shortly before the deadline would require a large workforce, so KLM Cargo uses peak spreading to more effectively use their workforce. By delivering cargo earlier than necessary, the peaks are more spread out leading to a lower peak workload [18]. With the implementation of the *Clean VOP* at the A-pier, delivering cargo to the aircraft stand earlier than necessary for the sake of peak spreading is not allowed prior to the aircraft's arrival. While not confirmed by AAS, many stakeholders involved in the implementation of *Clean VOP* at the A-pier believe that the concept may be introduced at other piers if it proves to be successful at the A-pier.

Currently, trains of cargo dollies and bulk carts are placed on the right side of the aircraft stand, in some cases before the aircraft arrives. This area is illustrated in figure 1.1 as the white hatched area between the aircraft stands labelled *10*. This white hatched area will not be present at the A-pier, which means cargo can only be delivered to the aircraft after the aircraft has arrived.

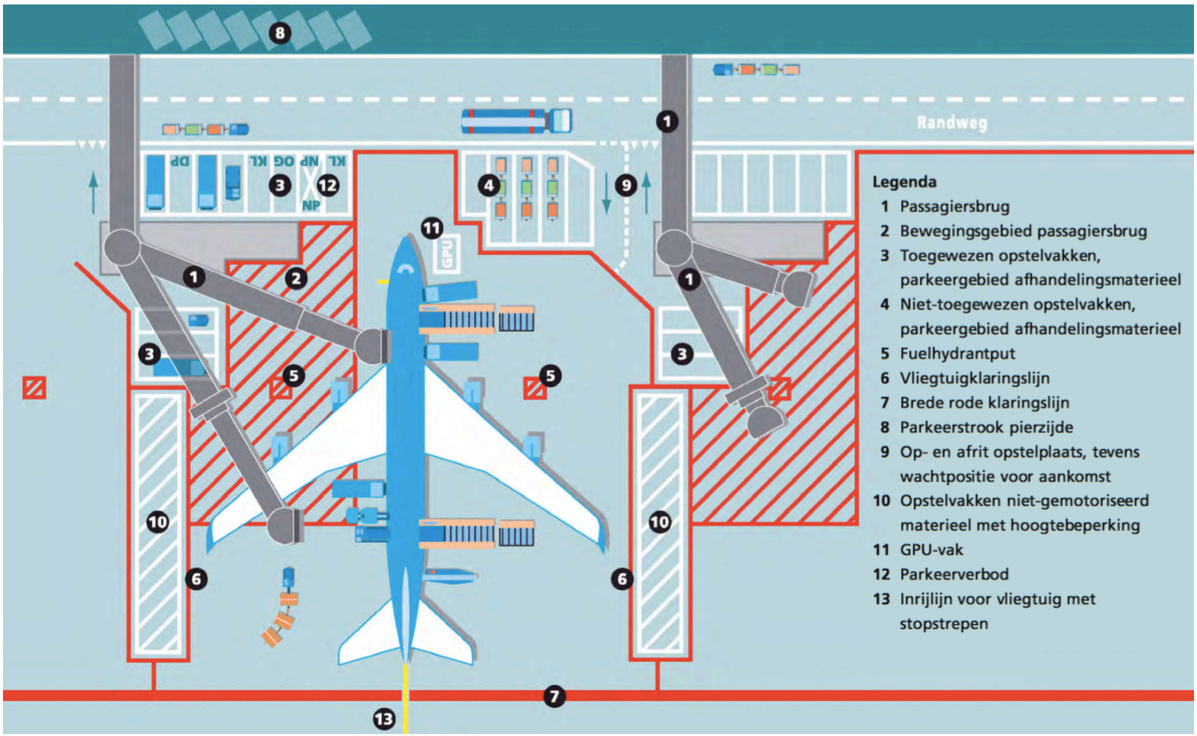

Figure 1.1: Layout of the aircraft stand, or *VOP* [19]

It is not possible for KLM Cargo to deliver all A-pier freight between the aircraft's arrival and the cargo delivery deadline due to space and capacity constraints of the PCHS and the shunting space. To facilitate a new handling strategy, AAS will provide a cargo buffer underneath the A-pier so that cargo handlers can more easily meet the *Clean VOP* requirements. This buffer consists of thirteen lanes of at least 3 metres wide, separated by barriers, and two lanes of 2 metres wide, with a drive through lane in between. This is shown in figure 1.2, where lane numbers 21 and 22 are the narrower lanes suitable for narrow cargo only. However, if and how this buffer will be used is entirely up to KLM Cargo. The buffer is assumed to be a given; construction has already commenced and changes to the dimensions of the available space are no longer possible.

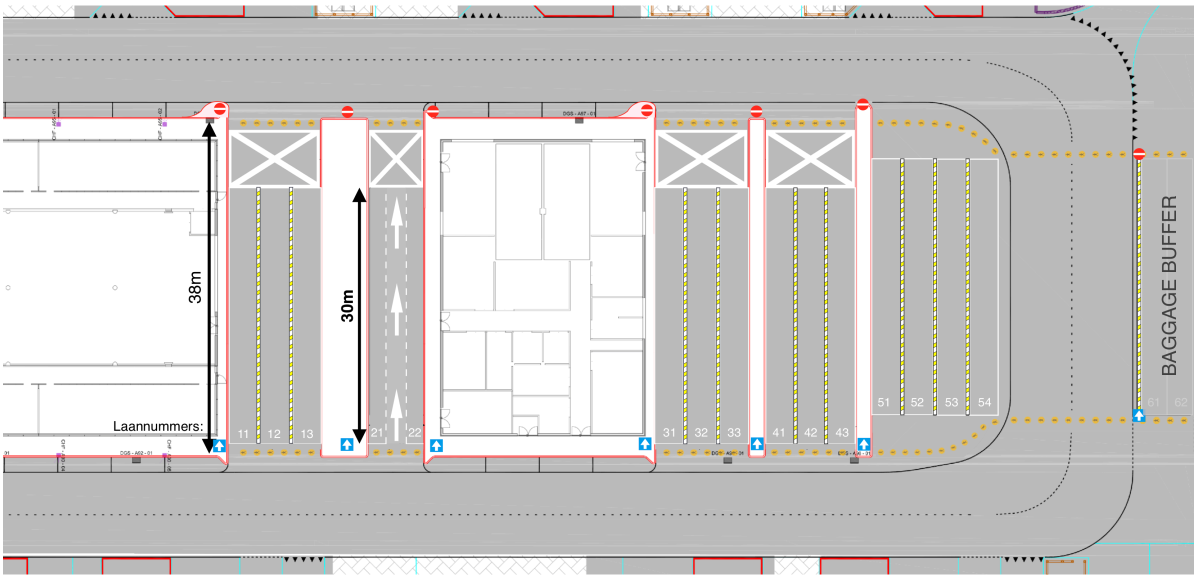

Figure 1.2: Buffer space under and around Schiphol's A-pier

1.3. Research Problem

With the opening of the A-pier, KLM Cargo will face new (stricter) regulations regarding the placement of cargo on the aircraft stand. These *Clean VOP* regulations will reduce the time window in which cargo may be delivered to the aircraft stand, putting a higher pressure on KLM Cargo's transport department. Currently, peak spreading is used to ensure that all cargo is delivered on time with the workforce and the equipment available. However, peak spreading may not be (sufficiently) possible if *Clean VOP* were to be introduced throughout the airport; the current cargo handling strategy would violate the *Clean VOP* regulations imposed by the airport authority.

1.4. Research Scope

The scope of this research is confined to the processes between the cargo being processed in the cargo warehouse and it being loading onto the aircraft, as shown by the blue line in figure 1.3. Preceding steps in the handling process are largely dependent on inbound trucking (or flights). Later steps, such as loading cargo onto the aircraft, are not KLM Cargo's responsibility; this is carried out by Apron Services.

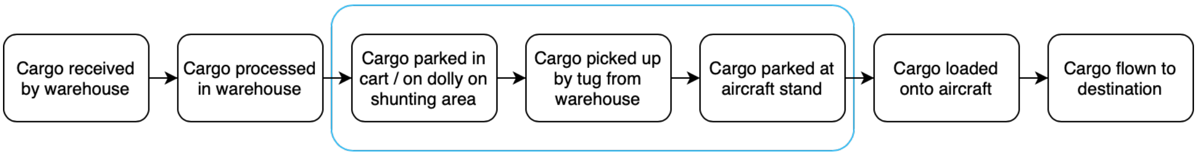

Figure 1.3: Scope of the research as part of the current outbound cargo process

The inbound process falls outside of the scope of this research. Although inbound cargo must be retrieved before the departure of the aircraft (in order to comply with the *Clean VOP* regulations), data shows that inbound cargo is picked up swiftly after unloading and KLM Cargo has indicated that this should not be taken into account.

Additionally, the research is limited to the freight transported by KLM Cargo only. Other ground handlers will not be taken into account. Although the A-pier buffer space will not be reserved exclusively for KLM, the pier will serve Skyteam airlines meaning the vast majority of flights will be handled by KLM.

1.5. Research Objective

The theoretical aspect of this research lies in providing insight into cargo ground operations can be reshaped to account for a *Clean VOP* policy, while maintaining a high on-time performance. A new handling strategy with or without a centralised buffer system may contribute to keeping vacant aircraft stands clear from carts and dollies to allow for larger aircraft, MARS stand operations and increased safety on the apron. This concept has not been implemented in any other major hub airport, but may prove to be a safer and more efficient means of handling air cargo and baggage. Identifying an optimal ground handling strategy to account for the *Clean VOP* policy will allow airlines to operate on MARS stands without harming the cargo's operational performance.

The practical objective of this research is to determine how KLM should redesign their cargo handling strategy for Schiphol's A-pier, where AAS will introduce the *Clean VOP* regulations. With the availability of the cargo buffer described above, this research will design a number of handling strategies and evaluate them as a multicriteria decision problem. The aim is to identify the strategy which does not lead to a deterioration of KLM Cargo's on-time performance, does not violate the *Clean VOP* policy, minimises the space used on the cargo premises, and minimises the distance driven with the cargo tugs. Furthermore, the solution is bound by a number of constraints. Finding and implementing the strategy which meets these requirements will allow KLM to operate its flights at the A-pier, while abiding by the airport's regulations and maintaining a high level of performance in terms of cargo operations.

1.6. Research Questions

In order to reach the objective, the following question will serve as the overall research question:

How can KLM Cargo maintain its on-time performance under Clean VOP regulations at Schiphol's A-pier, given the available buffer space underneath the pier?

This question will be broken down into a number of subquestions, namely:

1. What strategies and technologies are used for buffering and/or help in facilitating on-time deliveries at other airports or in other industries?
2. How is cargo currently transported from the warehouse to the aircraft, and why is this process insufficient for operations at the A-pier?
3. How does the current cargo handling system perform in terms of punctual cargo deliveries to the aircraft stand?
4. How do different handling strategies affect the performance of outbound cargo transportation under *Clean VOP* regulations?

1.7. Research Approach

Six Sigma is a business philosophy which aims to reduce the variation in production in order to increase the product quality and customer satisfaction. The standard six sigma methodology used to improve business processes is the DMAIC model, where DMAIC stands for Define, Measure, Analyse, Improve and Control [20]. The method represents a structured approach to implementing incremental improvements after a problem has been identified and measured, in order to improve the quality of production [21]. In this case study, however, an entirely new process is designed for a new airport pier. For this reason, DMAIC is unsuitable and instead the DMADE methodology will be used to answer the research questions.

The DMADE methodology is suitable for the design of a new process such as the cargo handling procedure at the A-pier under new regulations [22]. Since addressing one issue may lead to the identification of a new issue, the methodology is used iteratively. For this reason it is often depicted as a cycle which leads to continuous improvement of the business, as shown in figure 1.4.

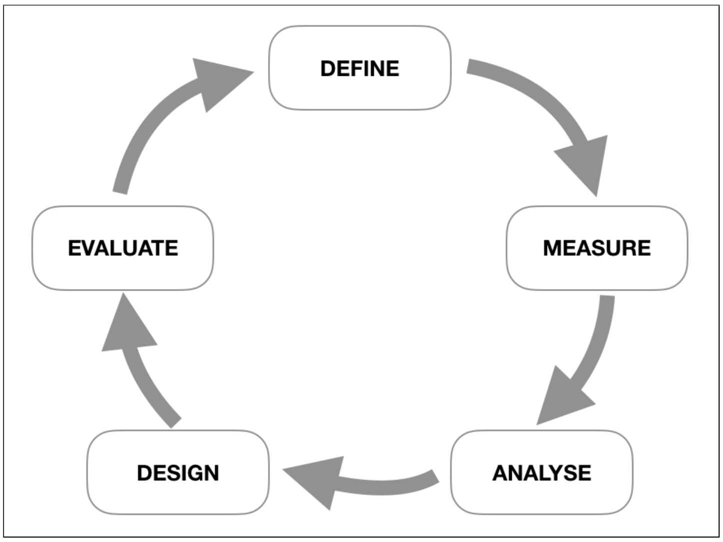

Figure 1.4: The DMADE cycle

Define: First, the context is described and KLM Cargo's problem is defined and demarcated.
Measure: In the second phase, the performance of the current system is measured. This determines the baseline of the process and allows for a comparison between the current and improved processes.
Analyse: The process of the current system is analysed, which allows for the root cause of the problem to be identified.
Design: In this phase, the process is improved by eliminating the cause of the problem. This may be done by designing a number of variants and testing their predicted effects on key performance indicators.
Evaluate: Finally, the variants must be ranked and the best strategy must be chosen and evaluated.

This approach can be visualised as a cycle as shown in figure 1.4. In this design cycle, the first three steps focus on the current system in order to define the problem and localise the root cause of this problem in the current process. Step four and five focus on an improved process which addresses this problem, and evaluating its expected effectiveness.

1.8. Research Methodologies

In the *measure* phase, the process of the air cargo transportation between the warehouse and the aircraft will be studied using the User Observation method as described in the Delft Design Guide [23]. This method is chosen since it is an effective means of uncovering tacit knowledge from employees with years of experience, which is necessary since not all aspects of the transportation processes at KLM Cargo are fully documented. Using the knowledge gained from this method, the handshakes within the process (i.e. the transfer of responsibility between parties) can be illustrated using a swimlane diagram. A swimlane diagram is an effective means of showing the steps in the process and the actor which is responsible for each of these tasks.

In order to determine the performance of the current system, historical data of KLM Cargo's outbound cargo flows in 2018 will be analysed. This will provide insight into the number of ULDs per flight, the times at which these ULDs became available after warehouse processing, as well as the on-time performance of the cargo deliveries to Apron Services. This data provides a performance benchmark to which future handling alternatives can be compared. Excel and MATLAB will be used to synthesise new random datasets based on distributions fitted using the empirical data. These datasets will subsequently be used to generate a flight schedule for the A-pier including the number of ULDs to be transported on each outbound flight, and an arrival table indicating when these ULDs become available for transport at the cargo warehouse.

Discrete Event Simulation (DES) will be used to create a simulation model of the system, including the buffer lanes which are to be built underneath the A-pier. The generated datasets will allow for the simulation of the future A-pier without the *Clean VOP* policy enforced. This means the model will represent current procedures followed by KLM Cargo's transport department, of which the results can be used for validation of the model.

After the current performance is analysed, the requirements for future procedures will be defined. These requirements will lead to a design envelope in which a number of strategies can be defined, based on the theory discussed in this chapter. These handling strategies can then be simulated using the DES model. Results of the model will be analysed using the Analytical Hierarchy Process (AHP). Using the weights assigned by the AHP, the best strategy to employ for the delivery of air cargo to the aircraft will be determined, which will address the research gap defined in section 2.7 and allow for the main research question to be answered. The reasoning behind the use of these methodologies is discussed in section 2.5.

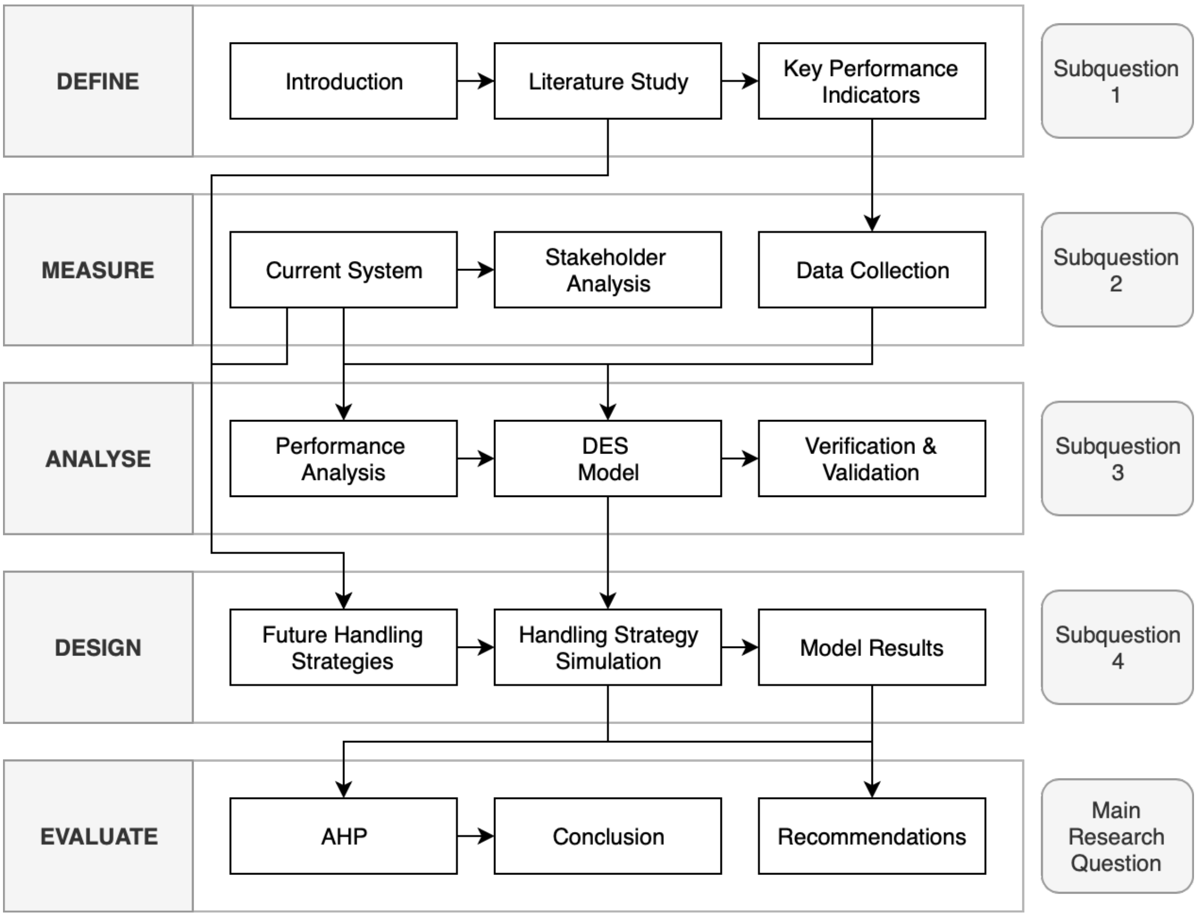

Figure 1.5: Thesis structure outline

In chapter 2, relevant theories and technologies employed in comparable industries will be explored in order to determine which may be of use to the A-pier project, as well as what problems there is not yet a solution for. This addresses subquestion 1. In chapter 3, the current process of transporting air cargo from the warehouse to the aircraft is discussed along with the identification of stakeholders and key performance indicators, addressing subquestion 2. Then, the 2018 data will be analysed in chapter 4 and a discrete event simulation model will be developed to simulate the current system and its performance. This addresses subquestion 3. Next, in chapter 5, requirements and constraints for the future process are discussed. A number of alternative handling strategies are defined and subsequently simulated using the DES model to give answer to subquestion 4. Then, in chapter 6, the analytic hierarchy process will be employed to score and rank the handling strategies based on the simulation results, and conclusions will be drawn in chapter 7, which will provide an answer to the main research question, as well as an evaluation of the model used to arrive at these conclusions. Furthermore, recommendations for future research and practical recommendations for KLM will be made.

2
Literature Review

The air cargo handling process has similarities with a number of other industries and may make use of technologies found in other sectors. Some of these industries will be explored in order to determine whether these may be relevant to the air cargo ground handling process and how they can help in delivering cargo to the aircraft stand under *Clean VOP* regulations. This will address sub-question 1.

2.1. Previous research at KLM

Oorsprong [24] designed a number of phases for the turnaround process at the A-pier. He argued this was necessary to improve the turnaround time and the safety on the apron and opted to separate the aircraft stands with a service road, increasing accessibility, visibility and overall safety). Cargo would be driven into one of two scan lanes in the buffer, which would scan the cargo and assign one of the fifty-four lanes for the cargo to be parked in. Next, an autonomous tug would pick up the cargo from the assigned lane and transport it to the aircraft when necessary. This, however, was a long term ideal solution which does not take today's constraints into account. It does, however, indicate that there is a goal to implement autonomous vehicles on the airside of the airport in order to increase safety and potentially reduce the operating costs as a result of a smaller workforce.

Verkade [25] compared the *Clean VOP* concept at Schiphol to similar implementations at other airports. Arlanda Airport in Stockholm, for example, removed all ground support equipment (GSE) from the aircraft stand and used underground systems to facilitate the turnaround process of the aircraft. This system is no longer in use, however, since it was not suited for winter weather and was only compatible with one type of aircraft. This system would not work at Schiphol, not only because winter weather is not uncommon, but most of all because the aircraft stands must be able to accommodate a wide variety of aircraft. Some other major airports, including London Heathrow, Frankfurt and New York JFK, do prohibit rolling stock form being placed on a vacant aircraft stand, but cargo handlers have no issues with positioning cargo since there is ample parking space around the aircraft stand, meaning that cargo can be positioned at any time without causing a *Clean VOP* violation.

Verkade ran a pilot of the *Clean VOP* at Schiphol in 2017. In this pilot, tug drivers were instructed to park the ground support equipment and the cargo in front of the aircraft in designated parking spaces rather than on the right hand side of the aircraft (similar to the *Clean VOP* found at Heathrow, Frankfurt and JFK). The pilot concluded oftentimes the supplied buffering space was insufficient and that cargo was parked on service roads in cases when it could not be positioned on the aircraft stand. However, many tug drivers also noted that, even during the pilot, not all parties met the *Clean VOP* requirements since in many cases ground support equipment was parked on the aircraft stand, violating the *Clean VOP* principles. They noted that if the *Clean VOP* were to be fully implemented, enforcing the rules would be necessary in order to avoid misconceptions and safety issues [17]. It was also noted that the difference in procedures was confusing for some tug drivers, and that uniform procedures across the airport would be preferred. Now that the definitive decision has been made to introduce the *Clean VOP* policy at the A-pier, handling procedures should be redesigned such that KLM Cargo's operations respect this policy. This may be measured by predicting the number of ULDs which would violate the *Clean VOP* principle on a monthly basis.

2.2. Air Cargo Operations

Worldwide, air cargo arriving by truck at any airport is handled in a similar way. Before the truck is unloaded by the airline's handling agent, it passes through documentation and it is screened by security [26]. The truck is then unloaded in the handling agent's cargo warehouse where the freight is built up onto a pallet suitable for air transportation. This pallet is then put onto a dolly which is picked up by a tug. The tug then transports this dolly to the airport's airside in order to drive it to the aircraft stand from which the flight will depart. The cargo is parked on the aircraft stand and left there until it is to be loaded onto the aircraft. This is done by the aircraft handling agent contracted by the airline (or in the case of hub airports, the airline's own aircraft handling department). The cargo's specifications such as weight and dimensions are verified before the cargo is loaded onto the aircraft [17].

The International Air Transport Association (IATA) has defined certain suggested operating procedures for many aspects of airport operations. For ground operations, the IATA published the *IATA Ground Operations Manual* (IGOM) which, as the name suggests, is a manual for many of the ground handling procedures at an airport. In terms of cargo logistics, the IGOM contains information on the acceptance of cargo, mail handling, cargo storage and preparation for flight, information/data transmission to load-control, and surface transportation. Procedures for the aircraft handling are specified as well, with section 4.1.2.3 specifying that no obstructions may be placed inside the Equipment Restraint Area (ERA; indicated by the red line on the aircraft stand) when an aircraft is arriving at or departing from the aircraft stand. While this suggests a policy comparable to the *Clean VOP* , it does not take MARS stand operations into account; the two narrow-body positions on a MARS stand do not have separate ERA markings. For this reason, the *Clean VOP* policy could be considered to be somewhat stricter than the IATA procedures found in the IGOM.

For cargo handling at the A-pier, IGOM sub-chapters 3.4 (storage) and 3.7 (ground transportation) are of special interest, and must be taken into account when designing new handling procedures for cargo destined for aircraft at the A-pier. Using an intermediate buffering space is allowed, as outlined by IGOM section 3.4.2.b. When makein use of the intermediate buffering space, however, the final point in IGOM's sub-chapter 3.4.1 is especially relevant: "Make sure that once cargo has been put in the storage area, its location is recorded and that all the information, as well as the location of the cargo, is correctly communicated for ease of retrieving the cargo when required" [27]. In short, if the cargo tug driver delivers the train of dollies to Apron Services at the A-pier buffer instead of at the aircraft stand, it is imperative that a system is put in place where KLM Cargo and Apron Services can communicate the location of the cargo so that it can easily be retrieved once the cargo is due to be loaded.

Checking the cargo for airworthiness after ground transportation is also a vital part of the ground handling process as described in IGOM 3.7.1 [27]. Depending on where the responsibility of the cargo is handed over to Apron Services, the cargo must be visually inspected by the tug driver of KLM Cargo or Apron Services, depending on which party transports the cargo to the aircraft. The buffer underneath the A-pier does not provide sufficient space between the cargo trains to allow for visual inspections, nor would it be effective since cargo must be inspected again once it has been driven to the aircraft stand.

In 2016, KLM Cargo's transport department started using *Real-time Planning* (RTP) to generate tasks for cargo rides between the cargo warehouse and the apron. Tug drivers see a list of tasks ordered by delivery deadline, and are able to select which cargo they wish to drive. Cargo with an earlier scheduled departure time has priority over cargo with a later scheduled departure time in order to maintain a high on-time performance. Cargo not delivered on time runs the risk of not being loaded onto the aircraft, meaning the cargo will have to be rebooked onto another flight. While on one hand this may cost the airline in terms of service and reputation, the direct cost associated with rebooking cargo and not being able to sell the cargo space is also a significant driver for ensuring cargo flies as planned [28].

Besides on-time performance, a number of additional performance measures were defined by Tabares et al. [29] for aircraft ground handling. These included the number of resources required, avoiding aircraft damage, and personnel incident and accident avoidance. Maximising on-time performance may in many cases be contradictory to minimising the number of resources used, but since both are important performance measures, a balance must be found such that both values are at an acceptable level.

Airport Baggage Handling

Baggage at Schiphol is brought to the aircraft stands by a tug pulling a maximum of six baggage carts. A striking difference with the cargo process is the fact that baggage is almost exclusively driven to the aircraft stand when the aircraft it is destined for has started its turnaround process. For air cargo, on the other hand, it is not uncommon to deliver the dollies with freight to the apron four to five hours before the scheduled departure—well before the aircraft has arrived—and in some cases even while the aircraft stand is still occupied by another aircraft. Since baggage in most cases only leaves the underground baggage handling facility once the aircraft is at the aircraft stand, there is no need to buffer the baggage in the case of *Clean VOP* and it may be brought directly to the aircraft. For the few exceptions where outbound baggage must leave the baggage handling facility before its aircraft has arrived, two buffer lanes are reserved for baggage storage. These lanes are opposite the cargo buffer on the other side of the airport road, and are not included in the number of lanes available to KLM Cargo.

One buffer which is currently in use at KLM is the cold storage buffer. This buffer is used to store incoming transfer baggage with a long transit time, in order to reduce the peak load on the baggage handling system. The incoming transfer baggage is held on this buffer until the baggage needs to be loaded into the baggage handling system for it to be sorted to its onward flight(s). This buffer is manned by a KLM Baggage Services employee who keeps track of baggage coming into the buffer and is responsible for sending the baggage out on time. This buffer has sufficient capacity to also handle the incoming baggage of the A-pier. No modifications are required in this regard.

Air Quality

A 2005 study on Hartsfield-Jackson Atlanta International Airport's emissions found that ground support equipment accounted for more than 8% of the total airport emissions per year [30]. This is illustrated in table 2.1. Although aircraft movements account for the majority of the emissons, reducing the emissions by GSE can benefit the local environment and working conditions. AAS and KLM both wish to improve the sustainability of their operations and minimise the impact on the local environment [31]. One means of achieving this is by replacing the fleet of vehicles with internal combustion engines with vehicles driven by electric motors. Although KLM has started to replace some of the GSE with electric variants [32][33], all of KLM Cargo's tugs transporting freight between the warehouse and the apron are (still) diesel powered. Reducing the movement of these tugs by minimising the total number of rides required to transport all cargo will contribute to the reduction of particulate matter and nitrous oxide emissions [34].

Table 2.1: 2005 air emissions at Hartsfield-Jackson Atlanta International Airport (tons per year) [30]

Pollutant	**Aircraft** [tons per year]	**GSE** [tons per year]	**Total** [tons per year]
CO	5204	584	5,788
NO_x	4,910	343	5,253
SO_2	473	46	519
VOC	1,013	43	1,056
PM_{10}	101	30	131
$PM_{2.5}$	70	27	97
Total [tons]	11,771	1,073	12,844
Percentage	91.6%	8.4%	100.0%

2.3. Automated Guided Vehicles

At present, all traffic movements on the airside of Schiphol are conducted by human drivers. The future, however, may have a significant percentage of vehicle movements performed by automated guided vehicles (AGVs). Heathrow tested AGVs in the cargo process on the airside and has expressed interest in expanding AGV technology across the airport, saying that throughput time and overall efficiency are the main reasons for considering this technology [35]. At London Gatwick, trials will be held to shuttle staff around the airport using autonomous vehicles. The system would become an on-demand service similar to platforms such as Uber and Lyft [36] in order to increase the utilisation of the vehicle fleet, since 90% of the vehicles are said to be stationary at any one time [37]. Firstly though, the technology will be tested thoroughly to ensure it is sufficiently safe to be employed in an airport environment.

In the Netherlands, Rotterdam The Hague Airport has recently launched a pilot involving AGVs used to sort baggage in the baggage handling facility. The main benefits of this application include that is it easily scalable, fixed conveyor belt infrastructure required is drastically reduced and a lower energy consumption is realised as a result [38]. This system of AGVs, however, is located in a closed environment and the AGVs therefore do not have to interact with other (regular) vehicles as would be the case on the apron. If a system were to be implemented at Schiphol to transport cargo between the cargo warehouses and the aircraft, the AGVs would need to be able to safely interact with humans and other vehicles since there are many types of vehicles from different companies and organisations driving on the airside of the airport.

Many ports around the world, including the Port of Rotterdam, utilise such AGVs to transport maritime containers between the ship and the stack. Rotterdam has had AGVs in operation for over 25 years and is constantly looking for ways to improve the use of such vehicles. New AGVs are to be 100% electric, as well as more efficient and less noisy than its predecessors [39]. The AGVs avoid collisions with humans and other vehicles, but are still located within a relatively controlled environment with rather homogeneous traffic flows. Similar situations occur in other industries such as distribution centres where AGVs have demonstrated to be a safe, efficient and reliable solution in these controlled environments [40].

AAS is known for its strong innovative character; it was named the most innovative airport in 2017's Future Travel Experience Europe Innovation Awards [41]. In order to maintain its position as a competitive and especially as an innovative airport, the exploration of AGVs on the airside is imperative. The use of AGVs allows for a smaller workforce and has the potential to create a safer and more efficient work environment. Additionally, emissions would be reduced when a fleet of 100% electric AGVs are to be used. Although this technology has not been implemented on a full-scale at any airport, it is a possibility and an opportunity which is currently being explored at a number of airports since it has the potential to decrease operating costs (due to a smaller required workforce), lead to smaller fleets of vehicles, improve air quality and increase safety.

However, automating GSE also presents many challenges, both practical and scientific. As mentioned, one of the biggest challenges is the ability to have automated and manual systems co-exist in the complicated environment that is an airport's airside. Since the traffic cannot be automated in the short term, there will need to be a transition period during which both can work side-by-side simultaneously. Government and/or airport authority regulations also, in many cases, do not allow fully autonomous vehicles on the apron, and airlines are typically known for their cautious operational innovations since "failure is not an option" [29].

Undisturbed Freight Transport

Van der Heijden et al. [42] describe a hypothetical system of AGVs running through an underground tunnel network between Hoofddorp, the flower auction in Aalsmeer and the cargo terminals at Amsterdam Airport Schiphol. This system of undisturbed freight transport (UFT) has the benefit that it reduces congestion caused on the public roads, as well as that it itself is less sensitive to congestion caused by external factors, leading to a higher rate of punctuality. Implementing a comparable underground system between the cargo terminals and the aircraft stands would most likely increase the reliability of the travel times as well as increase the overall punctuality.

There is, however, a high cost to such a UFT system. The investment in the infrastructure is expensive due to the fact that much of the time the infrastructure will have to be built underground [43]. Although this is feasible in rural areas between urban areas, doing so at an airport environment poses many challenges due to the many underground systems already present at an airport, one of which is the network of fuel lines used for aircraft refuelling on the apron.

2.4. Other Industries

Other industries use technologies and theoretical concepts which may also be used in the air cargo processes. Below, maritime container terminals, railway yards and flower auctions are examined to determine to what extent the experience of these industries can contribute to cargo processes in an airport environment:

Container Terminals

Shipping container terminals use so-called *stacks* to buffer containers which need to be loaded onto a ship which hasn't moored yet. Since containers can be vertically stacked, a stacking strategy must be chosen. This is because although putting a container on top of another container is an efficient use of the space available, it does mean that the container underneath is less accessible. Using stacking strategies, an approach to stacking may be chosen which works best for the port. With category stacking, containers of the same category are stacked on top of one another. With the residence time strategy, containers are stacked specifically such that the top container has a departure time earlier than the containers below it. This reduces the need for reshuffling, which is the process of moving containers to another stack in order to reach a container underneath [44]. Apart from stacking strategies, the location of the containers must also be taken into consideration. The yard may be divided into import and export areas, certain yard areas may correspond with a specific berthing place, or stacking location may be assigned stochastically in real-time. These are considerations which are also relevant to the A-pier buffer; whether certain lanes correspond to certain aircraft stands or whether these are assigned or chosen in real-time. In essence, this is a trade-off between simplicity and flexibility/capacity. Saanen & Dekker suggest that while it is a bad idea to have fixed destinations for certain containers within the yard, it is beneficial to have the containers stacked near their berth of destination [45]. In the context of the A-pier, this means that while lanes should not be assigned to a fixed aircraft stand, the cargo should be buffered near the aircraft stand (i.e. in the A-pier buffer) and not at another part of Schiphol.

One key difference between container stacking and cargo dolly buffering is the fact that air cargo cannot be stacked and lanes are one-directional. This means that it is not possible to park a train of dollies *behind* another train in the same lane, since the tug would have no means of exiting the lane with barriers on either side. Additionally, reversing a train of dollies is not possible. This means that each lane is limited to one dolly train, regardless of its length.

Another consideration in shipping yards is *housekeeping versus immediate final grounding*, which means either placing the container anywhere and moving it to another location later on, or finding the 'final' location for the container and moving it there immediately in order to prevent it from being moved later on. The benefit of housekeeping is that productivity is higher; containers are placed in a certain location quickly only to be moved to their final location later on. In the case of immediate final grounding, the extra move is eliminated, which reduces costs. However, it means that a different strategy must be employed in order to move all containers to the correct location straight away [45]. In the case of the A-pier, housekeeping could be comparable to initially moving the cargo to the buffer, only to move it to the aircraft stand at a later stage. Similarly, immediate final grounding could be interpreted as positioning the cargo at the aircraft stand straight away; something which may only be done after the aircraft arrives at the gate.

Railway Yards

Dollies destined for the same aircraft are placed on the shunting area on the airside of KLM Cargo's warehouse in order to be transported together in one train (with a maximum length of 5 dollies). This shunting is done on parallel lanes in order to maintain overview and to maximise the capacity of the space. A similar situation can be found at Prorail's hump yard, *Kijfhoek*. In this yard, cars of incoming freight trains are automatically sorted onto various tracks by destination in order to make up a new train. This is done using a technique known as *gravity shunting*; decoupled cars are *pushed* slowly over a hump. When at the top of said hump, gravity causes the cars roll down one by one. The yard sorts the rolling stock automatically using its switches and uses retarders[1] to ensure the cars do not collide with a high velocity [46].

Theoretically, a similar technique could also be used for cargo expelled from the warehouse by the PCHS. If trains of max. 5 dollies destined for any of the A-pier aircraft stands were to be constructed,

[1] Rail brakes gripping the rolling stock's wheels in order to reduce its velocity

these could be decoupled in front of the lanes of the A-pier buffer, and each dolly could be sorted / pulled into its respective lane by a robotic arm , forming a new train (of max. 5 dollies), all made up of dollies destined for the same aircraft. Instead of utilising gravity shunting, automated guided vehicles (AGVs) or robotic arms similar to those found in the baggage sorting facility may be used to guide the car to the correct lane.

The buffer underneath the A-pier could also theoretically be used as a hub in a hub and spoke system as is done by the Swiss Federal Railways SBB Cargo Ltd. Rail cargo is brought to Däniken, the central hub, each night from all outstations. The cars are subsequently shunted and sorted into new trains heading to each outstation. In the case of the buffer underneath the A-pier, this would translate into all cargo destined for the A-pier being brought to the buffer in order to be sorted into their respective lanes as the buffer would be acting as the hub. The air cargo would subsequently be sent out to the outstations, the aircraft stands, once the aircraft has arrived. This moves the shunting and sorting process from the shunting area at the cargo warehouse to the buffer underneath the pier. Although this reduces the pressure on the shunting area at KLM Cargo's facility, it is simply moving the issue to another location. Additionally, due to safety concerns, shunting will not be allowed at the A-pier buffer due to a lack of visibility combined the safety risks involved with shunting.

Flower Auctions

At the flower auction in Aalsmeer, a push-based system is in place where orders are fulfilled and distributed to the customer in the order of purchase. In practice, this leads to inventory blocking paths, unfinished orders being sent to customers, and the use of more resources than required. According to Binneveld, a pull-based operation is desired in order to meet customers' expectations in fulfilling the orders on time, as well reducing the work required to fulfil the orders and reduce the number of incomplete orders being sent out [47].

This concept is comparable to the cargo delivery process in the sense that a push-based system is currently used since cargo is 'pushed' from the warehouse straight to the aircraft stand; oftentimes cargo is sent to the aircraft stand as a short train since other cargo is not yet ready. This results in multiple short trains being transported from the cargo warehouse to the apron instead of one longer train, as well as the possibility of the aircraft stand becoming cluttered when large amounts of cargo are placed on the apron before they are needed by Ground Services.

A pull-based operation as described in Binneveld's thesis could be translated to KLM cargo's operations as follows: the cargo warehouse is the supplier and the aircraft (stand) is the client. The client specifies the time at which the order must be fulfilled and a planning is made accordingly. Cargo is no longer sent to the aircraft stand once processed by the cargo warehouse, but a planning is made to either send the cargo to the buffering area underneath the A-pier (if needed), or dispatch the cargo straight to the aircraft stand once the aircraft is present at the gate.

2.5. Choice of Methodologies

A number of logistics concepts may be explored to study the possibilities of alternative outbound air cargo handling strategies. The concepts include lean manufacturing, push/pull systems, and queuing theory. Furthermore, the methods of discrete event simulation and the analytical hierarchy process will also be discussed.

Lean Manufacturing

The Toyota Production System is a management system developed by Toyota Motor Corporation in Japan in the 1970s in order to deal with unfavourable economic conditions. The core of the Toyota Production System is the elimination of waste within the processes of a company. By decreasing costs associated with this waste and thereby increasing productivity, profits increased and the Toyota Production System became a model for many other companies to follow [48].

Lean manufacturing is a philosophy where products can be made at a high quality standard but at lower costs. This is achieved by eliminating (parts of) processes which do not add value to the final product, also known as *waste* [49] [50]. All processes can be classified as one of three options:

1. Value added work: this is the work which adds value to the product. Examples are shaping, assembling and treating. In the case of the cargo process, this would include the buildup and breakdown of the cargo pallets, the transportation of the cargo on the aircraft, etc.

2. Incidental work: this is work which does not add value to the end product, but is sometimes necessary in order to be able to manufacture the end product.

3. Waste: this is the work which does not add value to the end product, and should therefore be eliminated. This waste is typically categorised into seven types of waste, commonly referred to as the acronym TIMWOOD [51]. These types of waste are:

   - **Transport**: while transport is necessary in many cases, transporting products without adding value is wasteful since it takes up time and resources and increases the risk of damage;
   - **Inventory**: goods which are not being sold or used have storage and/or maintenance costs associated with them, while not generating more income;
   - **Motion**: where transport refers to the transportation of goods, motion refers to the moving around of equipment and employees. Similarly, time lost to employees looking for tools or products is wasteful since this time can be reduced or eliminated if the necessary tool/product is available;
   - **Waiting**: products waiting between workstations in a production line cost money while no value is being added during this waiting time;
   - **Overprocessing**: this refers to completing more work on a product than required by the customer. This is work which is not being paid for, and may therefore be eliminated;
   - **Overproduction**: this occurs in the case of defects. Time and resources have been spent on the production of a good or service, but this use of time and resources is useless if a defect leads to the need to repeat this production. Similarly, producing more than necessary in order to account for possible defects is considered wasteful;
   - **Defects**: Defects cause the work put into the product to be rendered useless. Eliminating the number of defects directly reduces the amount of waste.

In the current and future cargo handling process within the scope of this research, an example of waste would be the cargo being parked on the aircraft stand, and having to *wait* for the aircraft to arrive. This cargo is brought to the apron before it was needed as a result of peak spreading. In many cases, however, cargo is driven to the apron in small quantities (i.e. short cargo trains). This means that more rides must be completed in order to deliver the same amount of cargo to the apron. This would be considered a transport waste.

Conversely, keeping the cargo on KLM Cargo's shunting area to maximise the efficiency of the transport, causes many ULDs to be stored, leading to an inventory waste. The storage of these ULDs requires space which can then no longer be used for other operations.

In the case of cargo being buffered intermediately, an extra step is introduced in the process. This step adds no value to the product for the customer (i.e. the transportation of goods from one airport to another) since the end result is the same with or without the cargo having waited in the buffer. For this reason, this would be considered waste; this added Transport and Movement step leads to increased complexity without adding product value.

Another type of waste identified in the current process includes overprocessing. Although required by IATA according to their Ground Operations Manual [27], time spent visually inspecting cargo prior to handing responsibility over the cargo over to Apron Services does not add value to the product. In fact, Apron Services carries out the same inspection prior to loading the cargo onto the aircraft. It may be argued, however, that multiple inspections increase the chance that any defects are identified sooner, meaning KLM Cargo has the opportunity to rectify the problem to avoid the cargo not flying as planned [17].

Push/pull Systems

Push and pull systems are manufacturing principles which determine when goods are produced within the supply chain. In a push system, the demand for the product is forecasted and the product is produced according to a predefined schedule [52]. This system works well when the information is available regarding how much product is needed at which moment and at which location. Typically, products with a stable demand pattern are easier to forecast and push based supply chains are suited to meet this demand [53] [54]. The current process of air cargo being driven from the warehouse to the apron is an example of a push system, since cargo is sent out to the apron as it becomes available for transport.

In cases where this information is not readily available or the demand pattern is more volatile, a pull system may be more suitable [55]. With this demand-driven system, goods are produced when an order for a specific amount is placed further down the supply chain. In other words, a production job is triggered by the completion of another job [52]. If the lead time is known, the order could be placed such that the product is delivered just in time when current stocks run out, thereby minimising inventory. However, when this lead time is long, reacting to the change in demand may not happen quick enough [56]. Kanban, which is Japanse for ”visual signal”, is a part of Toyota’s Production System and is a type of pull system. In the Toyota factories, production line workers used physical cards to communicate what was to be produced or delivered and when it was needed. By standardising this process, waste was reduced since this pull system ensured only that what was needed was produced when it was needed [48].

A hybrid system, called a push-pull system, aims to combine the benefits of both systems by operating the initial parts of the supply chain with a push system, and later stages have a pull system in place [57]. This way the lead times can be reduced by having stock further down the supply chain, but still in a central place [53]. It may be argued, however, that this approach would not be considered lean since there is waste to be found in the form of inventory/waiting.

The supermarket concept is a term given to a situation in in-house logistics where parts needed in a production line are intermediately stored in order to increase the reliability of JIT deliveries to the workstation. It is called the supermarket concept because its principles are comparable to that of supermarkets; customers need certain products at a specific time (when they are visiting the supermarket). The supermarket has to be able to supply the products JIT and therefore keeps a supply of the goods and replenishes these as they are bought by the customers. Saaidia et al. define the supermarket as ”a decentralized in-house logistics area where parts are intermediately stored then loaded on small tow trains which travel across the shop floor to make small-lot deliveries needed by the stations of the assembly line” [58]. While the use of the intermediate buffer may seem similar to the model of a supermarket, the fact that each ULD already has a specific destination by the time it is built-up in the cargo warehouse, means that air cargo being centrally buffered cannot be interpreted as a form of the supermarket concept.

As discussed in section 2.2, most ground handlers utilise a push system since there are no restrictions on when cargo is placed on the apron. This minimises the amount of space required for the storage of freight on the ground handler’s premises, as well as ensures that cargo is delivered well ahead of its deadline. With the implementation of the *Clean VOP*, however, there are restrictions on when cargo may be positioned on the aircraft stand. This can be addressed by changing the location of the delivery of cargo, or by implementing a pull or push-pull system. A pull system would entail that cargo is held at the warehouse and is only sent to the aircraft once it is ’pulled’ by Apron Services by means of a kanban system. However, given the limited shunting space available on KLM Cargo’s premises, a push-pull strategy may offer an optimal solution. As the PCHS continues to expel cargo hours ahead of time in order to ensure cargo is not expelled too late, the A-pier buffer could be used to buffer the cargo. The cargo may subsequently be ’pulled’ to the aircraft stand at the time of the aircraft’s arrival, ensuring that cargo is delivered on time while minimising the required storage space at the cargo warehouse.

Queuing Theory

Queuing theory encompasses the study and analysis of queuing systems. Queuing systems occur in countless aspects of daily life, and these systems can be analysed in terms of inter-arrival times, serving speed, utilisation, et cetera. Where providing too little service will cause the queues to grow, offering too much service will have high costs associated with it. It is, therefore, a challenge to balance the costs associated with service with the costs of queuing [59].

When looking at the A-pier buffer, the system can also be described using queuing theory. The A-pier buffer is analogous to queues in that a ULD train (pulled by a tug) represents a customer and the lanes in the buffer represent the servers. Assuming all lanes are usable for all aircraft stands, a tug will deliver the ULD train to any of the available (empty) lanes. The serving time is subsequently determined by the parking duration of the ULD train; there is no actual service mechanism other than the provision of parking space. A server (lane) can only serve one customer (ULD train) at any one time. Even short ULD trains are not able to share a single 30m lane since this introduces accessibility issues for the tugs. Carts and dollies cannot be reversed, so it is essential that ULD trains enter the lane from one end, and drive through (and exit) on the other side. For this reason, a lane can only be occupied by one ULD train, even if said train has a length of 1.

Using this system, balking behaviour can be monitored to analyse how many *Clean VOP* infractions occur. In other words, if cargo is to be stored in the buffer while the buffer is fully occupied, the tug will balk and (illegally) place the ULDs on the aircraft stand instead. Although this would violate the *Clean VOP* principles, there is no physical queue available for the tug and ULD train to wait for a lane to become available. Since tugs may not wait on the airport roads since this may lead to congestion or accidents, the driver is forced to place the cargo elsewhere. The number of ULDs balked tugs will be useful in determining how frequently cargo is unable to be stored in the cargo buffer underneath the A-pier.

Discrete Event Simulation

In order to study the effects of the different cargo handling strategies on the key performance indicators, the system itself must be studied. According to Law & Kelton [60], a system may be studied in a number of ways, as shown in figure 2.1. The first question is whether one can experiment with the actual system. Since this research involves the A-pier which is still under construction, this is not physically possible. Therefore, the experiment must be done using a model. Next, the choice must be made for either a physical model or a mathematical model. Due to the fact that there are many entities involved and many decisions need to be made, a physical model (such as a scale model) would become too complex to efficiently give answer to the main research question. Therefore, a mathematical model is to be used. Finally, due to the many decisions which are to be made which are dependent on other variables' states, it is not feasible to find an analytical solution. Simulation is therefore selected as the most suitable method for studying the system.

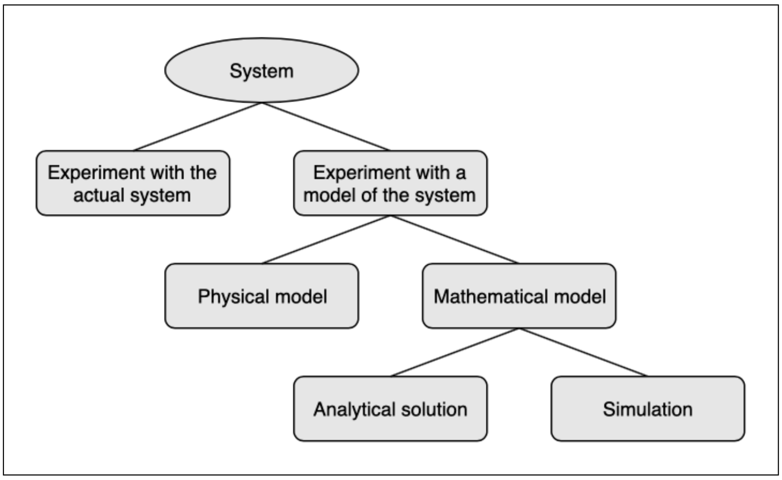

Figure 2.1: Ways to study a system [60]

The possible cargo handling strategies will be subjected to the new generated flight schedule using discrete event simulation (DES). This method of simulation is highly suitable for this application since it models real-life processes which are triggered by events (e.g. aircraft arrives at aircraft stand, cargo is expelled from warehouse, etc.), and there are many variables and calculations which need to be applied for various transportation policies which are to be tested. Simulation is an efficient means of predicting KPI values of different designs and/or strategies without actually implementing them. Moreover, simulations can be made in such a way that they are visually easy to understand and interpret. Modelling the cargo flows expected at the future A-pier allows for the effects of different strategies on the punctuality of the cargo to be predicted.

Many software packages are available for modelling a discrete event simulation, such as Matlab, Simio, Arena and AnyLogic. While all would be capable of modelling the flows between the cargo warehouse, buffer and aircraft stand, eventually Simio was chosen due to previous experience with the software, as well as the intuitive user interface which makes it relatively easy to create a graphical simulation which aids the understanding of the effects of the different buffering strategies. The model will give insight into the system's behaviour using performance indicators defined in section 2.6.

Analytical Hierarchy Process

A multiple criteria decision problem is defined as a situation in which there is a defined set of variants or solutions as well as a set of criteria on which each solution is assessed [61]. In this research, a number of strategies for delivering cargo to the aircraft under *Clean VOP* conditions are developed. These strategies will subsequently have different KPI values and a trade-off will have to be made between the strategies. Since not all KPIs will be of equal importance to KLM Cargo, the Analytical Hierarchy Process (AHP)—a type of MCDA—will be used to assign weights to each of the KPIs. This process accounts for inconsistencies in the problem owner's judgment with regards to the relative importance of each criterion on which alternatives are to be scored. AHP uses pair-wise comparison of each of the criteria to determine their relative importance, with weights being assigned as a result of these ratios [62]. These weights are subsequently used to calculate each alternative's weighted score, allowing for a direct comparison of the alternatives.

The main benefit of this process is that it is often seen as a more systematic approach than having the problem owner assign weights directly to the criteria based on their intuition [1]. Furthermore, assigning the relative weights with a group of people rather than a single problem owner, a more balanced view may be reached through consensus, ensuring that different actors representing the problem owner do not arrive at vastly different KPI weights. Furthermore, to prevent inconsistencies in the relative importances assigned by the problem owner, a consistency ratio is used to ensure that the assigned weights can be accepted.

The AHP method has been used in many theoretical and practical applications in the past, as outlined by Saaty [1]. AHP has proven to be a reliable method for assigning weights to KPIs, normalising score values and making the tradeoff between various alternatives. The method will be applied to the simulation results in chapter 6.

2.6. Key Performance Indicators

The main objective in the case of the A-pier is to continue to deliver cargo to the aircraft stand on time, while adhering to the stricter regulations with regards to the access to the aircraft stand due to *Clean VOP* as discussed in section 2.1. The buffer space which is provided by AAS can be used to store cargo between the cargo warehouse and the aircraft stand, but when the buffer is full (i.e. 100% utilisation), additional cargo will have to be brought to the aircraft stand instead. This, along with the fact that disruptions may call for more available buffer space, means that a lower maximum recorded buffer utilisation is preferred.

Additionally, the number of kilometres driven by the Mulag tugs are to be minimised to decrease the number of employees required, as well as the emissions as a direct result of the cargo operations at the A-pier, as discussed in section 2.2. Finally, the space at KLM Cargo's shunting area is scarce, so minimising the amount of space required in order to abide by the *Clean VOP* regulations is preferred. In order to measure to what extent these objectives are reached in future scenarios, the following key performance indicators (KPIs) will be used to evaluate the performance of the cargo handling alternatives:

- **Violations:** The number of *Clean VOP* violations (ULDs) per month;
- **OTP:** The on-time performance;
- **Max. Utilisation:** The highest recorded utilisation of the A-pier buffer space;
- **Distance:** The total distance covered by all of KLM's tugs due to A-pier cargo transport;
- **Space:** The amount of space required (ULDs) for buffering A-pier cargo on the KLM Cargo shunting area.

These KPIs will be further defined and discussed in section 3.3.

2.7. Summary and Research Gap

To summarise, the implementation of the *Clean VOP* presents many challenges. Air cargo handling procedures which have been employed for decades are no longer feasible since they do not account for the restrictions imposed by the *Clean VOP* and will therefore lead to countless violations. To answer subquestion 1, strategies and technologies in other industries where punctuality is of high importance have been explored. These industries use AGVs, buffering, pull-systems, or a combination of these concepts to achieve their goal more efficiently. An overview is shown in table 2.2.

Table 2.2: Overview of concepts used by other industries

Industry	**Description**
Air Cargo Operations	Air cargo is typically pushed to the aircraft stand as soon as it becomes available for transport at the cargo warehouse. This may be as much as several hours prior to departure.
Airport Baggage Handling	Baggage is generally pulled to the aircraft when it is needed for loading. This ensures that there are no *Clean VOP* violations. In some cases, baggage may need to be pushed out to the aircraft sooner due to a lack of buffering space in the baggage facility.
Container Terminals	Freight is stored in stacks. For these stacks, different strategies may be applied. While some will minimise the reshuffling required, other strategies will place containers close to their next ship's berthing place: housekeeping versus immediate final grounding.
Railway Yards	Prorail's Kijfhoek shunting yard uses automation to sort/shunt cars onto the correct track and SBB Cargo uses a hub and spoke system for its cargo.
FloraHolland Aalsmeer	Transforming the logistics processes from a push system to a pull system increases the quality of the service, reduced the workload and ensures fewer incomplete orders are sent to customers.

The introduction of automated guided vehicles to transport goods autonomously is an effective means of decreasing operating costs while increasing safety and reliability. They have been used extensively in the container terminal industry and have proven to be effective in this closed environment. Introducing such a system of vehicles in a complex environment where many different types of vehicles are present and where cargo is bound by IATA regulations, presents its challenges. However, airports such at Heathrow and Gatwick are leading the industry by already running pilots of AGVs on the airside of the airport. Unlike the proposed UFT network between Hoofddorp, Aalsmeer and Schiphol, this system of AGVs uses the existing road infrastructure of the airport, meaning it is probably just as likely to be affected by congestion as the current system using tugs and tug drivers.

For deliveries where timing is of high importance, pull systems or push-pull systems are generally preferred over push systems. Since the *Clean VOP* policy impacts the delivery times at which a ground handler may position cargo on the aircraft stand, the impact of different handling strategies is to be explored. While the cargo handling is also subject to sections 3.4, 3.7 and 4.1.2.3 of the the IATA Ground Operating Manual as discussed in section 2.2, different types of logic such as push, pull or push-pull may have a significant impact on the operational performance of the cargo handling. Much research has been done on other aspects of the air cargo industry, such as network planning [63][64][65], flight scheduling [66][67][68] and location selection for the cargo hub [69][70][71], but little to no research has been done on the handling of cargo between the warehouse and the aircraft, especially under *Clean VOP* regulations. This research aims to address this research gap using theoretical concepts to design future cargo handling strategies, and subsequently testing these strategies in a simulation environment. The strategies will consist of a push, pull or push-pull system, or a combination of these approaches, and will be discussed in depth in part III.

For KLM, the practical knowledge gap lies in fact that it is unknown which strategy is best to employ at Schiphol's A-pier to adhere to the *Clean VOP* regulations, and what effects can be expected on the cargo operations when the cargo is to be driven to the aircraft stand only when the aircraft is present. The cargo flows expected at the A-pier will be subjected to the various future handling strategies using discrete event simulation. Doing so will address the practical knowledge gap and will give KLM insight into which strategy will minimise *Clean VOP's* impact on the cargo handling operations.

Part II

Measure & Analyse

3

Current State

In order to answer subquestion 2 in this chapter, the current state of the system will be discussed and analysed, as well as the stakeholders involved in the outbound cargo process. Processes and corresponding key performance indicators will be discussed which will be used to assess the performance of both existing and future ground handling procedures.

3.1. Current Outbound Air Cargo Process

KLM Cargo has three cargo warehouses; freight buildings 1, 2 and 3 (FB1/2/3) as seen in figure 3.1. The outbound cargo process is as follows: at first, trucks arrive in the documentation area and are checked by security. Once the cargo is accepted, the trucks may drive to the trucking area where cargo can be unloaded from the truck in the freight building. FB1 is solely used for mail, parcels, high-value cargo, active temperature controlled containers and live animals. FB2 handles inbound cargo (import) and FB3 handles outbound freight (export). Cargo may also transit at Schiphol, meaning that cargo arrives by plane and is brought to the cargo warehouse for processing before its connecting flight.

If not already done so, outbound cargo is built up onto ULDs suitable for air transport, and put onto a cargo dolly. This dolly is then positioned on the shunting area within the KLM Cargo premises as shown in figure 3.1 where it forms a train of up to five cargo dollies.

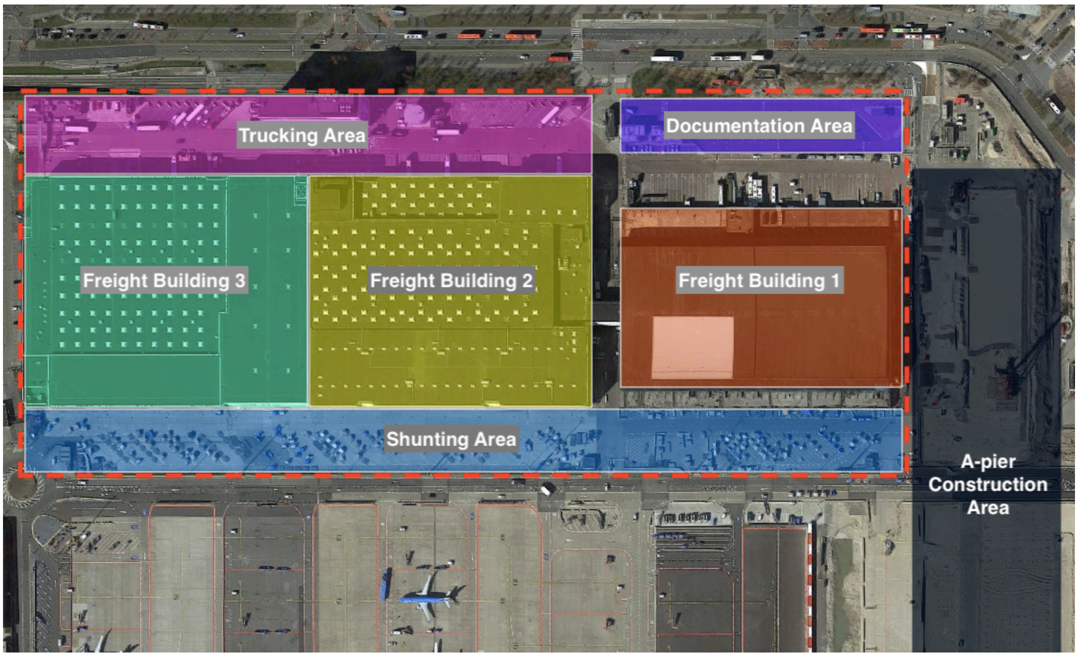

Figure 3.1: Layout of the KLM Cargo premises (red dashed line) at Schiphol [72]

From this shunting area, a Mulag tug (as seen in figure 3.2) may pull the train of dollies and/or bulk carts—any combination with a maximum length of 27,5 metres including the tug—to the apron [19]. The tug may also pull a combination of dollies destined for different aircraft; the tug will then drop the freight at the various aircraft stands in one milk-run. Upon entering the airport's airside security restricted area, the tug and its driver are checked by airport security personnel; the driver's identity is verified using an iris scan, their belongings are x-rayed and the vehicle is inspected for prohibited items.

On the apron, the dollies are driven onto the aircraft stand and are decoupled from the tug, usually on a dedicated white hatched parking area (as seen in figure 3.3), or near the aircraft's starboard wing. After decoupling, the driver performs a visual inspection of the cargo to ensure the cargo is still airworthy and if the contents have not shifted during transport. Once the cargo has been placed on the aircraft stand and has been visually inspected, responsibility of the cargo is transferred to KLM Apron Services (AS). AS is subsequently in charge of loading the cargo onto the aircraft. The outbound process is illustrated in appendix A.

Cargo passing through Schiphol may be subject to customs screening. If this is the case for outbound cargo, the tug driver will see the customs facility as the cargo's destination rather than the aircraft stand. At the customs facility, the ULDs are x-rayed individually and must be cleared by customs before they may be transported to their destination. This process takes around 15 minutes for a single train of dollies, but may take longer when there is a queue for the screening facility. After screening, the cargo may be driven from the customs facility directly to the aircraft stand.

In some cases, the gate at which an aircraft will be turned around may change due to various operational reasons. When this happens, cargo placed on the apron prior to the aircraft's arrival must be driven to the new aircraft stand by KLM Cargo. Only when this gate change occurs less than an hour before departure, Apron Services will ensure the cargo is brought to the aircraft.

Each ULD movement between the warehouse and the apron is logged using drivers' handheld devices. The handheld is used by drivers to select a ride and verify the ULD numbers in the ride match those printed on the ULD. Data such as weight, destination and delivery deadline may also be found on this handheld device. The use of this handheld in combination with the database storing ride data allows for the analysis of the data which can provide insight into the efficiency of the current operations, as well as identify where there is room for improvement.

Figure 3.2: Left: Mulag tug used by KLM Cargo for the transport of air cargo between the cargo warehouse and the apron. Right: 10-foot pallet dolly used to transport one 10-foot pallet or two AKE containers.

Figure 3.3: Left: AKE dolly used for transporting single AKE containers.
Right: Bulk cart used for bulk cargo (i.e. mail and express parcels).

3.2. Stakeholder Analysis

Since an airport is such a complex organisation with many stakeholders making use of the same infrastructure, the implementation of new ground handling regulations affects many of these stakeholders around the airport. In the case of the A-pier buffer and the *Clean VOP* principle, the stakeholders shown in figure 3.4 have been identified:

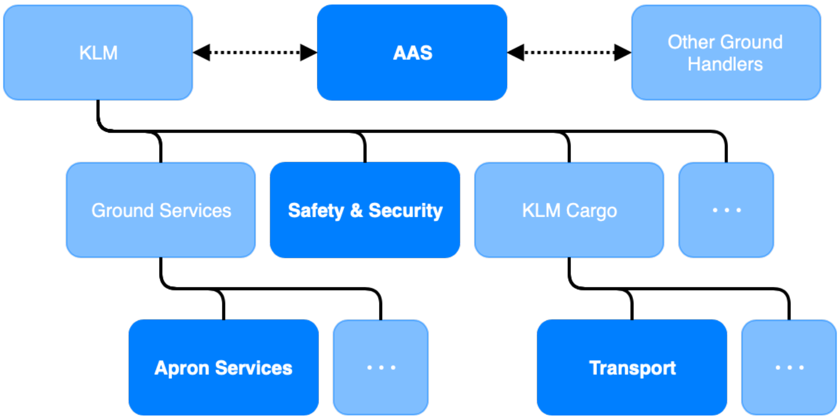

Figure 3.4: Main stakeholders of the A-pier's *Clean VOP*

Amsterdam Airport Schiphol

AAS is the authority at the airport and the owner of the infrastructure. They are also responsible for enforcing the rules and regulations in the airside security restricted area. As such, ground handlers must abide by the *Clean VOP* principle when this is imposed by AAS. Additionally, AAS provides the buffer space underneath the pier to be used for cargo, allowing KLM and other ground handlers to operate in the direct vicinity of the pier without having to position carts and dollies on the aircraft stand. AAS has little to no interest in how KLM Cargo changes its procedures for delivering cargo to the A-pier under *Clean VOP* regulations, so long as there are no violations.

Schiphol's main interests are:

- Timely departures of aircraft;
- Safety and security at the airport;
- Implementing and enforcing the *Clean VOP* at the A-pier;
- Ensuring adequate traffic flows on service roads.

KLM Cargo

KLM Cargo will be the biggest ground handler of cargo around the A-pier. As such, the impact of the *Clean VOP* requirement will be felt the most in their operations. As the main user of the A-pier, KLM Cargo is affected most by the implementation of *Clean VOP* and is responsible for adapting procedures in order to comply with the regulations. This makes KLM Cargo the problem owner. Their objectives, however, remain unchanged; cargo is to be delivered on time to all aircraft to ensure cargo flies as planned.

KLM Cargo's main interests are:

- Delivering cargo on time for the flight;
- Reducing the costs associated with transporting the cargo to the aircraft stand;
- Uniform handling procedures across all piers.

KLM Apron Services

Apron Services (AS) ensures that aircraft parked at the A-pier are turned around in a timely manner. This includes cleaning, catering, loading, refuelling, etc. KLM Apron Services is also responsible for the loading of cargo and baggage onto the aircraft.

At present, cargo and baggage are placed on the aircraft stand by the respective party and AS loads them onto the aircraft. In a future scenario where cargo may be buffered underneath the A-pier, it is unknown whether or not AS would be responsible for locating and transporting the cargo from the buffer to the aircraft, or whether KLM Cargo would still be responsible for transporting the goods from the buffer to the aircraft stand themselves.

KLM Apron Services' main interests are:

- Orderly and safe aircraft stand;
- Receiving baggage and cargo on time;
- Timely departure of aircraft;
- Adequate traffic flow on service roads.

KLM Safety & Security

Safety and security are crucial to an airline and airport's operations. KLM's Safety & Security department oversees these aspects of the processes that take place at the airport, as well as the design of the infrastructure, including that of the A-pier. Besides the safety of the aircraft, care is also taken to protect the employees' occupational health and safety. In the case of the A-pier buffer, KLM Safety & Security is consulted for the physical design of the buffer, but also the procedures which are to be followed.

KLM Safety & Security's main interests are:

- Protecting workers' health and safety;
- Protecting the aircraft from damage and maintaining flight safety;
- Ensuring safe standard operating procedures are in place;
- Uniform handling procedures across all piers.

3.3. Key Performance Indicators

In order to assess the performance of KLM Cargo's transport department, a number of key performance indicators are used. The transport department logs all rides using handheld devices and stores this data in a central server. Analysing this data gives insight into the performance of the system, which can be assessed using a number of Key Performance Indicators (KPIs). In the simulation model, future performance can be predicted using the these KPIs, allowing for a direct comparison of the performance of various cargo handling alternatives. In section 2.6, the following KPIs were identified:

1. **Violations:** The number of *Clean VOP* violations (ULDs) per month;
2. **OTP:** The on-time performance;
3. **Max. Utilisation:** The highest recorded utilisation of the A-pier buffer space;
4. **Distance:** The total distance covered by all of KLM's tugs due to A-pier cargo transport;
5. **Space:** The amount of space required (ULDs) for buffering A-pier cargo on the KLM Cargo shunting area.

Since the *Clean VOP* sets very clear boundaries for when cargo may be brought to the aircraft stand, care must be taken to avoid any infringements. Cargo illegally placed on the aircraft stand may cause a collision with an aircraft taxiing in, which leads to unsafe situations and is likely to cause damage to the aircraft. Furthermore, a *Clean VOP* violation in many cases will also mean a violation of IGOM section 4.1.2.3; keeping the ERA clear of obstructions during arrival and departure of aircraft. For this reason, any time a ULD is parked on the aircraft stand due to the intermediate buffer being fully occupied, a violation of the *Clean VOP* will be recorded. Although AAS in unclear on the sanctions which may result from violations, this KPI must be minimised so that KLM Cargo follows a cargo handling strategy which adheres to the regulations set by AAS as much as possible.

The on-time performance of cargo is defined as the share of ULDs which is delivered to Apron Services on or before the agreed upon deadline. For European flights, this deadline is 60 minutes prior to the scheduled time of departure, whereas for intercontinental flights this is 80 minutes prior to departure. These deadlines are found in the Ground Operating Manual Schiphol (GOMS, see appendix B) but may be changed if Cargo and Apron Services agree to new values. Cargo delivered to the aircraft stand too late may miss its flight, which potentially increases the costs for KLM Cargo due to the rebooking of the cargo. For this reason, on-time performance must be maintained (or increased) in order to ensure all cargo flies as planned and to minimise delays on the ground.

The buffer space underneath the A-pier consists of a total of fifteen lanes which KLM Cargo can use to store cargo in. However, when this buffer is full, additional cargo must be brought to the aircraft stand since waiting on the airport service roads leads to congestion and may cause unsafe situations. This can be avoided if the buffer is not over-utilised. A lower maximum buffer utilisation is therefore preferred, as it reduces the chance of *Clean VOP* violations and ensures that there is always a buffer lane available to store cargo in.

The total distance covered by KLM's Mulag tugs for the transportation of cargo is an indicator for the amount of equipment and manpower required for a certain strategy, as well as the environmental impact that the strategy leads to. As discussed in section 2.2, the Mulag tugs used by KLM Cargo have diesel engines which contribute to the airport's air pollution. Since KLM wishes to profile itself as a sustainable airline, minimising the total number of kilometres driven with these tugs will benefit the air quality and contribute to the airline's goal to decrease its impact on the local environment.

Finally, the amount of space required for holding freight on KLM Cargo's own shunting area is an indication of how much infrastructure is required by each handling strategy. While space is already scarce on the cargo premises, increasing the required space for the handling of A-pier cargo is unfavourable. For this reason, an alternative that requires less space is preferred over alternatives requiring more space compared to the current situation.

The combination of these five KPIs provide a good insight into the performance of the future cargo handling process, and can be used to compare simulated handling strategies at the A-pier to current operating procedures in terms of operational performance.

3.4. Data Collection

In order to analyse the performance of the current system, first the relevant data must be collected. All rides performed by KLM Cargo's Transport department are logged in CHAIN; KLM Cargo's warehousing program. As of mid-2016 the timestamps for each of these rides became much more accurate since tug drivers were issued a handheld device on which rides could be started and ended. This replaced the less accurate system of recording these timestamps by writing them down on forms in the transport department *after* the ride was completed and the tug was driven back to the cargo warehouse.

For this case study, data on all outbound ULDs handled by KLM Cargo between December 1, 2017 and December 1, 2018 were collected and exported to an Excel file. A full year was selected since this would account for any seasonal changes in cargo volume, as well as weather conditions and disruptions throughout the year. These specific months were chosen since this was the most recent data available.

The dataset contained many movements and parameters which were not of interest for the purpose of this research. This meant that the data first had to be cleaned. Rides within the KLM Cargo premises were removed since the focus of this research lies on the movement from the cargo warehouse to the apron. Similarly, all cargo destined for full-freighter aircraft was removed since no freighters will be handled at the A-pier. Finally, incorrectly recorded rides were filtered out; rides with a duration of less than two minutes or rides which recorded the delivery time of the cargo being later than the *actual* departure time of the aircraft. Also ULDs being driven to the aircraft more than twelve hours prior to departure were removed since these rides were assumed to be either erroneous, or extreme exceptions which do not need to be taken into account for the A-pier.

The remaining dataset contained 276,163 ULDs which were brought by KLM Cargo to the aircraft stand between December 1, 2017 and December 1, 2018. Each row of data in this dataset contained the following parameters:

- **ULD ID**: a unique number assigned to each ULD;
- **Ride ID:** indicates which ULDs were driven to the apron together, which is used to calculate each train's length;
- **Aircraft stand:** location of the aircraft at Schiphol;
- **Aircraft type:** allows for the differentiation between wide- and narrow-body cargo;
- **Flight number:** allows for the calculation of the number of ULDs per flight;
- **Flight departure date and time:** allows for the calculation of delivery deadlines for each ULD;
- **Time of delivery:** indicates the time prior to departure at which the ULD was delivered to the aircraft stand.

The ULD ID is a unique number assigned to each ULD, whereas the Ride ID is equal for all ULDs transported simultaneously by a single tug. This allows for the analysis of the length of the trains in the dataset. The aircraft stand indicates the location of the aircraft at Schiphol, whereas the aircraft type distinguishes wide-body from narrow-body cargo. Each flight is also assigned a flight number which is unique for each day. This number is used to determine how many ULDs flew on each aircraft each day. Finally, the flight's scheduled time of departure together with the aircraft type determines the deadline for cargo delivery, and the actual time of delivery can indicate for each ULD whether is was delivered before, on or after the delivery deadline.

3.5. Summary

To answer subquestion 2, the current state of KLM's outbound air cargo process at Schiphol Airport is explored. Currently, all cargo follows the same procedure, regardless of the pier from which its aircraft departs. This is in the interest of KLM Cargo since this simplifies the procedures across the airport, ensuring easier training of the workforce and safer operations. For the A-pier, however, following the current procedures would lead to many *Clean VOP* violations since cargo is placed on the apron regardless of the aircraft's presence. Since each *Clean VOP* infraction may lead to sanctions from the airport authority, the handling procedure currently in place is infeasible for A-pier operations.

There are a number of stakeholders involved in the A-pier project; besides KLM's Safety and Security department, whose goal is to ensure that operations run safely for man and machine, Apron Services is a key player on Schiphol's airside and is responsible for the air cargo after it has been delivered to the aircraft stand. While the implementation of *Clean VOP* does affect their operations, one may argue that a *Clean VOP* is beneficial to Apron Services' overview and control of the aircraft stand.

Finally, since all rides are logged using handheld devices, the system's performance can be assessed using five key performance indicators. These KPIs can therefore be used to predict the performance of simulated alternative handling procedures at the future A-pier. The analysis of the current system is done in chapter 4, while alternative handling strategies are designed and simulated in chapter 5.

4 Analysis

In this chapter, the data recorded of all outbound cargo transport rides between December 2017 and December 2018 are analysed. This data will subsequently be used to fit the distributions of a number of variables in order to synthesise a new dataset. Also, the simulation model of the A-pier is described along with the assumptions made. Finally, this model will be verified and validated. This chapter will answer subquestion 3.

4.1. Data Analysis

The empirical dataset contains 276,163 outbound ULDs that were transported from the cargo warehouse to the apron. Of these ULDs, 83,5% was destined for wide-body aircraft and 16,5% for narrow-body aircraft. Figure 4.1 shows the histogram of the number of ULDs on the wide- and narrow-body aircraft, respectively. In order to determine the distribution of the number of ULDs per flight from the empirical dataset for both wide- and narrow-body flights, a distribution fitter was used [73], which produced the distributions and corresponding log-likelihoods as shown in table 4.1. As a result of this analysis, the assumption is made that the number of ULDs on a wide-body flight follows a negative binomial distribution with parameters $R = 8.8610$ and $P = 0.4875$, while the number of ULDs on a narrow-body flight is assumed to follow a gamma distribution with parameters $a = 4.0995$ and $b = 0.3887$. These distributions will be used to generate a random number of ULDs for each of the flights in the discrete event simulation of the A-pier.

Figure 4.2 indicates the time at which cargo was delivered to the aircraft stand prior to its scheduled departure time. Both wide- and narrow-body cargo show similar distribution shapes, with most ULDs being delivered around ninety minutes prior to departure and the extremes being placed on the aircraft stand close to six hours before departure. Using MATLAB's distribution fitter, the data is analysed and is assumed to follow a generalised extreme value distribution with values $k = -0.0469$, $\sigma = 45.0510$, and $\mu = 99.2256$ for wide-body cargo, and values $k = 0.2483$, $\sigma = 45.7809$, and $\mu = 83.3188$ for narrow-body cargo.

The number of ULDs towed by a tug simultaneously indicates the length of the train. These values were obtained from the 2018 dataset by counting the number of ULDs associated with each (unique) ride ID per aircraft stand for each day in 2018. The distribution of train lengths in 2018 is illustrated in figure 4.3.

Analysis of the 2018 dataset yielded some statistics which give insight into the performance of the current system. However, not all key performance indicators could be found in the dataset. Data required for KPIs *Distance* and *Space* were not recorded, since these KPIs would be A-pier specific and in 2018 there was no A-pier and there was no *Clean VOP* in effect. Some other statistics were found, however, which will allow for the validation of a discrete event simulation model of the A-pier. These are shown in table 4.2.

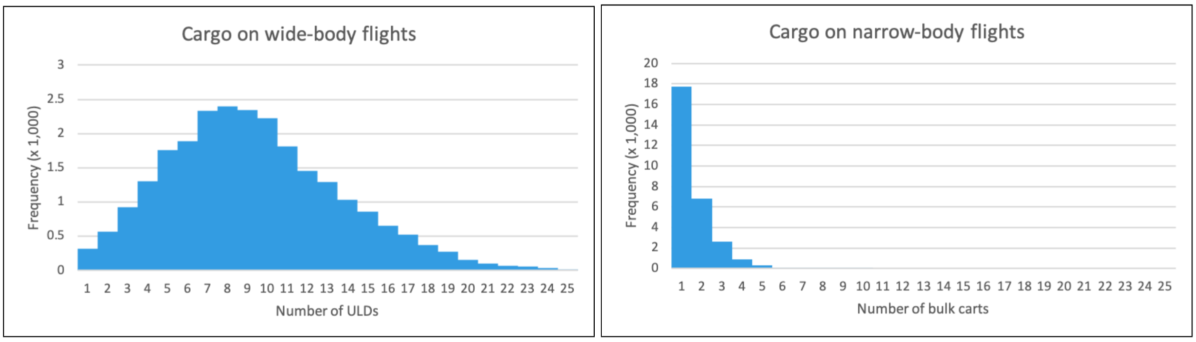

Figure 4.1: Distributions of outbound ULDs on wide- and narrow-body aircraft in 2018

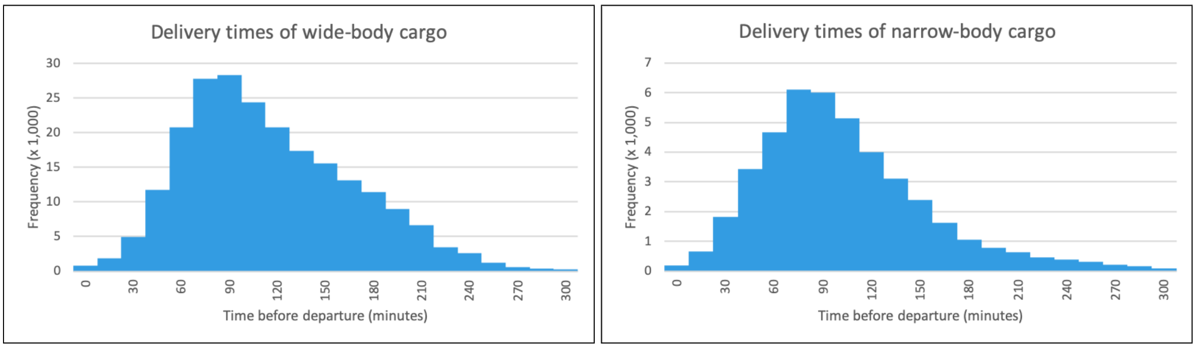

Figure 4.2: Distributions of outbound cargo's time on apron in 2018

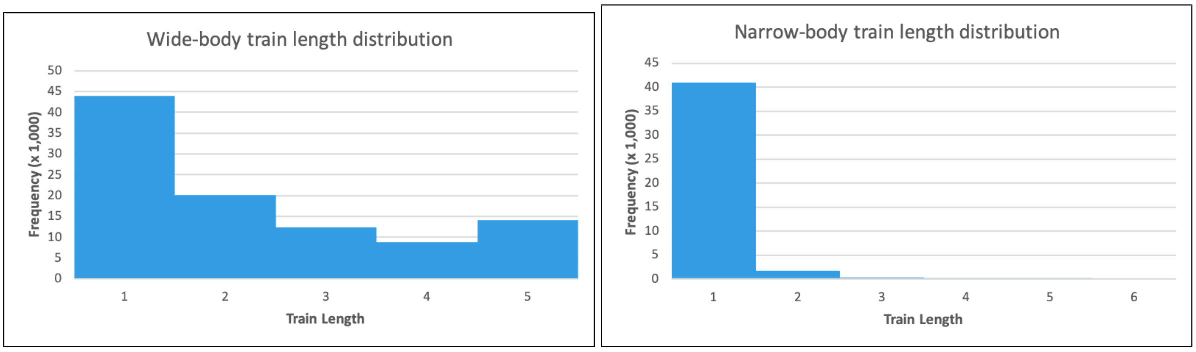

Figure 4.3: Distributions of outbound cargo train lengths in 2018

Table 4.1: Log-likelihoods for the distributions of the number of ULDs per flight

Distribution	**Log-likelihood**	
	Wide-body flights	*Narrow-body flights*
Binomial	-74,483.7	-39,406.5
Exponential	-79,974.5	-41,905.6
Gamma	-70,913.0	-31,245.4
Negative Binomial	-70,581.6	
Normal	-71,401.9	-39,011.1
Poisson	-74,472.0	-39,407.5

Table 4.2: 2018 outbound cargo statistics

KPI	Wide-body	Narrow-body	Overall
On-time performance [%]	78.22	86.11	79.52
Average delivery prior to departure [mins]	123.25	115.1	121.91
Average train length [# dollies/carts]	2.28	1.06	1.91

ULDs which are delivered on or before the deadline set in the GOMS are regarded as being delivered on time. The KPI values for *on-time performance* show that approximately 80% of all cargo is delivered on time, indicating 20% is delivered late. This can have a number of causes, such as highway congestion leading to a late delivery from the forwarder to the cargo warehouse, problems building up the ULD, congestion within the PCHS, delays at the customs scanning facility, and/or delays on airport service roads leading to longer driving times. Although cargo delivered late may still fly if Apron Services is able to load it on time, this value must be minimised in order to avoid costs associated with rebooking cargo onto alternative flights.

The *average time of delivery prior to departure* is rather similar for cargo destined for narrow- and wide-body aircraft, despite the fact that wide-body aircraft typically have much longer turnaround times. Due to the fact that wide- and narrow-body cargo have different delivery deadlines, this also indicates why narrow-body cargo has a higher on-time performance than wide-body cargo.

The *average length of the trains* is significantly higher for wide-body cargo than for narrow-body cargo. This is explained by the fact that 47% of the narrow-body flights which contained cargo had just one belly cart of cargo on board, 29% had two belly carts, and less than 24% had three or more carts of cargo on board. This indicates why the vast majority of rides to narrow-body aircraft consist of trains of length one, as shown in figure 4.3. 64% of the narrow-body flights containing cargo had *all* of the cargo delivered in a single ride. For wide-body aircraft, a different distribution can be identified. Since 91% of the wide-body flights had more than five ULDs of cargo on board, cargo for these flights would always have to be transported to the aircraft stand by multiple trains. However, the fact that the majority of tugs delivered one or two ULDs to the aircraft stand at a time means that there is room for improvement from an efficiency point of view.

4.2. Data Synthesis

In order to simulate outbound cargo flows at the A-pier, new data is synthesised, that can be used as input for the simulation model. A Matlab script is used to estimate the distributions of the number of ULDs and the delivery times prior to departure for both wide- and narrow-body cargo. From each of these distributions, new random values are drawn and stored in an array for later use. The data of the lengths of the trains is shuffled and stored in an array, since no distribution was found that resembled the empirical data points.

Next, the flight schedule provided by KLM for the A-pier is imported by Matlab in the form of an Excel file, and is stored as an array. The script then iteratively moves through the flight schedule array and for each flight assigns it a random number of ULDs (drawn from the array synthesised earlier). Each flight's quantity of ULDs is then broken up into different trains (drawn from the new train-length array) which each get assigned a time prior to departure at which they become available at the cargo warehouse (drawn from the delivery time array).

Once all flights have been processed and each flight's ULD trains have been synthesised, the data is stored into tables and exported as *Aircraft Arrival Tables* and *Cargo Arrival Tables* in the form of Excel files. The data in these Excel files are formatted in such a way that these can later be imported by the discrete event simulation of the A-pier. The Matlab scripts used can be found in appendix C.

4.3. Model Properties

Simio is used to create a discrete event simulation model of the A-pier. The model's purpose is to use the inputs and controls shown in figure 4.4 to determine the effects of these controls on the model's output, which includes the KPI values.

The Aircraft and Cargo Arrival Tables are generated by Matlab as described in section 4.2. The delivery deadlines are set to 80 and 60 minutes prior to departure for ICA and EUR flights, respectively.

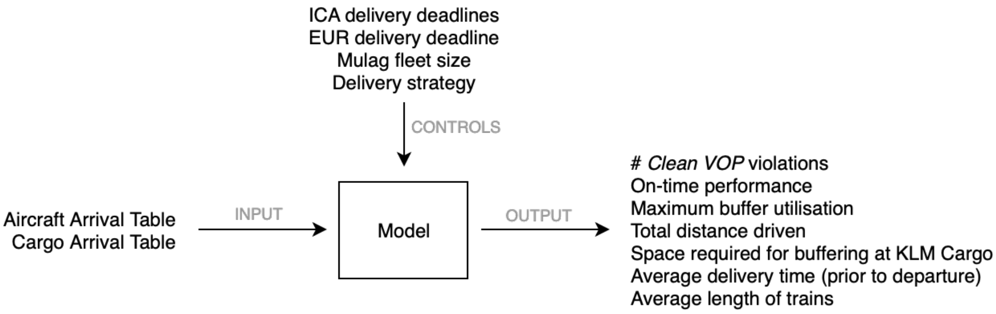

Figure 4.4: In- and outputs of the simulation model

These values are found in the GOMS but may be changed in the simulation for testing purposes. Additionally, the delivery strategy can be set before a simulation run, and the number of Mulag tugs available can be modified.

The conceptual model shown in figure 4.5 is subsequently used to model the process logic of the simulation. In the current situation, cargo is driven to the aircraft stand when it becomes available, as illustrated by the figure. This is independent of the aircraft being physically present at the pier. At the aircraft stand the responsibility over the cargo is handed over to Apron Services, and the time of delivery prior to the flight's departure is recorded.

The simulation model also has controls which allow for the delivery strategy employed by KLM Cargo's transport department to be modified, meaning that the model is able to base its process logic on this control input. This will be used in chapter 5 to test the effects of different cargo handling strategies.

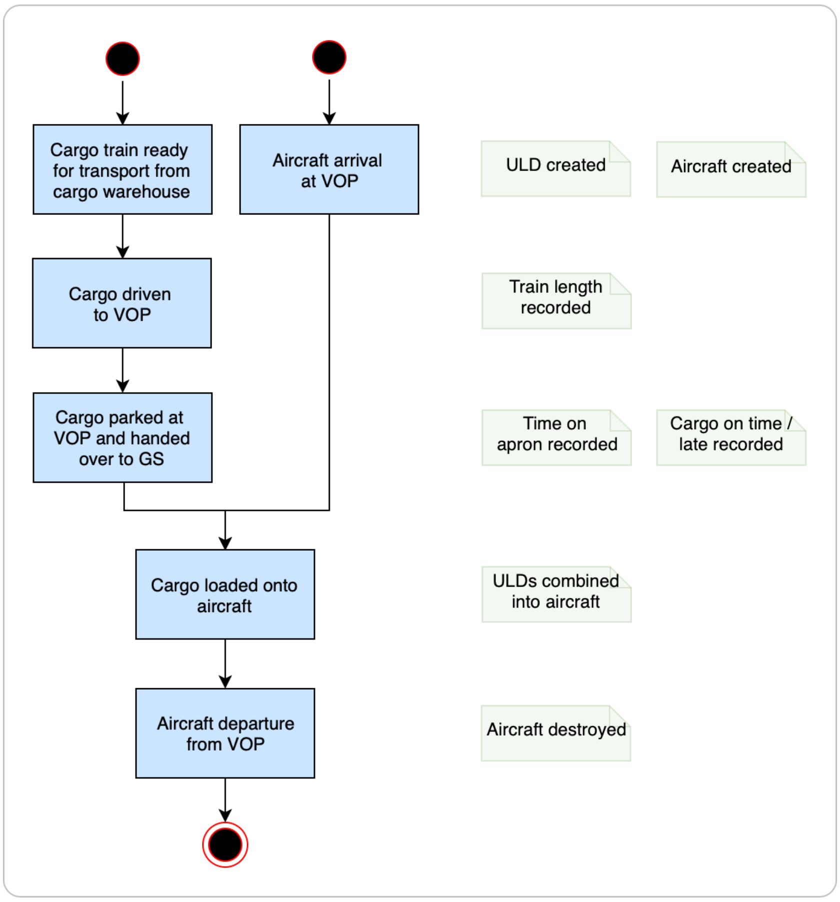

Figure 4.5: Conceptual model of the current situation

The outcome of the simulation of the current situation will serve as a baseline in terms of key performance indicator values for the current cargo handling procedures. It will allow for the direct comparison with *Clean VOP* handling procedures since other variables such as the distance to the aircraft stands and the number of aircraft and ULDs will remain constant.

4.4. Model Design

The A-pier is modelled to scale on top of a map, with two separate networks of nodes and links; one aircraft network connecting the taxiways to the aircraft stands, and one tug network connecting the cargo warehouse to the airport roads and the aircraft stands. The status of aircraft stands is indicated by a 'traffic light'. Red indicates the aircraft stand is empty and would have to be empty under *Clean VOP* regulations. A green light indicates an aircraft is being turned around and the aircraft stand is accessible. Orange indicates that the aircraft is still present, but that the cargo delivery deadline has passed; any cargo delivered beyond this time would be considered late. A graphical representation of the simulation can be seen in figure 4.6.

Cargo entities are generated by a source at the cargo warehouse (bottom-left) according to an arrival table generated in the Matlab scripts (appendix C). Each cargo entity is also assigned its properties at this time. The entities then need to be transported to the apron by a transporter, i.e. a tug. Tugs driving from the cargo warehouse to the apron are subject to a security screening taking anywhere from two to five minutes. After this screening, cargo is driven to the aircraft stand (regardless of the presence of the aircraft) and parked on the starboard side of the aircraft stand. Tug drivers moving back from the apron to the cargo warehouse must have their identity card checked by security in order to be granted access; this is takes approximately fifteen to thirty seconds, after which the tug becomes available for another ride.

In the bottom-right corner, on the taxiway, aircraft are generated according to the generated aircraft arrival tables. The aircraft taxi from the bottom right along the taxiways to their assigned gate / aircraft stand. The aircraft stand itself is modelled as a combiner, where the ULDs on the aircraft stand associated to that particular flight are combined into the aircraft before its departure. In the current situation, an occupied or empty aircraft stand can contain cargo destined for different flights (as seen in figure 4.7). For this reason, the combiner matches cargo to the aircraft's flight number to ensure the correct cargo is loaded, ignoring cargo destined for other aircraft on the apron. Once the turnaround is completed, aircraft will push back onto the taxiways and taxi up north towards a sink in the top-right corner where the aircraft entity is destroyed.

4.5. Model Assumptions

In order to model the current situation of outbound air cargo, a number of simplifying assumptions are made:

1. Flights follow the synthesised aircraft arrival table without major disruptions;
2. Flights arrive between 10 minutes early and 20 (EUR) or 30 (ICA) minutes late;
3. All intercontinental KLM flights have at least one outbound ULD scheduled;
4. 70% of European KLM flights have at least one outbound ULD scheduled;
5. KLM Cityhopper, Transavia, and non-KLM aircraft do not have cargo on board;
6. There is no limit on the number of ULDs which can be parked on the aircraft stand;
7. All tugs driving from KLM Cargo to the apron are subject to a security screening with a duration of 2 to 4 minutes;
8. All tugs driving from the apron to KLM Cargo are subject to an identification check with a duration of 15 to 30 seconds;

Assumptions 1 and 2 are made to simplify the model since the ability to handle major disruptions would require much more data input in order to be able to handle gate changes across the whole airport. Since the flight schedule provided by KLM contains only flights at the A-pier, replacement flights in

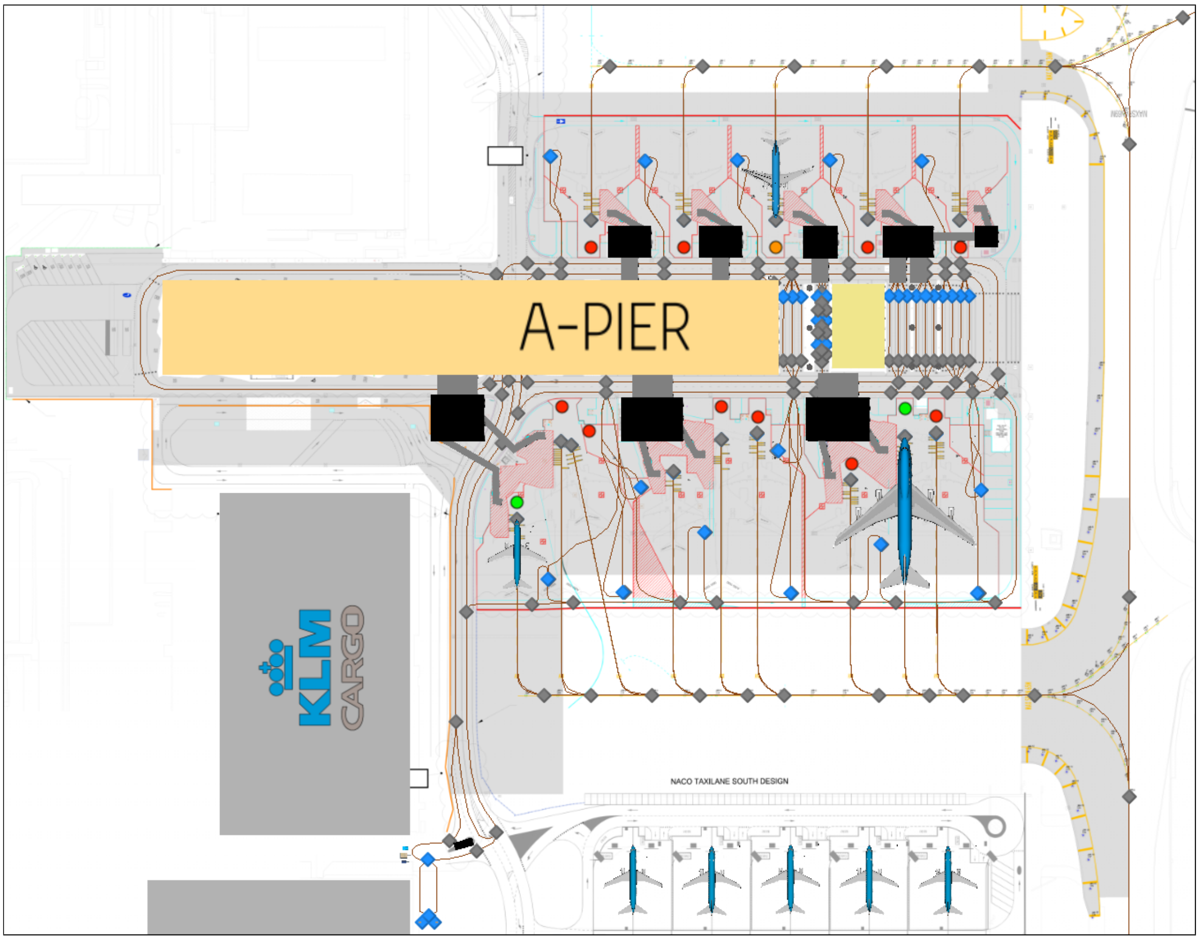

Figure 4.6: Graphical representation of the A-pier simulation depicting the cargo warehouse, the A-pier with its buffer lanes, as well as the networks of taxiways and airport service roads.

Figure 4.7: Graphical representation of the simulation showing cargo placed on the aircraft stand without aircraft present.

the case of big delays or major disruptions are not provided. Assumptions 3, 4 and 5 are based on interviews with KLM subject matter experts [17][74]. Although these values may be changed in the Matlab code provided in appendix C, these values are assumed by KLM to be a constant, meaning this does not need to programmed to be a flexible control for the model. Also, while KLM Cityhopper does occasionally carry mail on board, this cargo flow is negligible and is therefore excluded from the model. Assumption 6 is based on the fact that lack of space is not a cause for a tug driver to place cargo somewhere other than on the aircraft stand, and assumptions 7 and 8 are based on personal experience validated by subject matter experts.

4.6. Verification and Validation

The model must be verified and validated to ensure that this model has been built according to the specifications of the conceptual model, that model behaviour is as predicted, and that it is an accurate representation of the real system [75]. First, the model's behaviour will be verified. Next, the model's representation of real life will be validated.

Verification

Verification is used to determine whether the model has been built correctly, i.e. that it models the logic from the conceptual model [76]. Throughout the modelling stage, test runs were done to ensure that entities behaved in the intended way. This means, for example, that cargo is not to move independently but has to be picked up by a tug, that cargo is sent to the correct aircraft stand, that aircraft follow the schedule provided by KLM, and that aircraft do not have cargo loaded intended for another other aircraft. The conceptual model has been verified by employees of KLM Cargo.

The model's behaviour to changes in the input is also measured by setting up various scenarios where an input parameter is increased or decreased in order to determine whether the model's response is as expected. Each scenario is run 25 times and the average KPI values are shown in table 4.3.

Table 4.3: Verification of the simulation model

Scenario	**OTP** [%]		**Delivery prior to departure** [mins]		**Train length** [# dollies/carts]	
	WB	NB	WB	NB	WB	NB
Baseline	84.04	87.90	128.27	117.65	2.28	1.05
Earlier Deadlines ICA	24.51	87.90	128.27	117.65	2.28	1.05
Earlier Deadlines EUR	84.04	38.17	128.27	117.65	2.28	1.05
Later Deadlines ICA	99.40	87.90	128.27	117.65	2.28	1.05
Later Deadlines EUR	84.04	98.77	128.27	117.65	2.28	1.05
Earlier Availability ICA	99.58	87.92	262.00	117.64	2.28	1.05
Earlier Availability EUR	84.04	99.24	128.27	240.70	2.29	1.05
Later Availability ICA	21.55	87.88	61.39	117.65	2.29	1.05
Later Availability EUR	84.03	35.48	128.26	56.11	2.29	1.05
Single Tug	80.19	86.56	124.35	115.74	2.54	1.36

The standard run in table 4.3 mirrors current operations and allows for other scenarios to be compared. The deadlines of ICA and EUR cargo are set at 80 and 60 minutes prior to departure, respectively. In the scenarios *Earlier Deadlines* these deadlines were doubled, meaning that cargo had to be delivered 160 and 120 minutes prior to departure. Since the availability of ULDs and the process logic was kept constant, the percentage of ULDs delivered on time decreased from 84% to 24% for wide-body cargo, and from 88% to 38% for narrow-body cargo. Conversely, halving the deadlines to 40 and 30 minutes prior to departure, the OTP increased from 84% and 88% to more than 99% for both wide- and narrow-body cargo.

The simulation model was also verified for its behaviour with cargo being available for transport earlier or later than usual. In the scenarios *Earlier Availability*, the cargo for ICA or EUR was made available twice as long before departure. This had a direct impact on the average time of delivery prior to departure; the value increased significantly in both scenarios. Conversely, decreasing the time between cargo becoming available for transport and the flight's departure leads to a decrease in average time of delivery prior to departure. Indirect effects of this increased and decreased delivery time are the changes in on-time performance; since ULDs are driven out to the apron as they become available, having ULDs become available earlier means a higher on-time performance is achieved.

Finally, if KLM Cargo were to only have one tug in total for transporting all cargo between the warehouse and the A-pier, cargo would have to wait longer at the warehouse for transport. This leads to a slightly lower OTP, less time between delivery and departure, but most importantly, the average length of trains is increased by more than 10% for wide-body cargo and more than 30% for narrow-body cargo. This is due to the fact that multiple batches of ULDs destined for an aircraft stand will have to wait for transport simultaneously, allowing the tug to transport these batches in one ride rather than multiple rides.

Validation

Validation is the step in which the quality of the model is assessed. That is, does the model sufficiently portray reality? Is it the right model? [76] In order to test this, the model's output is compared directly to the KPI values calculated from the empirical dataset from 2018. The values are put side by side in table 4.4 and show the simulation model's performance and its deviation from the empirical dataset.

Table 4.4: Validation of the simulation model

Output Parameter		**Empirical data**	**Simulated value**	**Difference**
On-time performance	WB	78.22	84.04	+7.44%
[%]	NB	86.11	87.90	+2.08%
Avg. delivery prior to departure	WB	123.25	128.27	+4.07%
[mins]	NB	115.10	117.63	+2.22%
Avg. train length	WB	2.28	2.28	-0.18%
[# carts/dollies]	NB	1.06	1.06	-0.61%

A model that is 100% valid does not exist, except for the real system itself. A simulation model can, however, imitate the real system with high accuracy. As shown in table 4.4, the on-time performance for wide-body cargo is slightly higher than measured in the 2018 dataset. This may be explained by the fact that wide-body cargo destined for the A-pier has significantly less distance to cover compared to the wide-body cargo in the dataset, which all had to travel to the D-, E-, F- and G-piers. Due to the shorter driving distance, the cargo can be delivered longer prior to departure, leading to a higher predicted on-time performance and delivery time prior to departure. The same can be said for narrow-body cargo, although the difference in distance between the A-pier and the current B-, C- and D-piers is smaller. This is reflected in the smaller difference in OTP and delivery time prior to departure. The length of the trains in the empirical dataset and the simulated data are virtually identical.

4.7. Conclusion

To answer subquestion 3, the empirical data from the dataset was analysed to determine the distribution of the number of ULDs per wide- and narrow-body flight, as well as the times at which ULDs were delivered prior to the aircraft's scheduled time of departure. Along with the distribution of the train lengths observed in 2018, a Matlab script was used to synthesise a new dataset which was exported as a flight schedule and a cargo arrival table which, as Excel files, could be imported directly by the Simio simulation software.

The simulation model was to use these files as input and, together with the control input of the simulation, determine the number of *Clean VOP* violations, the on-time performance, the total distance driven, the space required on the shunting area of KLM Cargo, the average delivery time prior to departure, and the average length of trains leaving the KLM Cargo facility.

Some values calculated by the simulation model were not relevant for comparison to the empirical data, since these values are calculated for the A-pier only, or because similar data was not available in the empirical dataset. These values include the number of *Clean VOP* violations, the total distance driven, as well as the space required at KLM Cargo for holding cargo. For this reason, the model's quality was assessed using the remaining parameters for both wide- and narrow-body cargo; the on-time performance, the average delivery time prior to departure, and the length of the trains.

While the model is a good representation of the A-pier and the outbound cargo handling procedures to be followed at this pier, it is not a complete model of Schiphol Airport with all eight piers and all flights being generated by the model. It is a model of the A-pier only and as such, it does have a number of limitations. First of all, last minute changes in the flight schedule are not supported since this would require gates to be changed which in most cases would mean other piers would have to be modelled in order to facilitate this. The model also does not take inbound cargo into account. Expanding the model to accommodate inbound cargo would allow for the calculation of the driving distance of the Mulag tugs for both inbound and outbound cargo, where rides may be combined to reduce the overall number of kilometres driven.

Although limited to the A-pier, the model has demonstrated to realistically portray the expected traffic and corresponding outbound cargo flows at the future A-pier. This model will be used in chapter 5 to simulate alternative handling procedures in order to comply with the *Clean VOP* regulations imposed by AAS. These alternative cargo handling strategies will be defined and discussed in chapter 5.

Part III

Design & Evaluate

5
A-pier Cargo Process

In this chapter, the future state of the cargo process under *Clean VOP* conditions around the A-pier will be explored. First, the ideal situation will be discussed, followed by the constraints due to the physical design of the buffer and the rules and regulations. Finally, insight will be given into a number of possible cargo handling alternatives, and these will be tested using the DES model discussed in chapter 4. This will provide an answer to subquestion 4.

5.1. Ideal Situation

An ideal implementation of the *Clean VOP* principle at Schiphol would be an automated, lean concept. Unnecessary steps, or waste, is eliminated and a fully automated cargo transport process ensures safe and reliable cargo transport. Cargo is always received at the warehouse on time and using IT-tooling, KLM Apron Services would know what cargo is to be loaded onto each aircraft and can 'pull' the cargo to the aircraft stand from the cargo warehouse when needed rather than have the cargo waiting on the aircraft stand hours beforehand. This is similar to the pull-process implemented at the FloraHolland flower auction. This would *theoretically* lead to a fully implemented demand-driven system and would remove the waste currently found in the process in the form of transport.

Similar to the Port of Rotterdam, using AGVs to handle all transport between the freight buildings and the aircraft stands will lower operational costs (labour costs) and increase the safety and reliability of the cargo transport. This is achievable because the AGVs are programmed to follow a predefined route and are able to drive precisely and accurately. Conversely, human drivers have a less precise driving behaviour which is more likely to lead to collisions, especially with dollies and carts cutting corners and colliding with infrastructure as a result. Ensuring a large fleet of fully electric AGVs is available, waiting times are reduced and all cargo can be delivered as required, avoiding any late deliveries to Apron Services. Additionally, since the AGVs no longer have an internal combustion engine, their negative impact on the local environment is eliminated.

This solution would create an emission-free, on-demand flow of cargo ensuring timely deliveries and a safer working environment at lower operating costs. However, investment costs for replacing the existing Mulag fleet with autonomous electric vehicles are extremely high, and development and testing of such vehicles would take a number of years. Furthermore, infrastructure changes on the airside are required and regulations must be revised to accommodate driverless vehicles moving between the airport's landside and airside.

5.2. Design Envelope

The solution for the ground handling procedure of cargo at the A-pier is bound by certain functional and non-functional requirements, as well as a number of constraints which are determined partly by KLM and partly by AAS. Together these form the design envelope; the space in which a feasible solution is to be found. For each of the following requirements and constraints, the source of the requirement/constraint is listed in parentheses.

Functional Requirements

- All cargo must be delivered to Apron Services (KLM);
- Aircraft stands must be kept clear of cargo in accordance with the *Clean VOP* regulations (AAS);
- Procedures must be implemented by the time of the opening of the A-pier in December 2020 (KLM & AAS).

Non-functional Requirements

- On-time performance should not deteriorate (KLM);
- Outbound cargo handling procedures should be similar to those at other piers at Schiphol Airport (KLM);

Constraints

- The size and layout of the buffer is fixed and may not be changed (AAS);
- Automated Guided Vehicles are not (yet) allowed on the airside of Schiphol due to enabling process at security checkpoints not being in place (AAS);
- Costs may not be too prohibitive (e.g. replacing the existing fleet of tugs with different vehicles) (KLM).

Based on the requirements and constraints listed, the ideal situation which was explored in section 5.1, is not realistically attainable in terms of costs, time as well as rules and regulations. Instead, a strategy must be found which meets the *Clean VOP* requirements while satisfying the constraints and criteria. Based on the theory analysis in section 2.5, this may be achieved by designing a pull and/or push-pull system to manage the time at which cargo is delivered to the aircraft stand, or modifying the current push system by changing the point of delivery to GS to avoid *Clean VOP* infractions. The following strategies have been drafted up in collaboration with KLM Cargo using these theories.

5.3. Handling Strategy Alternatives

The introduction of the *Clean VOP* concept means that outbound cargo must be handled differently when destined for the A-pier. In order to determine the optimal handling procedure, a number of strategies must be identified and tested. A brainstorm session with KLM Cargo employees (including tug drivers and ride planners) led to a number of combinations of decisions which could be made throughout the cargo handling process which affect the procedure and the time at which the cargo is delivered to Apron Services. The possible alternatives are based on push, pull, push-pull or a combination of these systems; modifying the current push system, converting the current push system to a pull system or using the buffer space provided by AAS to design a push-pull system. Organising these considerations into a decision tree shows the possible outcomes of the decision rules. This decision tree is shown in figure 5.1.

Direct to VOP only suggests the the push system currently in place is replaced by a pull system. Cargo would still only travel directly from the warehouse to the aircraft stand, although the ride is not triggered by the time at which the cargo becomes available, but rather by the arrival time of the aircraft. This ensures that cargo can never be placed on the apron prior to the aircraft's arrival, and does not make use of the A-pier buffer at all. This is referred to as strategy 1. A different approach, however, is that cargo may be placed in the buffer underneath the A-pier. *Force to buffer* suggests that *all* cargo is pushed to the buffer as soon as it becomes available for transport. Strategy 2 means cargo is delivered to Apron Services at the buffer, meaning that the current push principle is used, but that the point of

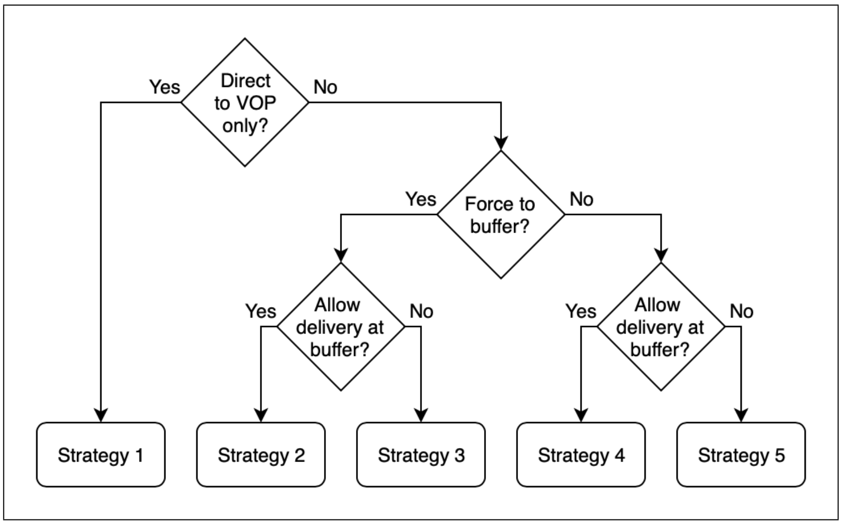

Figure 5.1: Decision tree for handling procedure strategies at the A-pier.

delivery is changed from the aircraft stand to the buffer. From this point, Apron Services is responsible for the handling and loading of the cargo. Strategy 3, however, embraces the push-pull logic discussed in section 2.5, where cargo is pushed directly to the buffer, where is waits until it is needed by Apron Services. At this point, KLM Cargo moves the ULDs from the buffer to the aircraft. Strategies 4 and 5 are variants of strategies 2 and 3, respectively, in that cargo is not forced to be placed in the buffer. These strategies facilitate direct rides from the warehouse to the aircraft after the aircraft has arrived at the gate.

Since the decisions *Direct to VOP only*, *Force to buffer* and *Allow delivery at buffer* can be represented as a binary variable (i.e. each can be answered with *yes* or *no*), a table can be constructed showing all possible combination sets. These eight combinations can be seen in table 5.1.

Table 5.1: Determining feasible strategies from process logic combination sets

Set	**Direct to VOP Only**	**Force To Buffer**	**Allow Delivery at Buffer**	**Strategy**
1	Yes	Yes	Yes	
2	Yes	Yes	No	
3	Yes	No	Yes	
4	Yes	No	No	Strategy 1
5	No	Yes	Yes	Strategy 2
6	No	Yes	No	Strategy 3
7	No	No	Yes	Strategy 4
8	No	No	No	Strategy 5

Sets containing red pairs indicate infeasible strategies due to contradicting decision rules. Sets 1 and 2, for example, force all cargo to be brought directly to the aircraft stand as well as to the cargo buffer underneath the A-pier. Set 3 also forces cargo to be brought from the warehouse directly to the aircraft stand, while cargo may also be delivered at the buffer. This contradiction causes this strategy to be infeasible. The remaining five strategies, the same as those identified through the decision tree in figure 5.1, will be described in the following subsections along with the expected benefits and drawbacks of each alternative.

Strategy 1: Direct deliveries only

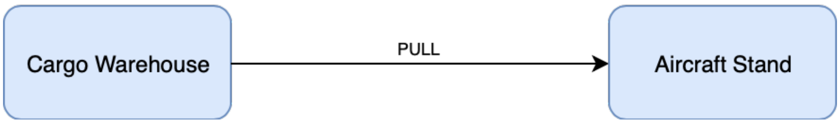

Figure 5.2: Strategy 1: Direct deliveries to aircraft only

The first strategy redesigns the current cargo handling strategy and uses pull logic to trigger the transportation of cargo from the warehouse to the aircraft stand by the arrival of the aircraft. This approach, therefore, simply delays the point in time at which the cargo is sent to airside from the cargo premises.

In this strategy, *Clean VOP* violations are avoided since cargo only leaves the KLM Cargo premises once the aircraft has arrived, meaning KLM is free to position cargo on the aircraft stand. Since the buffer is not used, a maximum utilisation of zero is expected. It is also expected that this strategy minimises the total number of kilometres driven by tugs for the transportation of cargo to the A-pier, since the buffer is bypassed and all rides are directly between the origin and destination. Furthermore, based on the conclusions drawn by Binneveld [47], this method is expected to reduce the number of incomplete orders sent out to customers, i.e. fewer rides will be required to deliver all cargo to Apron Services, which should translate to a further reduction in the kilometres driven by the cargo tugs.

The downside to this approach may be that more space at the cargo warehouse will be occupied by cargo awaiting the arrival of its aircraft. Furthermore, since all three wide-body aircraft stands are typically filled within less than an hour of each other, this approach is likely to cause a peak in demand for rides from the cargo warehouse to the apron. Finally, one consideration is that some narrow-body aircraft will have a turnaround of less than 60 minutes, while the cargo delivery deadline for narrow-body cargo is set at 60 minutes. Given the current delivery deadlines, this cargo by definition will never be delivered on time, meaning the OTP is expected to suffer.

Strategy 2: All cargo delivered to buffer

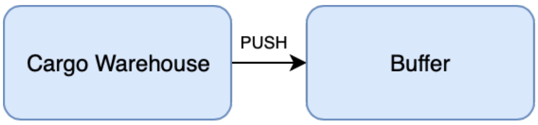

Figure 5.3: Strategy 2: All cargo delivered to buffer

Another approach would be to use the push system currently in place, but to embrace the availability of the centralised buffer by changing the location where cargo is handed over to Apron Services. By delivering cargo to Apron Services *in* the A-pier buffer, no *Clean VOP* restrictions apply as the buffer is always accessible. From the buffer, Apron Services would pick up the cargo needed for loading, ensuring only the required cargo is brought to the aircraft stand.

The benefits of this approach are twofold. First, KLM Cargo's shunting area is kept as empty as possible by pushing cargo out to the airside as soon as it becomes available for transport. Secondly, the cargo placed on the aircraft stand is controlled by Apron Services, who oversee the turnaround process of the aircraft, instead of all cargo being placed on the aircraft stand simultaneously. This may make it easier to Apron Services to load the aircraft since cargo takes up less space on the aircraft stand.

A possible drawback to this approach would be that this is a slightly different handling procedure than at other piers, where cargo is always delivered to Apron Services at the aircraft stand. Also, sending all cargo to the buffer may lead to an over-utilised buffer which can result in *Clean VOP* violations due to a lack of available buffer space. Finally, this approach would require IT systems to be put in place which communicate to Apron Services the delivery time and location of cargo placed in the buffer. This is necessary so that KLM employees do not need to search for the cargo within the buffer, but can simply see which buffer lane the cargo is stored in.

Strategy 3: All cargo buffered until needed

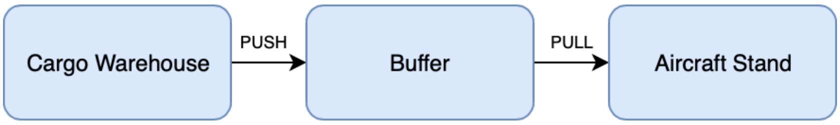

Figure 5.4: Strategy 3: All cargo buffered until needed

Similarly to the previous strategy, all A-pier cargo is sent to the buffer in order to vacate the space on KLM Cargo's shunting area, while adhering to the *Clean VOP* regulations. However, in this variant, KLM Cargo remains responsible for the delivery of cargo to the aircraft stand. This means that when all cargo is buffered, KLM Cargo will also provide the transport from the buffer to the aircraft stand once the aircraft has arrived. This means the strategy follows the push-pull principle as discussed by Takahashi and Nakamura [57].

The benefit of this system is that no investments need to be made for the creation of an interface between the cargo system and the Apron Services system in order to communicate the delivery and location of cargo, since the buffer location of cargo is not of interest to Apron Services.

One drawback, however, is that extra rides will have to be completed by the transport department. This leads to a higher distance covered by the Mulag tugs since all cargo must first be delivered to the buffer, and a second ride needs to be completed in order to move the cargo from the buffer to the aircraft. In strategy 2, this second ride was completed by Apron Services who is already present at the A-pier, whereas in this strategy, a KLM Cargo tug must drive from the cargo premises to the A-pier and back in order to deliver the cargo to Apron Services.

Strategy 4: Deliveries to buffer and to aircraft

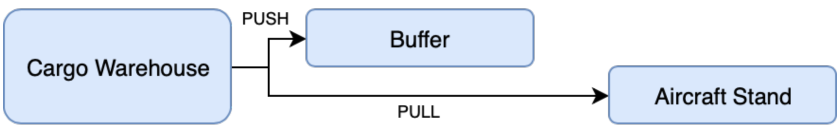

Figure 5.5: Strategy 4: Deliveries to buffer and to aircraft

In the fourth strategy, a combination of strategies 1 and 2 is used. The destination of the cargo is determined at the time at which it becomes available for transport. If, when departing the cargo premises, the aircraft is present on the aircraft stand, cargo may be driven directly to the aircraft and handed over to Apron Services on the aircraft stand. However, if the aircraft has not yet arrived, the cargo is to be brought to the A-pier buffer and handed over to Apron Services there. This approach touches upon the lean concepts discussed in section 2.5 by moving cargo directly to the aircraft when possible, while ensuring the space required for storing cargo on KLM Cargo's shunting area is minimised by using the buffer when the aircraft has not yet arrived. This reduces the waste of *transport* compared to strategy 2.

Whether the aircraft is present or not at the time of cargo transportation, KLM Cargo will only have to perform one ride per train of ULDs. Cargo brought to the buffer is taken to the aircraft by Apron Services once they are needed, similar to strategy 2, since they are already present at the A-pier.

One possible drawback of this approach, however, is the fact that cargo destined for one flight will oftentimes be delivered to Apron Services in different locations. This approach would require close communication with Apron Services to ensure that no ULDs are left behind, since rebooking cargo onto new flights is costly, and reduces the level of quality delivered by KLM Cargo to its customers.

Strategy 5: Direct and buffered deliveries to aircraft

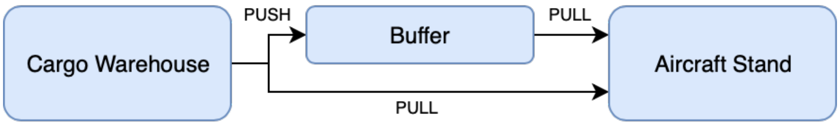

Figure 5.6: Strategy 5: Direct and buffered deliveries to aircraft

The final strategy is also a hybrid. It combines strategies 1 and 3; cargo is brought to the aircraft stand unless the aircraft is not yet present, in which case it is brought to the buffer underneath the A-pier. However, contrary to strategy 4, cargo must always be delivered to Apron Services at the aircraft itself. This means that KLM Cargo must transport the ULDs from the buffer to the aircraft stand once the aircraft has arrived. This would be the result of the silo mentality described in section 1.1; departments with a common goal not working together as a result of a lack of transparency and communication. This strategy is expected to lead to more distance covered by the cargo tugs, since some ULDs will require a cargo tug to drive to and from the A-pier multiple times. However, the distance should be less than that of strategy 3, since some of the rides will be driven directly to the aircraft instead of through the buffer.

The benefit of this approach compared to strategy 4, however, is that there is a single place for delivering cargo to Apron Services. This would mean that the standard operating procedures for cargo destined for the A-pier would be similar to those at other piers, since all cargo has to be delivered to the aircraft itself.

5.4. Uniformity of Handling Procedures

Each of the strategies described in section 5.3 follow a process which may be different to some extent to the current procedures at Schiphol. As mentioned in the stakeholder analysis in section 3.2, a strategy which does not differ greatly from procedures at other piers would be preferred since this is beneficial for training purposes as well as operational and safety purposes. However, the uniformity of operating procedures is not a criterion for the selection of the optimal cargo handling strategy. It is expected that the procedures will differ to some extent since the *Clean VOP* will (initially) only be implemented at the A-pier. Table 5.2 summarises the expected differences of each strategy compared to handling procedures at other piers from a tug driver's perspective.

Table 5.2: Differences in handling procedures for each A-pier handling strategy

Strategy	Similarity	Description
1	Identical	For tug drivers there is no difference in the handling procedures between the A-pier and the other piers. Cargo is always driven from the cargo premises to the aircraft stand, without the use of an intermediate buffer.
2	Slightly different	All cargo is delivered to the buffer underneath the A-pier instead of the aircraft stand. The tug driver only sees the buffer as the destination for the cargo.
3	Slightly different	All cargo is sent directly to the A-pier buffer and parked there. When the aircraft arrives, a ride is generated from the buffer to the correct aircraft stand, which is then assigned to a cargo tug driver.
4	Very different	The location of the handover to Apron Services is dependent on whether or not the aircraft has arrived at the time at which the cargo becomes available for transport. This may lead to confusion and/or unsafe situations such as *Clean VOP* violations.
5	Slightly different	Cargo is routed either directly to the aircraft, or to the buffer if the aircraft has not yet arrived. A second ride from the buffer to the aircraft stand is generated once the aircraft arrives, and a cargo tug driver will deliver the cargo at the aircraft.

5.5. Conceptual Models

The delivery strategies discussed in section 5.3 are translated into conceptual models which illustrate the model's decision logic for each of the cargo handling alternatives at the A-pier. These conceptual models will be shown and discussed on the following pages.

Strategy 1: Direct deliveries only

As discussed in section 5.3, strategy 1 ensures all cargo destined for the A-pier is delivered straight to the aircraft stand. The cargo is to stay at the warehouse's shunting area until the aircraft arrives, at which point the cargo will be sent to the aircraft stand.

Any delays of arriving aircraft translate into cargo being held at the warehouse longer. KLM Cargo's transport department remains responsible for the cargo until delivered to Apron Services at the aircraft itself.

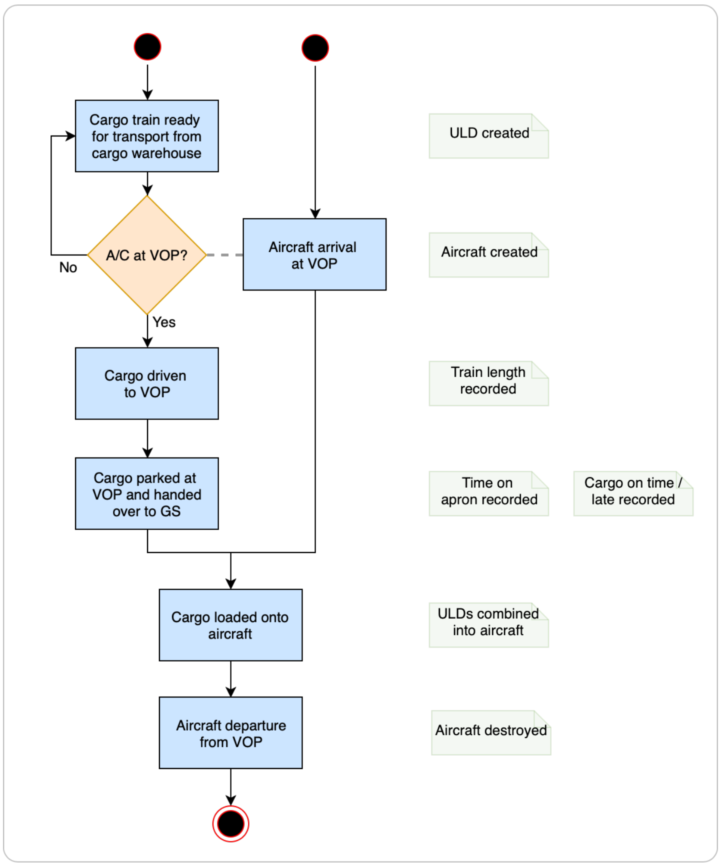

Figure 5.7: Conceptual model 1: Direct deliveries only

Strategy 2: Delivery to buffer only

In strategy 2, all cargo destined for the A-pier is to be delivered to Apron Services at the buffer, where the time of delivery is recorded (for OTP calculation purposes). This means that KLM Cargo does not need to consider whether or not the aircraft has arrived, since the transport department will not bring any cargo to the aircraft stand. Cargo in the A-pier buffer becomes the responsibility of Apron Services, who will ensure that cargo is brought from the buffer to the aircraft stand once the cargo is due to be loaded onto the aircraft.

One exception occurs when the buffer is full. In this case, KLM Cargo will deliver the freight to the aircraft stand (regardless of the presence of the aircraft). If this happens when the aircraft is not yet present, this is recorded as a *Clean VOP* violation.

The model also considers the time at which Apron Services retrieves cargo from the buffer. Since this may be *after* the cargo delivery deadline—since the cargo is already delivered to Apron Services—this can put more pressure on the buffer capacity.

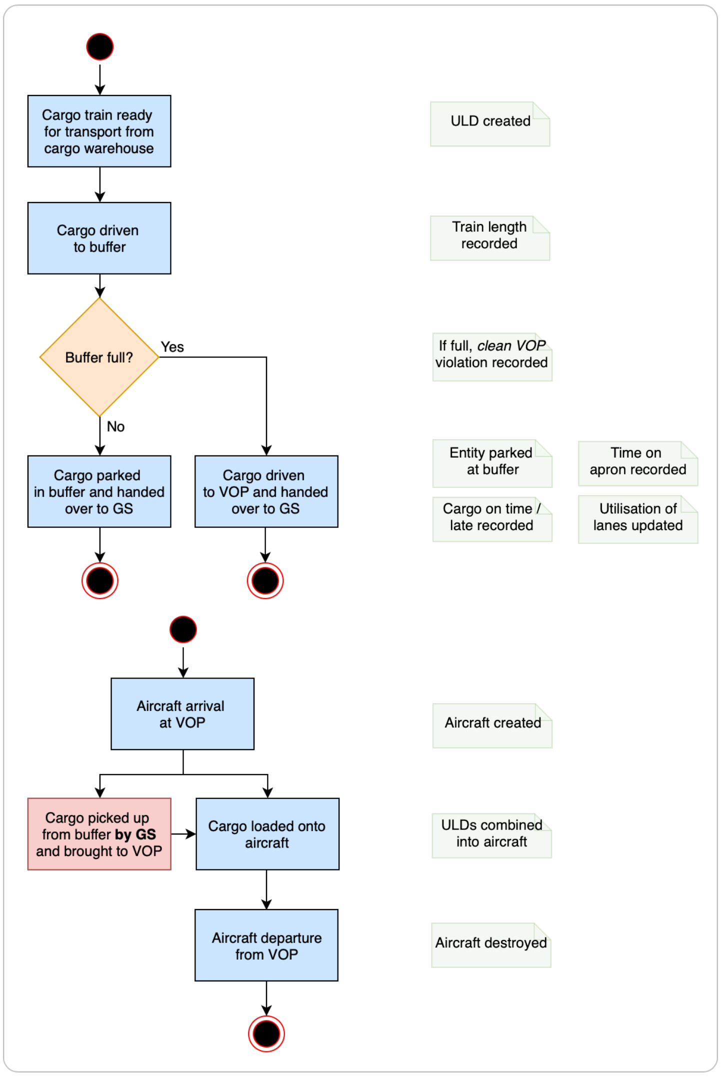

Figure 5.8: Conceptual model 2: Delivery to buffer only

Strategy 3: Delivery to aircraft stand via buffer

In this strategy, all cargo is driven to the buffer and parked in a vacant lane. Since KLM Cargo remains responsible for the delivery of the cargo to the aircraft stand, the cargo will be picked up from the buffer and brought to the aircraft stand after the aircraft arrives. At the aircraft stand, the time of delivery is recorded and responsibility over the cargo is transferred to Apron Services.

In the case of the buffer being full, the cargo will have to be forwarded to the aircraft stand, despite the aircraft not being present yet. This will lead to a *Clean VOP* violation, meaning this should happen as little as possible. Simulation will be used to determine whether or not the available buffer capacity is sufficient for this strategy.

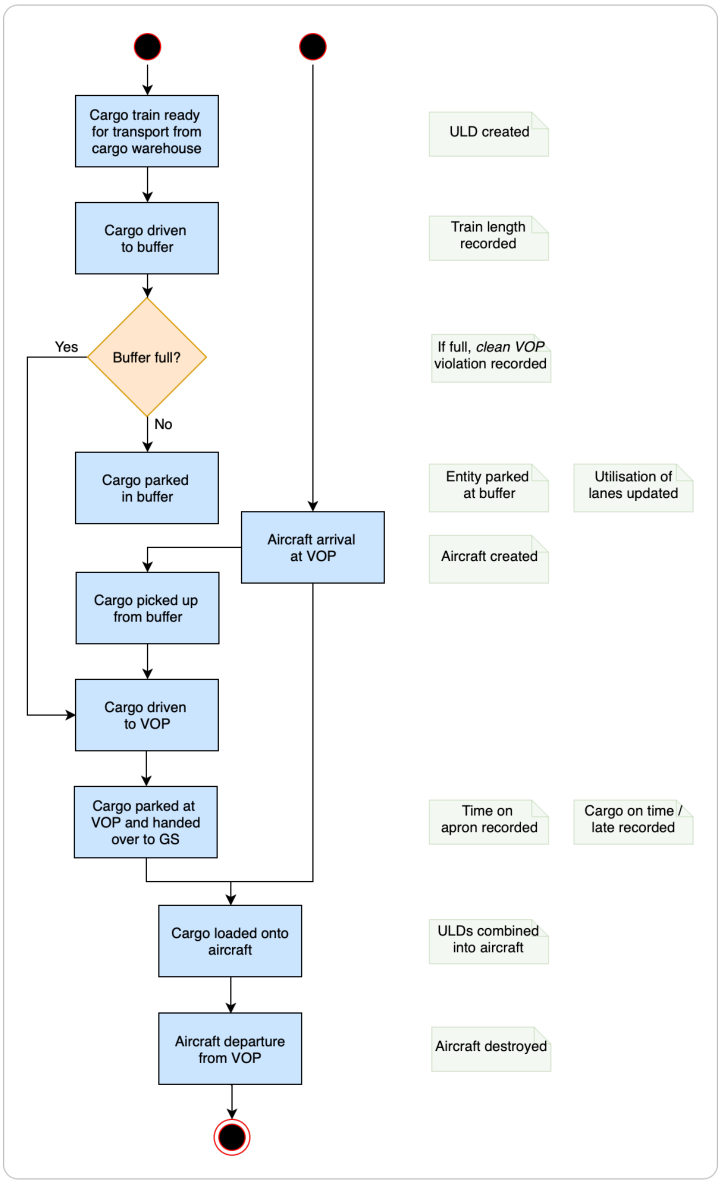

Figure 5.9: Conceptual model 3: Delivery to aircraft stand via buffer

Strategy 4: Deliveries to buffer or to aircraft

In the fourth strategy, the destination of the cargo is determined once it becomes available for transport. When the cargo is driven to the apron *before* the aircraft is present, the cargo is driven to the A-pier buffer, parked in a vacant lane and handed over to Apron Services at that point. However, if the aircraft *is* present at the time cargo is being driven to the apron, the cargo is delivered to Apron Services at the aircraft itself. The time of delivery of each ULD is therefore recorded at the buffer *or* at the aircraft stand, depending on where the ULD is delivered.

If, upon arrival at the buffer, no buffer lanes are available, the cargo is sent to the aircraft stand regardless of the aircraft's presence, similar to strategies 2 and 3. The delivery time will be recorded at the aircraft stand and a violation will be recorded for each ULD.

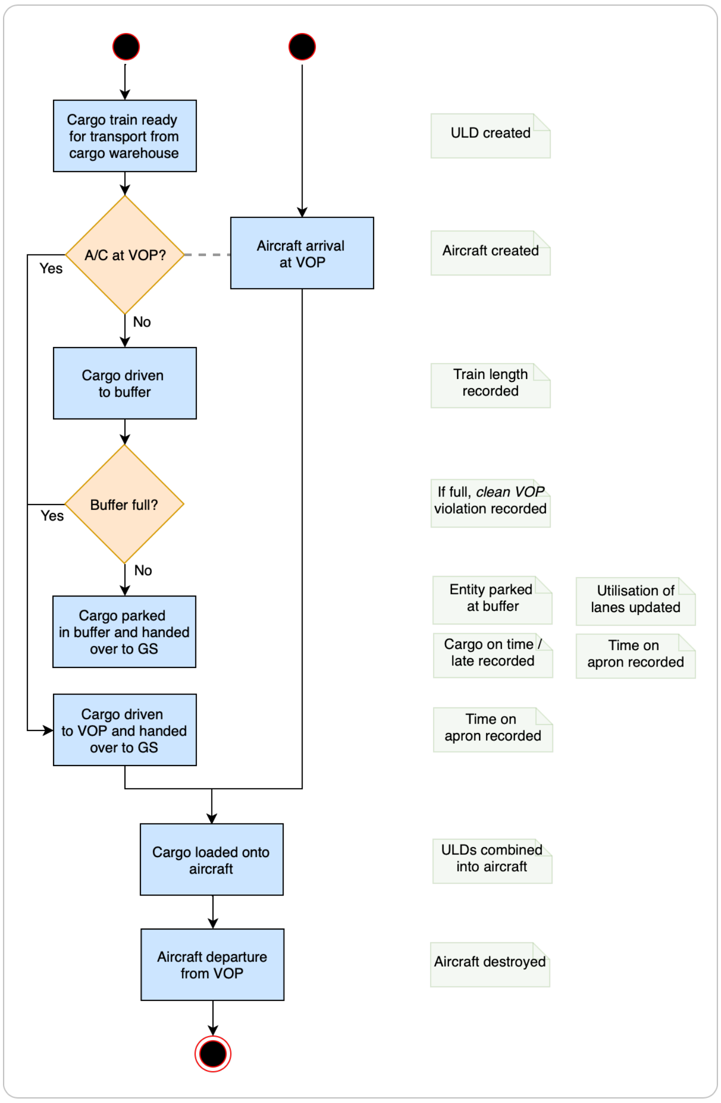

Figure 5.10: Conceptual model 4: Deliveries to buffer or to aircraft

Strategy 5: Combination of direct and indirect deliveries

In the final strategy, the routing of the cargo is determined at the time at which it becomes available for transport. When the cargo is ready to be transported while the aircraft is already at the aircraft stand, the cargo is sent straight to the aircraft. However, if the aircraft is *not* yet present, cargo will be buffered underneath the A-pier until the aircraft arrives. Buffered cargo will subsequently request to be brought to the aircraft stand by a KLM Cargo tug once the aircraft arrives.

If, upon arrival at the buffer, no buffer lanes are available, the cargo is sent to the aircraft stand regardless of the aircraft's presence, similar to previous strategies. The delivery time will be recorded at the aircraft stand and a violation will be recorded for each ULD.

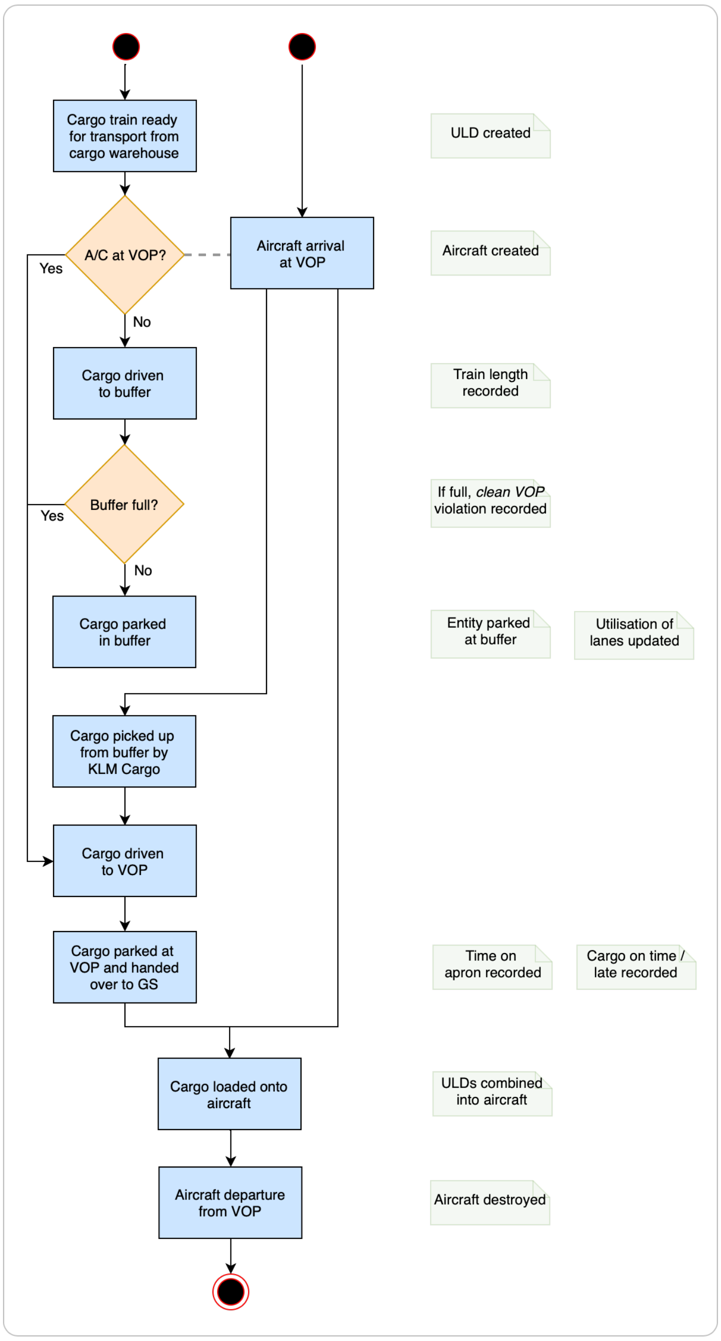

Figure 5.11: Conceptual model 5: Combination of direct and indirect deliveries

5.6. Simulation Results

In order to predict the effects of each of the cargo handling strategies for the A-pier, the five strategies were tested in the DES model described in chapter 4. Each strategy was run 25 times with a duration of four weeks and the average of these runs was recorded for the simulation results.

The results of the experiment with the current cargo delivery deadlines are shown in table 5.3, where *Violations* indicates the number of ULDs placed on and empty aircraft stand in the simulated month, and *OTP* represents the on-time performance; the percentage of ULDs delivered on or before their delivery deadline. The *Max. Utilisation* shows the (average) maximum recorded utilisation of the A-pier buffer in the simulated month, and *Distance* refers to the distance driven by all tugs in a month for the handling of outbound cargo at the A-pier. Finally, *Space* indicates how many ULDs need to be accommodated on KLM Cargo's shunting space simultaneously (for the A-pier) as a result of the chosen handling strategy. The full results for these strategies in combination with later delivery deadlines can be found in appendix D.

Table 5.3: Simulation results of outbound cargo handling strategies for the A-pier

Strategy	**Violations** [# ULDs]	**OTP** [%]	**Max. Utilisation** [%]	**Distance** [km]	**Space** [# ULDs]
Baseline	1,319.88	85.38	0.00	1,684.94	8.16
Strategy 1	0.00	55.89	0.00	1,349.39	23.50
Strategy 2	14.15	84.97	99.61	2,949.04	8.15
Strategy 3	0.00	51.01	80.26	3,239.75	8.18
Strategy 4	0.00	85.27	72.05	2,492.31	8.14
Strategy 5	0.00	54.38	70.18	2,735.00	8.10

5.7. Changes in Delivery Deadlines

The results in table 5.3 show the KPI values achieved when the cargo delivery deadlines remain at 80 and 60 minutes prior to departure for ICA and EUR flight, respectively. However, these deadlines may be changed if KLM Cargo and Apron Services agree to new standards. To determine whether changing the deadlines has any impact on the optimal strategy, the simulation is run multiple times with the delivery deadlines decremented by ten minutes each time (with a minimum of 50 and 30 minutes for ICA and EUR, respectively). Figure 5.12 shows the effect of moving the cargo delivery deadlines closer to departure on the on-time performance of the system. As shown, all strategies achieve an on-time performance of more than 80% when deadlines are shifted 30 minutes closer to departure. This suggests that a change in cargo delivery deadlines may lead to a different optimum delivery strategy.

Modifying the cargo delivery deadlines leads to a change in the calculated on-time performance because the point at which ULDs would be considered late is shifted. Furthermore, the number of *Clean VOP* violations recorded using strategy 2 increases, as shown by figure 5.13 (other strategies did not result in *Clean VOP* violations). This is due to the fact that in strategy 2, Apron Services is responsible for the collection of the cargo which is delivered to the A-pier buffer. However, since the deadline for the deliveries is later, Apron Services can also free up the buffer space at a later time, causing the buffer to be over-utilised and forcing more tug drivers to deliver cargo to the aircraft stand prior to the aircraft being present.

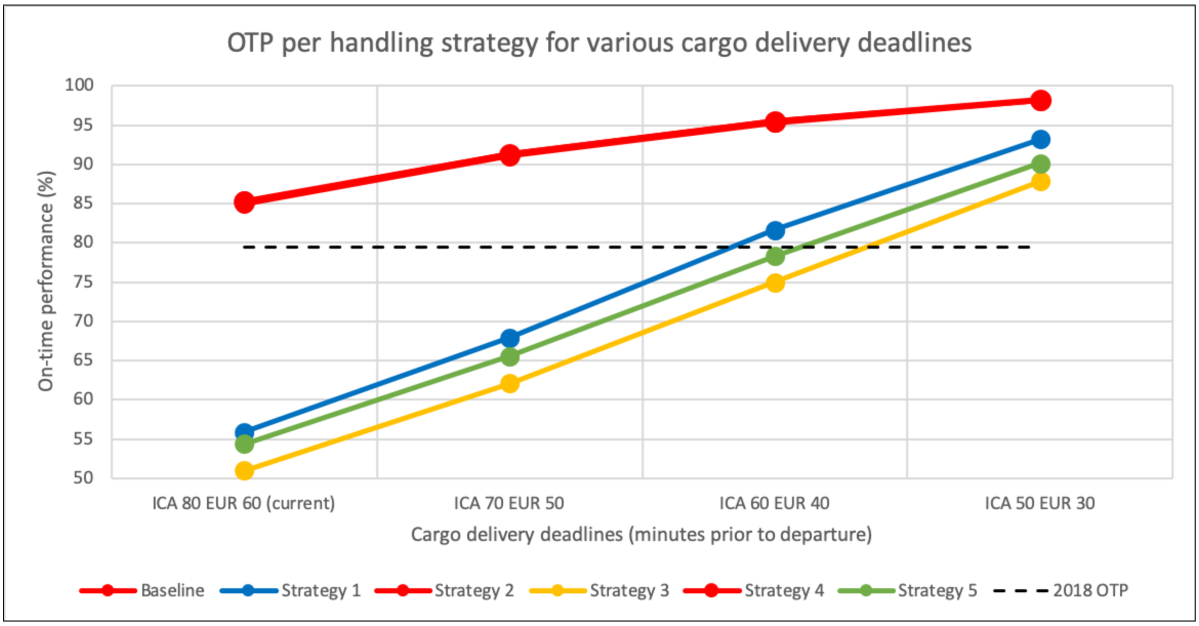

Figure 5.12: On-time performance per strategy for various cargo delivery deadlines

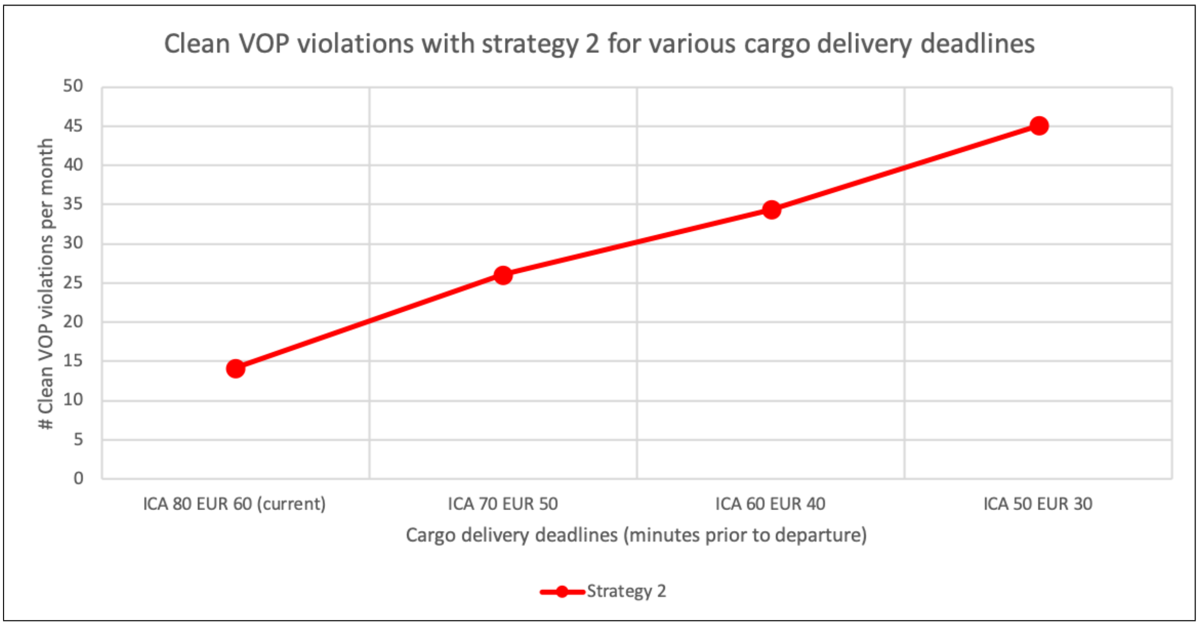

Figure 5.13: *Clean VOP* violations as a result of strategy 2 with various cargo delivery deadlines

5.8. Summary

The KPIs of the five handling strategies which were simulated using the DES model indicate that the different approaches have significant impacts on the operational performance. While strategy 2 leads to *Clean VOP* violations, strategies 1, 3 and 5 lead to a decrease in on-time performance. Furthermore, while strategy 1 leads to a slight decrease in the distance covered by the cargo tugs (at the cost of increased space usage), strategies 2 through 5 lead to a distance increase of 48–92%. In order to determine which of the above strategies would be the optimal strategy to follow, the strategies will be analysed and ranked using the analytic hierarchy process in chapter 6.

6 Analytic Hierarchy Process

In this chapter, the analytic hierarchy process (AHP) will be used to analyse the results from the simulation model found in chapter 5 in order to determine which strategy would be the optimal strategy to employ for meeting the *Clean VOP* requirements at the future A-pier. To compare the strategies to one another, weights must be assigned to each of the key performance indicators to represent the relative importance of each indicator, and KPI values must be normalised. After doing so, the strategies can be ranked using these weights [1].

6.1. Weight Assignments

Since not all KPIs are of equal importance to the problem owner, weights were assigned to the KPIs in order to take the problem owner's preferences into account when ranking the simulated strategies. This was done using the AHP method with a number of KLM Cargo employees: a project manager, a ride planner and a tug driver. This group of employees represented KLM Cargo as the *problem owner* for the A-pier.

The key performance indicators were presented to the problem owner, where for each combination of KPIs the problem owner would select which of the two was more important and to what extent. This was done by assigning a score between 1 (equally important) and 9 (infinitely more important) to the more important KPI, and assigned score's reciprocal to the less important KPI. This leads to a pairwise comparison matrix mirrored along the diagonal as shown in table 6.1. To calculate each KPI's weight, the sum of the row was divided by the sum of all rows, resulting in a weight between 0 and 1 [1].

Table 6.1: Pairwise comparison matrix of KPIs [1]

	Violations	**OTP**	**Max. Utilisation**	**Distance**	**Space**	**Weight**
Violations	1	2	5	4	5	0.355
OTP	1/2	1	5	4	6	0.345
Max. Utilisation	1/5	1/5	1	1/2	1	0.061
Distance	1/4	1/4	2	1	1/2	0.084
Space	1/5	1/4	4	2	1	0.156

Although this approach is a systematic way of assigning weights, it is also prone to inconsistencies on the problem owner's part. To account for this, a check was done for inconsistency using the consistency ratio as described by Saaty [1]. The online AHP-OS tool was used to calculate the consistency ratio of the pairwise comparison matrix completed by weights assigned to the KPIs by KLM Cargo [77]. Saaty stated that only pairwise comparison matrices with consistency ratios $CR < 0.1$ are to be accepted. The resulting consistency ratio of the weights assigned to the KPIs in this case study was 0.057, which means that the pairwise comparisons were done with an acceptably high level of consistency. Therefore, the weights displayed in the last column in table 6.1 are used as weights for each of the KPIs.

6.2. Data Normalisation

The same AHP method was used to normalise the output values of the DES model, allowing the values of each KPI to be compared to one another. The result is that all indicators have values between 0 and 1, with higher values being more favourable. The matrices used for the normalisation of the values can be found in appendix E, and the resulting normalised values for all outbound cargo handling strategies are shown in table 6.2, where all values are between 0 and 1, with higher values being more desirable.

Table 6.2: Normalised KPI scores of each strategy

	Violations	**OTP**	**Max. Utilisation**	**Distance**	**Space**
Baseline	0.058	0.369	0.547	0.216	0.187
Strategy 1	0.723	0.056	0.547	0.270	0.065
Strategy 2	0.219	0.369	0.112	0.123	0.187
Strategy 3	0.723	0.056	0.341	0.112	0.186
Strategy 4	0.723	0.369	0.112	0.146	0.187
Strategy 5	0.723	0.056	0.341	0.133	0.188

6.3. Ranking of the Alternatives

With all output values being normalised and each KPI having been assigned a weight by the problem owner, each strategy can be given a total weighted score. This weighted score was calculated as the sum of each KPI value multiplied by its KPI weight. The resulting weighted scores are shown in table 6.3.

Table 6.3: Ranking of ountbound cargo handling strategies at the A-pier

	Violations *0.355*	**OTP** *0.345*	**Max. Utilisation** *0.061*	**Distance** *0.084*	**Space** *0.156*	**Weighted Score**	**Rank**
Baseline	0.058	0.369	0.547	0.216	0.187	0.228	6
Strategy 1	0.723	0.056	0.547	0.270	0.065	0.342	2
Strategy 2	0.219	0.369	0.112	0.123	0.187	0.251	5
Strategy 3	0.723	0.056	0.341	0.112	0.186	0.335	4
Strategy 4	0.723	0.369	0.112	0.146	0.187	0.432	1
Strategy 5	0.723	0.056	0.341	0.133	0.188	0.337	3

As shown, the strategy with the highest weighted score is strategy 4. The worst performing strategy is the current strategy closely followed by strategy 2, which is due to the *Clean VOP* violations which are heavily penalised in the assessments of the strategy's performance. Strategies 1, 3 and 5 suffer from a low on-time performance due to the current cargo delivery deadlines. Since OTP was assigned a large weight by the problem owner, an alternative handling strategy leading to a significantly lower on-time performance is not preferred. Strategy 1, however, is considered the second best alternative due to the fact that distance is minimised by not using the buffer space and only delivering cargo directly to the aircraft. However, the combination of the first strategy's poor OTP and the fact that the cargo would take up significantly more space at KLM Cargo's shunting area, led to strategy 4 being the optimal strategy to employ with no *Clean VOP* violations and an on-time performance on par with the current performance at Schiphol.

6.4. Changes in Delivery Deadlines

Since KLM Cargo may agree with Apron Services to change the cargo delivery deadlines for all piers at Schiphol, the effect of different delivery deadlines on the ranking of the outbound cargo handling strategies for the A-pier was also analysed using the same AHP method as above. As discussed in section 5.7, changing the cargo delivery deadlines has a direct effect on the on-time performance of all strategies. Indirect effects include changes in the number of *Clean VOP* violation, and (small) changes in the driven distance[1]. Figure 6.1 shows the effect that the different cargo delivery deadlines have on the strategies' weighted scores and their ranking.

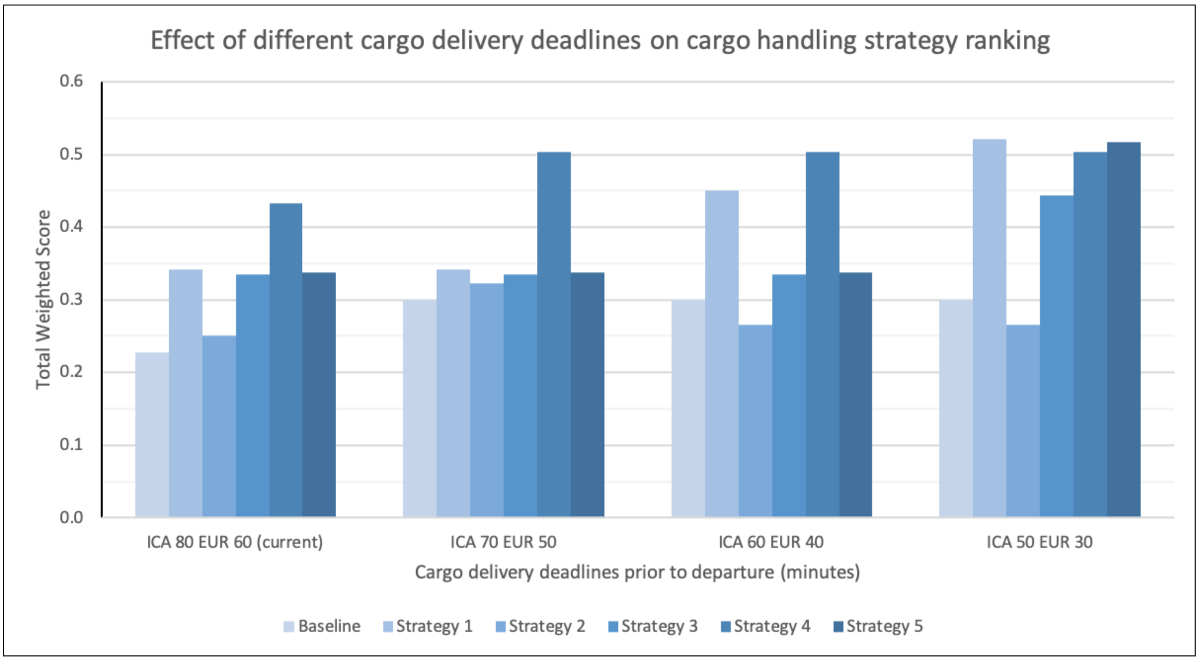

Figure 6.1: Effect of different cargo delivery deadlines on cargo handling strategy ranking

As the deadlines get closer to the departure time of the aircraft, all strategies achieve or surpass the current benchmark OTP of 80%. When deadlines for both ICA and EUR cargo are shifted 30 minutes closer to departure, the top rankings of the cargo handling strategies change: strategy 1 attains the highest weighted score of all strategies, making this the best strategy to implement. Strategy 1 is closely followed by strategy 5, which also achieves a weighted score slightly higher than strategy 4.

For this reason, the outbound cargo delivery deadlines which are agreed upon by KLM Cargo and Apron Services play an important role in the selection of the optimal cargo handling strategy for the A-pier. If these deadlines were to be shifted significantly closer to the time of departure, a different handling strategy may produce better overall results.

[1]All result tables for the four simulated deadline combinations can be found in appendix D

7 Conclusions & Recommendations

In this chapter, conclusions will be drawn from the case study at KLM Cargo and the simulation model used. The answers to the subquestions given in previous chapters will be discussed, after which the main research question will be answered. Furthermore, the limitations of the study will be discussed, along with recommendations for future research and practical recommendations for KLM.

7.1. Conclusions

This research first looked into literature on the subject of air cargo and ground handling, as well as relevant technologies found in other industries, in order to answer the first subquestion:

1. *What strategies and technologies are used for buffering and/or help in facilitating on-time deliveries at other airports or in other industries?*

Industries such as air cargo, airport baggage handling, container terminals, flower auctions and railway yards were explored. While air cargo still heavily relies on a push system, airport baggage handling and the flower auctions experience the benefits of a pull system, as discussed in chapter 2. A push-pull system could also be implemented when cargo would be buffered underneath the pier, combining the benefits of push logic and pull logic. With any handling strategy, however, airlines are bound by procedures outlined in IATA's Ground Operating Manual. This means that the location information of buffered cargo must always be known and the airworthiness of the cargo must be verified on the aircraft stand prior to loading (regardless of who transports the cargo to the aircraft stand). This procedure is currently carried out by the cargo handler, but the IGOM does not specify that the aircraft handlers cannot perform this inspection instead. While AGVs have the potential of increasing reliability, air quality and safety, current system constraints mean that a solution requiring AGVs would be considered infeasible at this time. For this reason, a solution is to be found using push-, pull- and/or push-pull approaches, either using the provided buffer space, or not.

The second subquestion of this research was:

2. *How is cargo currently transported from the warehouse to the aircraft, and why is this process insufficient for operations at the A-pier?*

In the current state, KLM Cargo is responsible for the delivery of cargo to Apron Services at the aircraft stand. Cargo may be positioned on the aircraft stand regardless of the presence of the aircraft, with Apron Services being responsible for the loading of the cargo onto the aircraft. Besides these two actors, KLM's Safety & Security department oversees the processes from an occupational safety point of view, as well as the cargo's security's point of view. Since the *Clean VOP* policy is not enforced anywhere at Schiphol Airport, there are no restrictions as to when cargo may be placed on the aircraft stand, meaning that KLM Cargo's transport department can free up space on its shunting area by sending cargo to the aircraft stand up to five hours prior to departure. When AAS introduces the *Clean VOP* policy, the current procedure will be insufficient due to the fact that cargo is placed on the apron regardless of the aircraft's presence. The handling strategy must be redesigned for the A-pier to account for the stricter delivery time windows to ensure that cargo is not placed on the aircraft stand illegally. Violating the *Clean VOP* is likely to lead to sanctions from the airport authority.

The current system was then analysed to determine the quality of its performance in order to answer subquestion 3:

3. *How does the current cargo handling system perform in terms of punctual cargo deliveries to the aircraft stand?*

An empirical dataset was used to analyse the outbound cargo rides from December 2017 to December 2018. The data indicated that an on-time performance of 78% and 86% was achieved for WB and NB cargo, respectively, with cargo being placed on the aircraft stand an average of 123 and 115 minutes prior to departure for WB and NB aircraft, respectively. Given the distances to the piers is greater than the distance to the future A-pier, the DES model indicated cargo is positioned slightly longer prior to departure, resulting in a 2–7% increase in on-time performance. The DES model was verified and validated with multiple KLM Cargo employees and through testing with control values. The model could therefore also be used to predict the effect of various cargo handling strategies on the KPIs.

Redesigned handling strategies were therefore simulated using the model to find the answer to subquestion 4:

4. *How do different handling strategies affect the performance of outbound cargo transportation under Clean VOP regulations?*

Five handling strategies were defined, based on the literature found on push-, pull- and push-pull-systems. Strategy 1 was based on a pull system; the buffer would not be used and KLM Cargo would hold all cargo destined for the A-pier on the shunting area until the aircraft arrived. Strategy 2 embraced the current push system, but changes the location of the delivery to Apron Services to the buffer lanes underneath the pier. Strategy 3 would implement a push-pull system, with all cargo being pushed directly to the A-pier buffer once it becomes available for transport. From the buffer, KLM Cargo would have to transport the cargo to the aircraft stand once the aircraft arrives. Strategy 4 allowed early cargo to be delivered to Apron Services in the buffer space, but would send cargo directly from the warehouse to the aircraft once the aircraft arrives, resulting in a hybrid of a push system and pull system. Finally, strategy 5 is hybrid of the push-pull and the pull systems. Cargo which is available prior to the aircraft's arrival is pushed to the buffer. After the aircraft's arrival at the A-pier, remaining cargo is sent directly to the aircraft, while buffered cargo is retrieved from the buffer and brought to Apron Services at the aircraft stand.

As for the performance of the different handling strategies, strategies 2 and 4 are able to maintain a high on-time performance in excess of 80%. The remaining strategies attain OTPs of 51–56%. While strategy 1 ensures that the distance driven by the Mulags is minimised by *only* driving directly between the warehouse and the aircraft, it does so by increasing the usage of the shunting area on the cargo premises. Other strategies do not use extra space on the shunting area, but make use of the A-pier buffer. The maximum utilisation of the buffer ranges from 70–100%, where only strategy 2 leads to IGOM and *Clean VOP* violations due to its demand for buffer lanes exceeding the supply, causing ULDs to be parked illegally on the aircraft stand.

The answers to the subquestions, along with the conclusions drawn from the AHP method used in chapter 6, can be combined to address the main research question used in this case study:

How can KLM Cargo maintain its on-time performance under Clean VOP regulations at Schiphol's A-pier, given the available buffer space underneath the pier?

The implementation of the *Clean VOP* regulations at Schiphol Airport will have a significant influence on KLM Cargo's outbound cargo flows to the A-pier. The simulation model demonstrated that a tradeoff has to be made between the key performance indicators, and that the assignment of the weights allow the problem owner to indicate which KPIs are of high importance. Since the *Clean VOP* regulations are imposed by the airport authority, KLM Cargo must ensure the new operating procedures do not (systematically) lead to violations of this regulation, since this would most likely also violate IGOM section 4.1.2.3, stating that the ERA must be clear of obstructions during the arrival or departure of an aircraft at the gate. Additionally, one of the (non-functional) requirements for a cargo handling alternative was that the on-time performance does not deteriorate compared to the on-time performance achieved in

2018. These requirements were reflected in the large weights assigned to these KPIs in relation to other KPIs.

Assuming the cargo delivery deadlines listed in the GOMS remain enforced at the time of the A-pier's opening, the analytical hierarchy process suggests that optimal results for handling outbound cargo flows at the A-pier may be achieved when a combination of a push- and a pull-system are adopted. This entails that cargo is driven to the airside as soon as it becomes available for transport. If the aircraft is already present at the aircraft stand, cargo is 'pulled' by Apron Services by means of a kanban system delivered directly to the aircraft, as is currently done at all piers at Schiphol. However, when the aircraft is not yet at the pier, cargo may not be brought to the aircraft stand. To minimise the buffering of cargo on KLM Cargo's shunting area, the cargo is 'pushed' to the buffer underneath the A-pier and placed in one of the vacant lanes. Both options are listed as accepted operations in section 3.4.2 of the IGOM. If brought to the buffer, the cargo's ride is ended by the tug driver and the buffer lane in which the cargo is placed is recorded using the handheld device, meeting the requirements of IGOM section 3.4.1. At this point, the responsibility over the cargo is transferred to Apron Services, meaning they are responsible for the transport of the cargo from the buffer lane to the aircraft whenever the cargo is needed for loading. This ensures that despite the aircraft not being present, cargo can be delivered to Apron Services and a high on-time performance of more than 80% can be achieved. Additionally, due to the cargo being delivered to Apron Services in the buffer, a second ride by KLM Cargo to the buffer to transport the cargo from the buffer to the aircraft is not necessary. Instead, Apron Services, which is operating from the A-pier itself, transports the cargo to the aircraft once it is due to be loaded. This reduces the total distance covered by the Mulag tugs which benefits the local air quality. Additional advantages for Apron Services include the fact that they can exercise more control over the aircraft stand, since part of the outbound cargo flow is pushed to the buffer instead of to the aircraft stand. Remaining cargo is pulled directly to the aircraft stand to avoid unnecessary rides and/or delays.

If Apron Services is not willing to accept part of the cargo deliveries at the buffer and transport this cargo to the aircraft when it is due to be loaded, it would be advisable to explore the possibilities of implementing a pull system (strategy 1) and completing only direct rides from the warehouse to the aircraft. Cargo ready for transport is held on the shunting area until the cargo is 'pulled' by Apron Services by means of a kanban system, once the aircraft has arrived at the gate. This strategy circumvents the buffer altogether, avoiding the waste incurred by KLM Cargo having to drive to the A-pier just to move the cargo from the buffer to the aircraft. This strategy only becomes most favourable, however, when the cargo delivery deadlines are shifted thirty minutes closer to the departure time (60 for ICA, 40 for EUR). If Apron Services can accommodate these new delivery deadlines, the only changes in procedure are the times at which cargo is driven to the apron; resulting in a demand-driven pull system. The On-time performance in that case is expected to exceed 80%, meaning that this solution would also not lead to a decrease in the OTP achieved in the current situation.

Modifying the current push system to deliver all A-pier cargo to Apron Services at the cargo buffer is an infeasible strategy as this is likely to result in more than 10 *Clean VOP* violations per month, and thereby also disregards section 4.1.2.3 of the IGOM. Since this leads to safety risks and possibly sanctions from the airport authority, a push system is undesirable for this situation with the limited buffer capacity at the A-pier. The strategies utilising push-pull logic are also not feasible, since these systems require more kilometres to be driven by the fleet of cargo tugs and, more importantly, they would lead to a significant decrease in on-time performance.

7.2. Limitations of the Research

This research does have a number of limitations. Firstly, the conclusions drawn from the simulation are specific for the infrastructure at Schiphol Airport, including the space available on the KLM Cargo premises, the number of aircraft stands subjected to the *Clean VOP* regulations, the distance of said aircraft stands from the cargo facility, and the amount of buffering space available are just a few of the factors which affect the outcomes of this case study. However, the approach to determining the optimal cargo handling strategy to implement, may be applied to other piers and other airports using parameters such as distance, number of buffer lanes, aircraft stands, shunting space, et cetera for the simulated environment.

Secondly, the model is limited to the simulation of outbound cargo only. For KLM Cargo this limitation was not an issue, as inbound cargo is generally brought to the warehouse before the aircraft departs. For this reason, the choice was made to limit the scope of the research to the outbound flow only. However, expanding the model to accommodate for the inbound flows would give a broader insight into the effect of combined flows on KLM Cargo's transport department under *Clean VOP* conditions.

Finally, the model does not account for big disruptions and/or gate changes occurring at Schiphol. The model uses a flight arrival table generated using the Matlab code supplied in appendix C, and adds some degree of stochasticity in the form of random deviations of the arrival time of the aircraft. However, the departure time of the aircraft is adhered to in order to prevent gate changes due to occupied aircraft stands. Expanding the model to include all aircraft stands across Schiphol Airport would allow for the system to dynamically assign a new gate to an aircraft if its planned gate is occupied at the time of arrival, similar to actual airport operations.

7.3. Recommendations for Further Research

This research designed a cargo handling strategy for a pier designed with the *Clean VOP* policy in mind. However, introducing the *Clean VOP* policy at existing piers which were not designed for *Clean VOP* operations may pose issues not identified in this research. For this reason, it is recommended to explore the expected effects of an implementation of the *Clean VOP* policy at other airports. Since AAS claims that the *Clean VOP* policy contributes to a safer working environment for both man and machine, implementing *Clean VOP* at other piers/airports may have significant benefits. However, the costs associated with meeting the *Clean VOP* requirements, such as an increase in the number of kilometres driven or the need for a centralised buffer to accommodate certain handling strategies, should be examined and considered prior to converting existing piers.

7.4. Recommendations for KLM

For KLM, it is recommended to address the silo mentality within the company and increase the level of collaboration and communication between departments of KLM. Especially the lack of communication between KLM Cargo and Apron Services leads to many missed opportunities, since there is no synergy resulting from collaboration. When the *Clean VOP* policy is implemented at the A-pier by the end of 2020, it is suggested to introduce a push system and a pull system similar to strategy 4. This would require an interface with Apron Services to communicate the location of the cargo within the buffer to be able to transfer the responsibility over the cargo. This would enable Apron Services to have more control over the aircraft stand, while reducing the number of kilometres driven by KLM Cargo's fleet of Mulag tugs. This win-win situation is only attainable, however, if both departments are open to such collaboration and if the necessary technological infrastructure is put in place. Although this may represent a high investment cost, the costs resulting from the silo mentality in the company can be (partially) addressed through such initiatives.

Secondly, KLM Cargo and Apron Services are advised to revise the cargo delivery deadlines recorded in the GOMS and consider shifting these deadlines closer to the time of departure. Doing so will likely increase KLM Cargo's on-time performance, and at the A-pier it may lead to strategy 1 being chosen over strategy 4 if the deadlines are shifted by thirty minutes. In order to determine what deadlines are realistic, data would be required from Apron Services on the time at which cargo is physically loaded on to the aircraft. This would give insight into when cargo is *actually* needed at the aircraft for loading purposes. This data would have to come from Apron Services since they are responsible for the loading of cargo, but since the data is currently not recorded, a system would have to be put in place to enable this.

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A

Outbound Cargo Process

In- and outbound air freight handled by KLM follows a number of procedures between arriving by truck/aircraft and departing by truck/aircraft. The processes were observed using the *User Observations* method as described in the Delft Design Guide [23]. Using this knowledge, a swimlane diagram was created which shows the players involved in each step as vertical swimlanes. The diagram illustrates where handshakes take place, and the journey of air cargo from arriving at the cargo facility to being loaded onto the aircraft.

User Observations

The *User Observations* method, as described in the Delft Design Guide, is a tool for studying and observing users' actions and reactions in specific situations. For this research, it was necessary to understand the steps taken in order to transport cargo from the cargo warehouse to the aircraft stand, and uncover what circumstances may lead the transport driver to deviate from the standard operating procedures.

On the 24th of July 2018 I joined Nick, a Transport driver at KLM Cargo, on his shift transporting cargo from the warehouse to the apron and vice versa. The aim was not to measure volumes transported or the duration of rides, but simply to gain insight into the process. Volume and duration data is recorded using *Real-Time Planning* which supplies the drivers with the necessary information, and tracks when and where certain rides are carried out. Since this information was already being recorded and available to me, I was able to focus on the process rather than collect quantitative data. Due to Schiphol rules and regulations, filming the processes was not permitted.

In order to ensure the interpretation of the current prodecures is correct, the swimlane diagram for the outbound process shown in figure A.1 was presented to Nick and he was asked to verify the process was illustrated correctly.

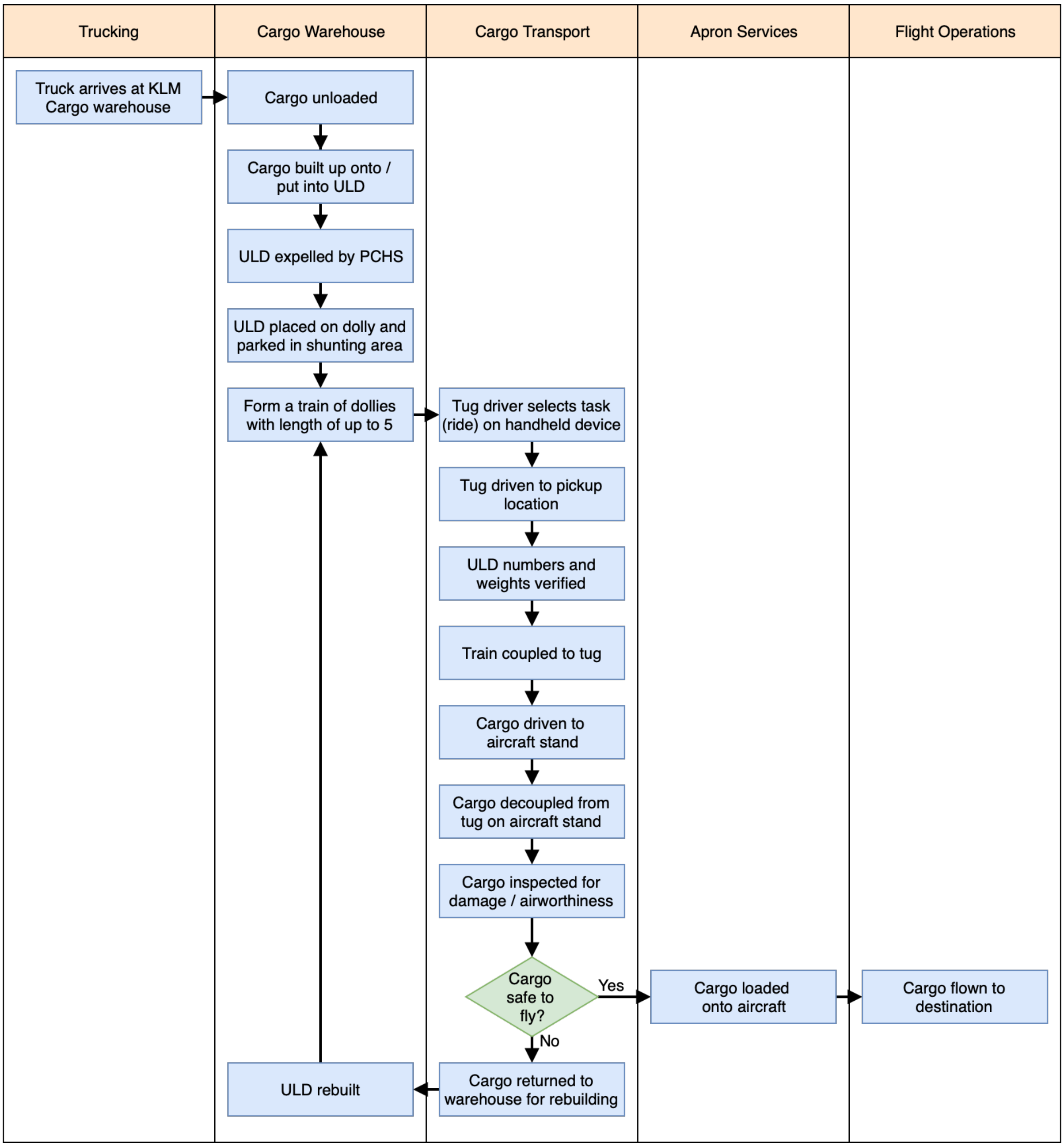

Figure A.1: Swimlane of outbound cargo process

B

Cargo Delivery Deadlines

Figure B.1 shows a page from the GOMS defining the deadlines for outbound cargo delivery for each of the aircraft types.

KLM

Ground Operations Manual Schiphol

HUB MANAGEMENT

NORMTIJDEN

	FH				CX	FH
	Load Release	Vracht	Express vracht (XPS)		Express vracht (XPS)	Vracht en Post documenten
			LIR/ NOTOC	ACTUALS	Overdracht	
	Afmelden aan Loadcontrol / K1 / K2 / K4 / K5	Overdracht aan K1/ K2 / K4 / K5	Afmelden aan Loadcontrol/ K1 / K2 / K4 / K5	Afmelden aan Loadcontrol/ K1 / K2 / K4 / K5	Overdracht aan K1 / K2 / K4 / K5	Overdracht aan K1 / K2 / K4 / K5
B747 ERF	V-150	V-90	V-120	V-75	V-60	V-20
B747 Combi	V-120	V-80	V-120	V-75	V-60	V-20
B747 Pax	V-120	V-80	V-120	V-75	V-60	V-20
B787-9	V-120	V-80	V-120	V-75	V-60	V-20
B777-200ER	V-120	V-80	V-120	V-75	V-60	V-20
B777-300ER	V-120	V-80	V-120	V-75	V-60	V-20
A330-200ICA	V-120	V-80	V-120	V-75	V-60	V-20
A330-200EUR	V-120	V-80	V-70	V-75	V-60	V-20
A330-300	V-120	V-80	V-120	V-75	V-60	V-20
B737-700	V-85	V-60	V-70	V-60	<100kg V-20 >100kg V-30	V-20
B737-800	V-85	V-60	V-70	V-60	<100kg V-20 >100kg V-30	V-20
B737-900	V-85	V-60	V-70	V-60	<100kg V-20 >100kg V-30	V-20
E190/E175	V-85	V-60	V-70	V-60	<100kg V-20 >100kg V-30	V-20

Vermelde rijden zijn uiterlijk tijden

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Figure B.1: Delivery deadlines for each outbound KLM aircraft type [78]

C

MATLAB Script

Matlab is used to fit the distributions of the number of ULDs per flight, the delivery times of these ULDs, and the length of trains. The fitted distributions are subsequently used to generate new datasets for the A-pier flight schedule provided by KLM.

C.1. Data Fitting

In order to find the distribution of the number of ULDs on flights in 2017, the code below was used in MATLAB to fit the distribution and use the same parameters to generate a new dataset of number of ULDs on flights for the expected traffic at the A-pier, as well as histograms of the 2018 dataset together with the randomly generated dataset for both narrow- and wide-body aircraft.

```
clear all;

% Make random values reproducible
rng('default');
rng(1);

% Determine distribution of ULDs on wide-body flights
wide_histogram = [316 567 917 1301 1758 1889 2333 2394 2346 2222 1814 1451
1291 1034 862 650 522 371 268 151 99 65 49 32 14 13 5 4 3 2 0 0 2 0 0 1 0 0
0 0];
wide_ulds = [];
for i = 1:40
    wide_ulds = [wide_ulds i.*ones(1,wide_histogram(i))];
end
wide_ulds_pdf = fitdist(transpose(wide_ulds),'NegativeBinomial');

% Determine distribution of ULDs on narrow-body flights
narrow_histogram = [17735 6849 2633 901 309 94 44 11 10 2 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
narrow_ulds = [];
for i = 1:40
    narrow_ulds = [narrow_ulds i.*ones(1,narrow_histogram(i))];
end
narrow_ulds_pdf = fitdist(transpose(narrow_ulds),'Gamma');

wide_length_hist = [43938 20101 12279 8828 14062];
wide_length = [];
for i = 1:5
    wide_length = [wide_length i.*ones(1,wide_length_hist(i))];
```

```
end
wide_length_new = transpose(wide_length(randperm(length(wide_length))));

narrow_length_hist = [34110 3914 832 163 61 0];
narrow_length = [];
for i = 1:6
    narrow_length = [narrow_length i.*ones(1,narrow_length_hist(i))];
end
narrow_length_new =
   transpose(narrow_length(randperm(length(narrow_length))));

% Use distributions to generate new random datasets of ULD amounts
wide_ulds_new = round(max(1,randraw('negbinom',[wide_ulds_pdf.R,
   wide_ulds_pdf.P],length(wide_ulds))));
narrow_ulds_new = round(max(1,randraw('gamma',[-0.2,narrow_ulds_pdf.b,
   narrow_ulds_pdf.a],length(narrow_ulds))));

% Determine distribution of delivery times of wide-body cargo
wide_delivery = xlsread('deliverywide.xlsx');
wide_delivery_pdf = fitdist(wide_delivery,'GeneralizedExtremeValue');
wide_delivery_new = gevrnd(wide_delivery_pdf.k,wide_delivery_pdf.sigma,
   wide_delivery_pdf.mu,[length(wide_ulds) 1]);

% Determine distribution of delivery times of narrow-body cargo
narrow_delivery = xlsread('deliverynarrow.xlsx');
narrow_delivery_pdf = fitdist(narrow_delivery,'GeneralizedExtremeValue');
narrow_delivery_new = gevrnd(narrow_delivery_pdf.k,narrow_delivery_pdf.sigma,
   narrow_delivery_pdf.mu,[length(narrow_ulds) 1]);

% Show new generated dataset (red) compared to 2017 dataset (black)
figure;
histogram(wide_ulds,'FaceColor','black');
hold on;
histogram(wide_ulds_new,'FaceColor','red');
hold off;
figure;
histogram(narrow_ulds,'FaceColor','black');
hold on;
histogram(narrow_ulds_new,'FaceColor','red');
hold off;

clearvars -except wide_ulds_new narrow_ulds_new wide_delivery_new
   narrow_delivery_new wide_length_new narrow_length_new;
```

C.2. Data Synthesis

The following Matlab script takes the output of the script above and modifies it so that it is compatible with Simio. The date and time values are converted, each flight is assigned the number of ULDs drawn from the fitted distribution, and trains are generated with random lengths equal to those found in the empirical dataset of 2018. The data is then converted to a number of tables which, after being exported to Excel, are imported directly by Simio and used for running the simulation model.

```
wide_aircraft = xlsread('matlab_input_wide.xlsx');
[num_flights,~] = size(wide_aircraft);
arrival = 1;
departure = 2;
vop = 3;
ulds = 4;
id = 5;
diffdays = 693960;

wide_cargo = [];
cargo_row = 1;
flight_arrivals = "";
flight_departures = "";
cargo_availables = "";
cargo_availables_double = "";
cargo_availables_half = "";
cargo_deadlines = "";
flight_vops = "";
flight_idss = "";
cargovops = "";
cargoids = "";
vopstringaircraft = 'ParentInput@VOP';
vopstringcargo = 'DropoffVOP';

for flight = 1:num_flights
    flight_arrivals(flight,1) = datestr(diffdays +
       wide_aircraft(flight,arrival));
    flight_departures(flight,1) = datestr(diffdays +
       wide_aircraft(flight,departure));
    flight_idss(flight,1) = num2str(flight);

    flight_vops(flight,1) = strcat(vopstringaircraft,
       int2str(wide_aircraft(flight,vop)));
    wide_aircraft(flight,id) = flight;
    wide_aircraft(flight,ulds) = wide_ulds_new(flight);
    flight_ulds = wide_aircraft(flight,ulds);
    ulds_left = flight_ulds;
    flight_trains = [];
    while ulds_left > 0
        % ULDs available:
        wide_cargo(cargo_row,arrival) = wide_aircraft(flight,departure)-
           ((wide_delivery_new(cargo_row))/60/24);
     cargo_availables(cargo_row,1) = datestr(diffdays+wide_aircraft(flight,
           departure)-((wide_delivery_new(cargo_row))/60/24));
        cargo_availables_double(cargo_row,1) = datestr(diffdays+
          wide_aircraft(flight,departure)-(2*(wide_delivery_new(cargo_row))
           /60/24));
        cargo_availables_half(cargo_row,1) = datestr(diffdays+
        wide_aircraft(flight,departure)-(0.5*(wide_delivery_new(cargo_row))
```

```
            /60/24));
        % ULD deadline:
        wide_cargo(cargo_row,departure) = wide_aircraft(flight,departure);
        cargo_deadlines(cargo_row,1) = datestr(diffdays +
            wide_aircraft(flight,departure));
        % ULD destination VOP:
        wide_cargo(cargo_row,vop) = wide_aircraft(flight,vop);
        cargovops(cargo_row,1) = strcat(vopstringcargo,
            int2str(wide_aircraft(flight,vop)));
        % ULD train length:
     wide_cargo(cargo_row,ulds) = min(ulds_left,wide_length_new(cargo_row));
        % ULD / flight ID:
        wide_cargo(cargo_row,id) = flight;
        cargoids(cargo_row,1) = strcat("0",num2str(flight));

        % Decrease ULDs left
        ulds_left = ulds_left - wide_cargo(cargo_row,ulds);
        % Increment cargo row
        cargo_row = cargo_row+1;
    end
end

flight_ulds = wide_aircraft(:,ulds);
cargo_available = cargo_availables;
cargo_available_double = cargo_availables_double;
cargo_available_half = cargo_availables_half;
cargo_deadline = cargo_deadlines;
cargo_vops = cargovops;
cargo_quantity = wide_cargo(:,ulds);
cargo_ids = cargoids;

varNames_flight = {'Arrival','Departure','VOP','ULDs','ID'};
varNames_cargo = {'Available','Departure','VOP','Quantity','flightID'};
flight_table = table(flight_arrivals,flight_departures,flight_vops,
   flight_ulds,flight_idss,'VariableNames',varNames_flight);
cargo_table = table(cargo_available,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);
cargo_table_double = table(cargo_available_double,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);
cargo_table_half = table(cargo_available_half,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);

writetable(flight_table,'matlab_output_aircraftwide.xlsx');
writetable(cargo_table,'matlab_output_cargowide.xlsx');
writetable(cargo_table_double,'matlab_output_cargowide_double.xlsx');
writetable(cargo_table_half,'matlab_output_cargowide_half.xlsx');

narrow_aircraft = xlsread('matlab_input_narrow.xlsx');
[num_flights,~] = size(narrow_aircraft);
arrival = 1;
departure = 2;
vop = 3;
ulds = 4;
id = 5;
airline = 6;
narrow_aircraft(:,6) = narrow_aircraft(:,4);
```

```
diffdays = 693960;
NBwithCargo = 0.7;

narrow_cargo = [];
flight_arrivals = "";
flight_departures = "";
cargo_availables = "";
cargo_availables_double = "";
cargo_availables_half = "";
cargo_deadlines = "";
flight_vops = "";
flight_idss = "";
cargovops = "";
cargoids = "";
vopstringaircraft = 'ParentInput@VOP';
vopstringcargo = 'DropoffVOP';

num_wide = flight;
cargo_row_wide = cargo_row;
cargo_row = 1;

for flight = 1:num_flights
    flight_arrivals(flight,1) = datestr(diffdays +
       narrow_aircraft(flight,arrival));
    flight_departures(flight,1) = datestr(diffdays +
       narrow_aircraft(flight,departure));
    flight_idss(flight,1) = num2str(num_wide+flight);

    flight_vops(flight,1) = strcat(vopstringaircraft,
       int2str(narrow_aircraft(flight,vop)));
    narrow_aircraft(flight,id) = num_wide+flight;

    % Set ULD quantity of Transavia and non-KLM-handled airlines to zero
    if narrow_aircraft(flight,airline) == 0
        if rand <= NBwithCargo
            narrow_aircraft(flight,ulds) = narrow_ulds_new(flight);
        else
            narrow_aircraft(flight,ulds) = 0;
        end
    else
        narrow_aircraft(flight,ulds) = 0;
    end
    flight_ulds = narrow_aircraft(flight,ulds);
    ulds_left = flight_ulds;
    flight_trains = [];
    while ulds_left > 0
        % ULDs available:
       narrow_cargo(cargo_row,arrival) = narrow_aircraft(flight,departure)-
           ((narrow_delivery_new(cargo_row))/60/24);
        cargo_availables(cargo_row,1) = datestr(diffdays +
           narrow_aircraft(flight,departure)-
           ((narrow_delivery_new(cargo_row))/60/24));
        cargo_availables_double(cargo_row,1) = datestr(diffdays +
           narrow_aircraft(flight,departure)-(2*
           (narrow_delivery_new(cargo_row))/60/24));
        cargo_availables_half(cargo_row,1) = datestr(diffdays +
```

```
            narrow_aircraft(flight,departure)-(0.5*
            (narrow_delivery_new(cargo_row))/60/24));
         % ULD deadline:
      narrow_cargo(cargo_row,departure) = narrow_aircraft(flight,departure);
         cargo_deadlines(cargo_row,1) = datestr(diffdays +
            narrow_aircraft(flight,departure));
         % ULD destination VOP:
         narrow_cargo(cargo_row,vop) = narrow_aircraft(flight,vop);
         cargovops(cargo_row,1) = strcat(vopstringcargo,
            int2str(narrow_aircraft(flight,vop)));
         % ULD train length:
         narrow_cargo(cargo_row,ulds) = min(ulds_left,
            narrow_length_new(cargo_row));
         % ULD / flight ID:
         narrow_cargo(cargo_row,id) = flight+num_wide;
         cargoids(cargo_row,1) = strcat("0",num2str(num_wide+flight));

         % Decrease ULDs left
         ulds_left = ulds_left - narrow_cargo(cargo_row,ulds);
         % Increment cargo row
         cargo_row = cargo_row+1;
     end
end

flight_ulds = narrow_aircraft(:,ulds);
flight_ids = narrow_aircraft(:,id);
flight_airlines = narrow_aircraft(:,airline);

cargo_available = cargo_availables;
cargo_available_double = cargo_availables_double;
cargo_available_half = cargo_availables_half;
cargo_deadline = cargo_deadlines;
cargo_vops = cargovops;
cargo_quantity = narrow_cargo(:,ulds);
cargo_ids = cargoids;

varNames_flight = {'Arrival','Departure','VOP','ULDs','ID','Airline'};
varNames_cargo = {'Available','Departure','VOP','Quantity','flightID'};
flight_table = table(flight_arrivals,flight_departures,flight_vops,
  flight_ulds,flight_idss,flight_airlines,'VariableNames',varNames_flight);
cargo_table = table(cargo_available,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);
cargo_table_double = table(cargo_available_double,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);
cargo_table_half = table(cargo_available_half,cargo_deadline,cargo_vops,
   cargo_quantity,cargo_ids,'VariableNames',varNames_cargo);

writetable(flight_table,'matlab_output_aircraftnarrow.xlsx');
writetable(cargo_table,'matlab_output_cargonarrow.xlsx');
writetable(cargo_table_double,'matlab_output_cargonarrow_double.xlsx');
writetable(cargo_table_half,'matlab_output_cargonarrow_half.xlsx');

% COMMUTER
% Import aircraft schedule
comm_aircraft = xlsread('matlab_input_comm.xlsx');
[num_flights,~] = size(comm_aircraft);
```

```
arrival = 1;
departure = 2;
vop = 3;
ulds = 4;
id = 5;
diffdays = 693960;

flight_arrivals = "";
flight_departures = "";
flight_vops = "";
flight_idss = "";
vopstringaircraft = 'ParentInput@VOP';

num_narrow = flight;
num_prev = num_wide + num_narrow;

for flight = 1:num_flights
    flight_arrivals(flight,1) = datestr(diffdays +
       comm_aircraft(flight,arrival));
    flight_departures(flight,1) = datestr(diffdays + c
       omm_aircraft(flight,departure));
    flight_idss(flight,1) = num2str(num_prev+flight);
    flight_vops(flight,1) = strcat(vopstringaircraft,
       int2str(comm_aircraft(flight,vop))); %done
    flight_idss(flight,1) = num_prev+flight;
end

varNames_flight = {'Arrival','Departure','VOP','ID'};
flight_table = table(flight_arrivals,flight_departures,flight_vops,
   flight_idss,'VariableNames',varNames_flight);
writetable(flight_table,'matlab_output_aircraftcommuter.xlsx');
```

D

Simulation Results

Table D.1 contains the data output from the Simio simulation experiment testing the five cargo handling strategies with different cargo delivery deadlines.

Table D.1: Simulation results per handling strategy for various sets of cargo delivery deadlines

Strategy	**Violations** [# ULDs]	**OTP** [%]	**Max. Utilisation** [%]	**Distance** [km]	**Space** [# ULDs]
ICA 80 EUR 60					
Baseline	1,319.88	85.38	0.00	1,684.94	8.16
Strategy 1	0.00	55.89	0.00	1,349.39	23.50
Strategy 2	14.15	84.97	99.61	2,949.04	8.15
Strategy 3	0.00	51.01	80.26	3,239.75	8.18
Strategy 4	0.00	85.27	72.05	2,492.31	8.14
Strategy 5	0.00	54.38	70.18	2,735.00	8.10
ICA 70 EUR 50					
Baseline	1,319.88	91.35	0.00	1,684.94	8.16
Strategy 1	0.00	67.94	0.00	1,349.39	23.50
Strategy 2	26.07	91.07	99.81	2,953.57	8.15
Strategy 3	0.14	62.11	81.39	3,248.86	8.18
Strategy 4	0.00	91.30	72.78	2,494.32	8.14
Strategy 5	0.00	65.57	70.18	2,736.55	8.10
ICA 60 EUR 40					
Baseline	1,319.88	95.48	0.00	1,684.94	8.16
Strategy 1	0.00	81.64	0.00	1,349.39	23.50
Strategy 2	34.37	95.28	100.00	2,958.60	8.15
Strategy 3	0.14	75.00	83.08	3,259.58	8.18
Strategy 4	0.00	95.50	72.96	2,498.53	8.14
Strategy 5	0.00	78.33	70.35	2,740.75	8.10
ICA 50 EUR 30					
Baseline	1,319.88	98.23	0.00	1,684.94	8.16
Strategy 1	0.00	93.20	0.00	1,349.39	23.50
Strategy 2	45.07	98.12	100.00	2,964.59	8.15
Strategy 3	0.14	87.87	83.65	3,272.37	8.18
Strategy 4	0.00	98.18	73.32	2,505.43	8.14
Strategy 5	0.00	90.14	70.70	2,745.42	8.10

E

AHP Matrices

In order to determine the scores of each of the cargo handling strategies, the Analytical Hierarchy Process is used to assign weights to each of the KPIs and assign normalised scores to each of the calculated values. In table E.1, pairwise comparisons of the KPIs are used to determine the weight assigned to each of the KPIs. This is calculated as the sum of the row divided by the sum of all rows.

Table E.1: Pairwise comparison matrix of KPIs

	Violations	**OTP**	**Max. Utilisation**	**Distance**	**Space**	**Weight**
Violations	1	2	5	4	5	0.355
OTP	1/2	1	5	4	6	0.345
Max. Utilisation	1/5	1/5	1	1/2	1	0.061
Distance	1/4	1/4	2	1	1/2	0.084
Space	1/5	1/4	4	2	1	0.156

The following tables show the pairwise comparison matrices used to determine the scores for each of the KPI values from the simulation model which do not follow a linear utility. The utility, or score, is determined using a pairwise comparison in order to determine the ratio of utility between the KPI values. The sum of the row divided by the sum of the matrix gives the value's score. Table E.2 shows the pairwise comparison matric for the number of *Clean VOP* violations per month.

Table E.2: Pairwise comparison matrix of *Clean VOP* Violation scores

Violations	**<1**	**1–30**	**>30**	**Score**
<1	1	7	9	0.723
1–30	1/7	1	4	0.219
>30	1/9	1/4	1	0.058

Table E.3 shows the pairwise comparisons for on-time performance values. Since KLM Cargo achieved an on-time performance of 80% in 2018, any value lower than 80% is penalised heavily, while higher values are rewarded.

Table E.3: Pairwise comparison matrix of OTP scores

OTP	**<80%**	**80–90%**	**>90%**	**Score**
<80%	1	1/7	1/9	0.056
80–90%	7	1	1/3	0.369
>90%	9	3	1	0.576

In table E.4, pairwise comparisons are made between values which may be recorded as maximum utilisation values in each of the simulation runs with different handling strategies. Lower maximum utilisation values are preferred since this indicates the buffer is not over-utilised, and is able to accommodate extra cargo in the case of disruptions or delays.

Table E.4: Pairwise comparison matrix of Max. Utilisation scores

Max. Utilisation	**<80%**	**80-90%**	**>90%**	**Score**
<80%	1	3/2	5	0.547
80-90%	2/3	1	3	0.341
>90%	1/5	1/3	1	0.112

Table E.5 shows the scores assigned to the values for the KPIs Distance and Space. These KPIs are assumed to have a linear utility, meaning that their scores can be calculated as the ratio between the values, with the sum of the scores being equal to 1. Since the distance driven and the space used are both KPIs which must be minimised, each of the scores is calculated as the multiplicative inverse of the value divided by the sum of all values' multiplicative inverses.

Table E.5: Calculation of Distance and Space scores

	Distance		**Space**	
	Kilometres	**Score**	**ULDs**	**Score**
Baseline	1,684.94	0.216	8.16	0.187
Strategy 1	1,349.39	0.270	23.50	0.065
Strategy 2	2,949.04	0.123	8.15	0.187
Strategy 3	3,239.75	0.112	8.18	0.186
Strategy 4	2,492.31	0.146	8.14	0.187
Strategy 5	2,735.00	0.133	8.10	0.188

Finally, table E.6 through E.9 shows all KPIs with their respective weights, and scores each outbound cargo handling strategy according to these weights for the various delivery deadline combinations. The strategy with the highest weighted score is the optimum strategy, given the relative importance of each KPI as determined by the problem owner, and is indicated by the ranking of the strategies.

Table E.6: Overview of weighted scores of all strategies with delivery deadlines ICA 80 and EUR 60 (current delivery deadlines)

	Violations 0.355		**OTP** 0.345		**Max. Utilisation** 0.061		**Distance** 0.084		**Space** 0.156		**Weighted Score**	**Strategy Ranking**
	# ULDs	**Score**	**%**	**Score**	**%**	**Score**	**Kilometres**	**Score**	**ULDs**	**Score**		
Baseline	1319.88	0.058	85.38	0.369	0.00	0.547	1,684.94	0.216	8.16	0.187	0.228	6
Strategy 1	0.00	0.723	55.89	0.056	0.00	0.547	1,349.39	0.270	23.50	0.065	0.342	2
Strategy 2	14.15	0.219	84.97	0.369	99.61	0.112	2,949.04	0.123	8.15	0.187	0.251	5
Strategy 3	0.00	0.723	51.01	0.056	80.26	0.341	3,239.75	0.112	8.18	0.186	0.335	4
Strategy 4	0.00	0.723	85.27	0.369	72.05	0.112	2,492.31	0.146	8.14	0.187	0.432	1
Strategy 5	0.00	0.723	54.38	0.056	70.18	0.341	2,735.00	0.133	8.10	0.188	0.337	3

Table E.7: Overview of weighted scores of all strategies with delivery deadlines ICA 70 and EUR 50

	Violations 0.355		**OTP** 0.345		**Max. Utilisation** 0.061		**Distance** 0.084		**Space** 0.156		**Weighted Score**	**Strategy Ranking**
	# ULDs	**Score**	**%**	**Score**	**%**	**Score**	**Kilometres**	**Score**	**ULDs**	**Score**		
Baseline	1319.88	0.058	91.35	0.576	0.00	0.547	1,684.94	0.216	8.16	0.187	0.299	6
Strategy 1	0.00	0.723	67.94	0.056	0.00	0.547	1,349.39	0.270	23.50	0.065	0.342	2
Strategy 2	26.07	0.219	91.07	0.576	99.81	0.112	2,953.57	0.123	8.15	0.187	0.322	5
Strategy 3	0.14	0.723	62.11	0.056	81.39	0.341	3,248.86	0.112	8.18	0.186	0.335	4
Strategy 4	0.00	0.723	91.30	0.576	72.78	0.112	2,494.32	0.146	8.14	0.187	0.504	1
Strategy 5	0.00	0.723	65.57	0.056	70.18	0.341	2,736.55	0.133	8.10	0.188	0.337	3

Table E.8: Overview of weighted scores of all strategies with delivery deadlines ICA 60 and EUR 40

	Violations 0.355		**OTP** 0.345		**Max. Utilisation** 0.061		**Distance** 0.084		**Space** 0.156		**Weighted Score**	**Strategy Ranking**
	# ULDs	**Score**	**%**	**Score**	**%**	**Score**	**Kilometres**	**Score**	**ULDs**	**Score**		
Baseline	1319.88	0.058	95.48	0.576	0.00	0.547	1,684.94	0.216	8.16	0.187	0.299	5
Strategy 1	0.00	0.723	81.64	0.369	0.00	0.547	1,349.39	0.270	23.50	0.065	0.450	2
Strategy 2	34.37	0.058	95.28	0.576	100.00	0.112	2,958.60	0.123	8.15	0.187	0.265	6
Strategy 3	0.14	0.723	75.00	0.056	83.08	0.341	3,259.58	0.112	8.18	0.186	0.335	4
Strategy 4	0.00	0.723	95.50	0.576	72.96	0.112	2,498.53	0.146	8.14	0.187	0.504	1
Strategy 5	0.00	0.723	78.33	0.056	70.35	0.341	2,740.75	0.133	8.10	0.188	0.337	3

Table E.9: Overview of weighted scores of all strategies with delivery deadlines ICA 50 and EUR 30

	Violations 0.355		**OTP** 0.345		**Max. Utilisation** 0.061		**Distance** 0.084		**Space** 0.156		**Weighted Score**	**Strategy Ranking**
	# ULDs	**Score**	**%**	**Score**	**%**	**Score**	**Kilometres**	**Score**	**ULDs**	**Score**		
Baseline	1319.88	0.058	98.23	0.576	0.00	0.547	1,684.94	0.216	8.16	0.187	0.299	5
Strategy 1	0.00	0.723	93.20	0.576	0.00	0.547	1,349.39	0.270	23.50	0.065	0.521	1
Strategy 2	45.07	0.058	98.12	0.576	100.00	0.112	2,964.59	0.123	8.15	0.187	0.265	6
Strategy 3	0.14	0.723	87.87	0.369	83.65	0.341	3,272.37	0.111	8.18	0.186	0.443	4
Strategy 4	0.00	0.723	98.18	0.576	73.32	0.112	2,505.43	0.146	8.14	0.187	0.504	3
Strategy 5	0.00	0.723	90.14	0.576	70.70	0.341	2,745.42	0.133	8.10	0.188	0.516	2

F

Research Paper

The following pages contain the research paper written on the research presented in this thesis.

Redesigning Air Cargo Ground Handling Procedures for a Clean Apron

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***Abstract*— The introduction of MARS stands at Amsterdam Airport Schiphol's new A-pier means a *Clean VOP* policy will be enforced. Under this regulation, vacant aircraft stands must be free of any cargo and baggage. In order to comply with this policy, KLM Cargo has to redesign its cargo handling procedure which is currently based on push logic. This paper explores the effects of various cargo handling procedures using pull and push-pull logic on KPIs such as on-time performance, space usage and distance covered. These handling strategies are simulated using a DES model of the future A-pier. The resulting KPI values are then analysed using the analytical hierarchy process, where weights are assigned to the KPIs by the problem owner. The resulting weighted scores indicate that a strategy employing a combination of a pull and push system is found to be most effective at ensuring cargo is delivered on time while respecting the *Clean VOP* regulations imposed by the airport authority.**

Keywords: Cargo Handling, Clean VOP, Schiphol, Push-Pull, OTP, DMADE, DES, AHP.

I. PROBLEM DEFINITION

Introduction

As the demand for air travel continues to grow [8], airports look for ways to increase the number of passengers without necessarily increasing the airport's footprint [4]. One way of achieving this is by the implementation of the so-called MARS stand; Multiaircraft Ramping System. MARS allows for an aircraft stand's configuration to be set for either one wide-body aircraft or two narrow-body aircraft at a time [3]. This configurable aircraft stand increases the flexibility and efficiency of the airport, as controllers have more options in the case of gate changes since a given aircraft stand can accommodate most aircraft types [10]. However, is many cases, pre-positioning cargo on MARS stands is not possible since the entire aircraft stand must be kept clear of ground support equipment to avoid a risk of collision when the configuration of the MARS stand changes [17]. For this reason, airport authorities may choose to introduce regulations prohibiting the pre-positioning of cargo when the cargo's aircraft is not (yet) on the aircraft stand. An apron subject to this regulation is referred to as a *Clean VOP* (VOP = Vliegtuigopstelplaats, Dutch for aircraft stand).

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Cargo handling agents typically transport cargo from the warehouse to the aircraft stand up to 5 hours prior to the aircraft's departure [13]. This is partly to spread the peak workload, as well as to clear space on the shunting area [25]. In many cases, cargo is delivered before the aircraft arrives at the gate. For this cargo, an alternate solution must be found when the *Clean VOP* policy is in effect. It is unknown how cargo handlers should shape their supply chain in order to maintain their operational performance while adhering to the *Clean VOP* regulations.

Case Study: KLM Cargo

This research problem is addressed in a case study at KLM Cargo at Amsterdam Airport Schiphol (AAS). AAS is introducing MARS stands at the A-pier which is currently under construction and is due to be completed by the end of 2020 [19]. KLM is expected to handle the vast majority of flights at this pier, with KLM Cargo handling the freight on these flights. Because of the MARS stands, *Clean VOP* regulations will also be implemented. AAS is providing a buffer space underneath the pier in the form of fifteen lanes where cargo on rolling stock may be buffered. However, which procedures are to be followed and how the buffer is to be used, is up to KLM Cargo. This research aims to determine how cargo should be handled under *Clean VOP* conditions by answering the research question:

How can KLM Cargo maintain its on-time performance under Clean VOP regulations at Schiphol's A-pier, given the available buffer space underneath the pier?

The research scope is limited to outbound cargo, from the moment cargo becomes available for transport at the warehouse to the cargo being delivered to the aircraft handling agent which is responsible for the loading of the cargo onto the aircraft.

Methodology

The research follows the DMADE process which is adapted from the DMAIC process used in the Six Sigma theory [21]. DMADE stands for Define, Measure, Analyse, Design and Evaluate. This method was used instead of DMAIC because the implementation of *Clean VOP* calls for a new handling procedure rather than an incremental change in the existing procedures. Furthermore, the outcomes of the research cannot be brought into practice and controlled because the A-pier is still under construction. For this reason, the outcome will be evaluated.

The DMADE process consists of the following steps:

- Define: Problem definition and demarcation, literature review and identifying research gap;
- Measure: Exploring the current procedures and the stakeholders involved, as well as collecting performance data of the current system;
- Analyse: Analysing the empirical data and creating a discrete event simulation (DES) model of the current system as a performance benchmark;
- Design: Designing new cargo handling procedures and testing their performance using the DES model;
- Evaluate: Ranking the handling strategies using the analytical hierarchy process (AHP), drawing conclusions and giving recommendations for further research.

A discrete event simulation approach is chosen because experiments with the actual system are not possible, since the pier is still under construction. Experimenting with a physical model or finding an analytical solution is also not feasible due to the complexity of the system. Therefore, a mathematical model in the form of simulation is the best approach.

For the analysis of the results, the AHP method is chosen since this normalises the values and determines weights/scores based on pairwise comparisons. This allows the problem owner to systematically indicate the importance of a KPI in relation to another KPI. The AHP method then infers the weights/scores based on these pairwise comparisons.

Literature Review

To explore the research problem, a literature study was conducted identifying technologies and strategies employed in other industries where on-time performance, space usage and/or safety play a role. Additionally, the environmental impact of ground support equipment at airports is explored.

In terms of airport operations, cargo handlers worldwide are subject to IATA regulations. Specifically aspects mentioned in IATA's Ground Operations Manual (IGOM) in subchapter 3.4.1 and 3.7 are of interest, specifying how storage and ground transportation should be approached in order to ensure air cargo is handled safely [7]. Tabares et al. defined a number of key performance indicators for aircraft ground handling [1]. For this case study, relevant KPIs were on-time performance (OTP) and number of resources required, where resources could be defined as the space at KLM Cargo's shunting area, as well as the buffer space underneath the A-pier [18][25].

A 2005 study on Hartsfield-Jackson Atlanta International Airport's emissions found that ground support equipment accounted for more than 8% of the total airport emissions per year [24]. With the aviation industry pushing for more sustainable operations [14][15], minimising the total distance driven with diesel-powered tugs is beneficial to the air quality at the airport as well as the size of the required workforce and tug fleet [18]. Replacing the fleet with electric vehicles eliminates the impact on local environment altogether [20].

While other industries such as maritime container terminals have already successfully introduced fully automated guided vehicles (AGVs) [22], the aviation industry is only now starting to experiment with autonomous vehicles operating on the airside of the airport [16][6]. The heterogeneous traffic flows and vehicle types, along with the fact that AGVs would have to operate side-by-side with human-operated vehicles, make the introduction of AGVs in an airport environment extremely challenging [1]. Additionally, the investment costs associated with the introduction of an AGV system are significant [11].

In terms of the logistics of air cargo, the system in place is a push system. A planning is made centrally, and cargo is sent to the apron as it becomes available for transport, keeping the space occupied on the shunting area to a minimum [25]. This is not a problem since there are no restrictions on when cargo may be placed on the apron when there is no *Clean VOP* policy in effect [18]. When this regulation is enforced, however, the cargo handler is limited in the time window at which they may position cargo on the aircraft stand. Altering the location of the delivery to the aircraft handler, or changing the system to a pull system may addresses this issue by only releasing the cargo for transport when the aircraft arrives at the stand [12]. A study of the in-house logistics at FloraHolland Aalsmeer also concluded that replacing the push system with a pull system was expected to lead to better results, with a higher on-time performance while reducing the number of incomplete orders sent to customers [2]. Additionally, the work required to fulfil all orders would be reduced. The pull system does, however, mean that products must be stored until they are pulled by the customer.

At many cargo handlers' facilities, space is scarce [25]. Due to the availability of the buffer space underneath the A-pier, an approach embracing this buffer may also be considered. A push-pull system is one where the first part of the supply chain follows the push principle, while the second part follows the pull principle [9]. This means that somewhere along the supply chain there needs to be inventory, which potentially reduces lead times for orders placed lower down the supply chain [23][5].

Little to no research has been done as to how a pull or push-pull system may be implemented for cargo handling in an airport environment in order to meet *Clean VOP* regulations and maintain a high on-time performance. This research addresses this knowledge gap by simulating different pull and or push/pull strategies and assessing their performance.

II. MEASURE

This section discusses the current outbound cargo handling procedure, the key performance indicators used to assess the operational performance, and the data collection used for the development of the DES model.

Current Process

At present, cargo processed by the cargo warehouse is expelled as a unit load device or as a bulk cart ("ULD").

The ULD is then placed on the shunting area (in a train of up to five ULDs) ready for transport to the apron. A tug driver picks up the train and brings this train to the apron after passing through security. At the aircraft stand, the train is positioned on the starboard side of the aircraft. After decoupling, the tug driver visually inspects the cargo for airworthiness to ensure no cargo has shifted during the ground transportation [18].

While KLM Apron Services is responsible for the aircraft handling (including the loading of the cargo), no communication takes place between KLM Cargo and Apron Services. This suggests a silo mentality is present within the KLM organisation which prevents close collaboration between the departments. This may need to be addressed in future handling procedures.

Stakeholders

Besides KLM Cargo, a number of other stakeholders are also affected by the implementation of *Clean VOP*. The AAS airport authority, for example, enforces the rules and regulations on the airport's airside. KLM's Safety and Security department ensures that standard operating procedures are safe for both KLM's employees and the cargo. Ground Services is the customer of KLM Cargo's transport department and oversees the processes on the aircraft stand, including the loading of the cargo. KLM Cargo in turn is responsible for a timely delivery of the cargo to Apron Services.

Each of the stakeholders have different—and sometimes conflicting—interests. While AAS wishes that no *Clean VOP* violations will take place, KLM Cargo needs to keep its shunting area clear and Ground Services wants KLM Cargo to achieve a high OTP so that cargo is delivered to the aircraft on time. Meanwhile, KLM Cargo wants to reduce the operational costs as well as the ground transport emissions.

Requirements & Constraints

A cargo handling process designed for *Clean VOP* operations must ensure all cargo is brought to the customer, but that aircraft stands without aircraft are kept clear of cargo. For Schiphol's A-pier, the procedures must be in place by December 2020, in time for the pier's opening. Furthermore, new procedures should not lead to the deterioration of the handler's on-time performance and ideally the procedure would not be too dissimilar from procedures followed at other piers.

In terms of constraints, the fifteen buffer lanes provided by AAS are fixed—no changes to the layout are possible. For KLM, costs associated with the new handling procedures may not be too prohibitive; the assets and equipment currently in use is to be used at the A-pier, as well. Additionally, AAS does not have the enabling processes in place to accommodate AGVs on the airport premises.

Key Performance Indicators

When simulating the ground handling of outbound air cargo at the A-pier using different handling strategies, the performance of each strategy must be measured in order to assess the strategies. Based on the literature study, the following five key performance indicators were identified:

- Violations: the number of ULDs illegally placed on the aircraft stand under *Clean VOP* conditions;
- OTP: the share of outbound cargo delivered to the aircraft handler before the delivery deadline;
- Max. Utilisation: the maximum recorded utilisation of the A-pier buffer space;
- Distance: the total distance covered by cargo tugs for outbound cargo handling at the A-pier;
- Space: the maximum number of ULDs destined for the A-pier simultaneously stored on the cargo handler's shunting area.

Data Collection

To determine how future handling strategies perform in comparison to the current handling procedure, the performance of the current system must be measured. This is done using a dataset of all outbound cargo rides completed by KLM Cargo's transport department in the period December 2017 – December 2018. The values of the KPIs served as a benchmark to which simulated strategies could be compared.

III. ANALYSE

Data Analysis

The number of ULDs per flight as well as the time of delivery of each ULD prior to the flights departure was analysed using Matlab. A distribution fitting tool was used to estimate the distribution the data followed, which could later be used to draw random values from.

In order to synthesise a cargo arrival table for the discrete event simulation, the A-pier's weekly flight schedule was used. Using Matlab, each of the flights at the A-pier was assigned a random number of ULDs (drawn from the distribution estimated from the 2018 dataset). For each of the ULDs, the time at which it became available for transport at the cargo facility (prior to the aircraft's departure) was also drawn randomly from the estimated distribution. The result was a flight schedule for the aircraft and a cargo arrival schedule for the ULDs. These two schedules would serve as input to the DES model which would simulate the cargo handling at the future A-pier.

Simulation

Simio was used to make a discrete event simulation model of the A-pier, with separate networks for aircraft and for cargo tugs. Figure 1 shows a visual representation of the simulation model.

Besides the input of the flight schedule and the cargo arrival table, the model allows control over the cargo tugs fleet size, the cargo handling strategy, and the cargo delivery deadlines for intercontinental flights and for European flights.

For the current situation, all cargo was pushed out to the apron as soon as it became available for transport, since no *Clean VOP* was in effect. The model records each ULD's time of delivery in relation to the ULD's delivery deadline

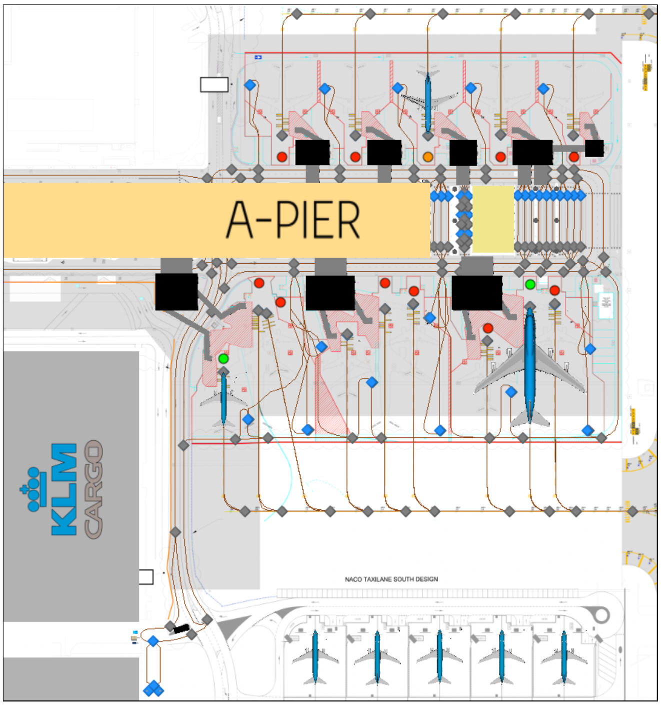

Fig. 1. Visual representation of simulation model of the A-pier

to monitor the system's on-time performance. Similary, each time a ULD or bulk cart is placed on the aircraft stand without an aircraft present, a violation is recorded. All other KPIs are monitored in a similar way, and are given as output values for each simulation run of one month. These values can then be compared to those found by analysing the empirical dataset. Besides the KPIs, the average delivery time prior to the aircraft's departure and the lengths of the trains were recorded in order to verify and validate the model.

The model was verified by altering the inputs as well as the control variables. Besides the base scenario, nine modified scenarios were run where just one input or control was altered, to ensure this had the expected effect on the outputs. Since all scenarios showed the predicted behaviour and did not affect non-related output variables, the simulation model was considered to have been programmed correctly.

The model showed a slightly higher on-time performance and delivery time prior to departure. This was explained by the fact that the A-pier is next to the KLM Cargo premises, which reduces the distance to be covered to reach the aircraft stand. These discrepancies were all less than +7.5% and were accepted on the basis taht this was a plausible difference. The length of the trains was also recorded for both wide- and narrow-body cargo. These showed deviations of less than 1%. The model demonstrated that it accurately portrayed the current situation, meaning it could also predict the effects of different handling strategies on the KPIs at the A-pier with *Clean VOP* in effect.

IV. DESIGN

As discussed in the literature review, systems with pull or push-pull logic enable the supply chain to account for the restrictions imposed by the *Clean VOP* policy. Different procedures may be designed which ensure all cargo is delivered while keeping vacant aircraft stands clear of cargo. In this section, different strategies will be defined using combinations of of push, pull and push-pull systems, which will subsequently be simulated using the DES model defined earlier.

Handling Strategies

An entirely new strategy utilising pull logic would allow for cargo to be delivered directly to the aircraft when it is needed rather than pre-positioning cargo and violating the *Clean VOP* regulations. This would mean that cargo is held on the shunting area at KLM Cargo's warehouse until the aircraft arrives and the cargo is 'pulled' to the aircraft. This pull system is strategy 1.

Secondly, the current handling procedure utilising push logic may be modified. If the push system were to push all the cargo destined for the A-pier to the buffer underneath the pier instead of the aircraft stand, and deliver the cargo to Apron Services in the buffer, the *Clean VOP* requirements would be met. From the buffer, the cargo is Apron Services's responsibility, meaning that cargo will stay in the buffer until it is picked up by Apron Services for loading the aircraft. This approach requires collaboration and communication between the departments regarding the location of the cargo in the buffer. This (modified) push system is strategy 2.

However, if the Apron Services refuses to transport cargo from the buffer to the aircraft or the communication required is not possible, KLM Cargo will remain responsible for the delivery of the cargo to the aircraft stand. In this case, upon the aircraft's arrival, a cargo tug must drive from the warehouse to the A-pier and back simply to move the cargo from the buffer to the aircraft. This creates a push-pull system where cargo is initially pushed to the buffer, where the cargo waits to be pulled to the aircraft stand which is triggered by the aircraft's arrival. This is strategy 3.

A hybrid of strategy 1 and 2 is also possible. This would mean that cargo is always driven towards the A-pier as soon as it becomes available for transport. However, the destination is determined by whether or not the aircraft has arrived at the gate. If so, cargo is sent directly to the aircraft. If the aircraft has not arrived, cargo is delivered to the aircraft handler in the A-pier buffer instead. From the buffer, Apron Services transport the cargo to the aircraft when it is needed for loading. This combination of a push and a pull system is strategy 4.

Finally, a hybrid of strategies 1 and 3 would also lead to all cargo being sent to the A-pier to either the aircraft or the buffer space (depending on whether or not the aircraft has arrived at its gate). However, in all cases, KLM Cargo is responsible for the delivery of the cargo at the aircraft itself. This means that all cargo sent to the buffer, must also be moved from the buffer to the aircraft by KLM Cargo. This system using both pull and push-pull logic is strategy 5.

TABLE I

SIMULATION RESULTS

Strategy	Violations	OTP*	Utilisation	Distance*	Space*
Current	1319.88	+0.0%	0.0%	+0.0%	+0.0%
1	0.0	-34.6%	0.0%	-19.9%	+190.1%
2	14.1	-0.5%	99.6%	+75.0%	+0.6%
3	0.0	-40.3%	80.3%	+92.3%	+1.0%
4	0.0	-0.2%	72.1%	+47.9%	+0.5%
5	0.0	-36.3%	70.2%	+62.3%	+0.0%

* Due to the confidentiality of the KLM performance indicators, *OTP*, *Distance* and *Space* are shown as a percentage change in relation to the current procedures.

Simulation Results

The strategies are tested using the discrete event simulation model, and allow the effects of each strategy on the KPIs to be explored. Table I shows the effect of each strategy compared to the baseline simulation of the current strategy.

While the current strategy would lead to countless *Clean VOP* violations, modifying the push system as is done in strategy 2 is not sufficient to prevent violations from occurring. Strategies 1, 3 and 5 cause the OTP to suffer, whereas strategies 2 through 5 significantly increase the distance driven with the cargo tugs. Since none of the strategies dominate all other strategies, a tradeoff is to be made between the KPIs. To do so, the AHP method is applied to analyse the results.

V. EVALUATE

In this section, the simulation results are analysed using the Analytical Hierarchy Process (AHP) to determine the ranking of the proposed strategies. Finally, conclusions will be drawn to answer the research question, the model itself will be evaluated and recommendations will be made for KLM as well as for future research on this subject.

Analytical Hierarchy Process

The AHP method allows problem owners to systematically determine the weights of the KPIs by using pairwise comparisons of each KPI and assigning them a weight relative to each other. The result is a pairwise comparison matrix which allows the KPIs weight to be calculated.

Furthermore, output values are normalised using the same technique allowing for a direct comparison between the different strategies. The sumproduct of the KPI weights and the KPI values gives a weighted score for each strategy. These weighted scores are shown in table II and allow for the ranking of the different strategies.

The weighted scores indicate that strategy 4 scores the highest, and is therefore the suggested strategy to implement when a *Clean VOP* is in effect, followed by strategy 1. Not implementing a new strategy is undesirable due to the high number of *Clean VOP* violations recorded in the base scenario. This is also reflected in the strategy ranking in table II where the current strategy scores the lowest.

TABLE II

STRATEGIES' WEIGHTED SCORES

Strategy	Weighted Score	Strategy Ranking
Current	0.228	6
1	0.342	2
2	0.251	5
3	0.335	4
4	0.432	1
5	0.337	3

Conclusion

To answer the main research question, maintaining the on-time performance while meeting the *Clean VOP* requirements is possible if the outbound cargo handling procedure is redesigned. Cargo driven to the airside after the aircraft has arrived is handled as usual; it is pulled to the aircraft stand and delivered to Apron Services at the aircraft. Cargo which becomes available prior to the aircraft's arrival follows a new procedure, this cargo is pushed to the buffer space underneath the A-pier and handed over to Apron Services at the buffer. From the buffer, Apron Services is to transport the cargo to the aircraft to ensure the freight is loaded on time for departure. This requires that the parties along the supply chain communicate and collaborate, to ensure that the location of buffered cargo is known.

If such collaboration for some reason is not feasible, implementing a pull-system ensures that cargo delivers all cargo to the aircraft after the aircraft arrives. This prevents *Clean VOP* violations and leads to no changes in the tug driver's procedures. The consequence, however, is that all early cargo must be held on the KLM Cargo premises until the aircraft arrives at the gate.

Although a combination of push logic and pull logic is the optimal strategy in the case of KLM Cargo for Schiphol's A-pier, this strategy may not be the optimal approach for other air cargo handlers faced with *Clean VOP* regulations. The strategy to implement is highly dependent on factors such as available shunting/buffering space at the cargo warehouse, size of the centralised cargo buffer, and the cargo delivery deadlines agreed upon by the parties involved in the cargo and aircraft handling process. However, this research has demonstrated that a combination of push, pull and/or push-pull logic may be utilised to successfully implement a cargo handling strategy which maintains a high on-time performance while respecting the *Clean VOP*.

Limitations of the Research

The model used for this research is a model of Schiphol's future A-pier, and only simulates outbound cargo handled by KLM. It does not account for other piers being converted to *Clean VOP* piers, and does not consider the infrastructure at other airports. Furthermore, the model uses a static flight schedule with a stochastic element allowing aircraft to arrive a few minutes early or late. The model does not, however, account for major disruptions or gate changes.

The weights obtained through the AHP method, while obtained systematically, are valid for KLM Cargo's (current) situation. Other cargo handlers may have different priorities with respect to, for example, shunting space availability and distance driven with cargo tugs. This would lead to somewhat different weights which could change the ranking of the cargo handling alternatives.

Recommendations

Practical recommendations for KLM include addressing the silo mentality which has developed over the years. Implementing strategy 4 will require a constant exchange of information to ensure that Apron Services knows where to pick up cargo delivered prior to the aircraft's arrival, and allowing cargo to be redirected to the aircraft if the aircraft has arrived at the gate. As an added benefit, Apron Services will have greater control over the aircraft stand, which may contribute to a higher efficiency and a shorter turnaround time. This, however, is still to be explored.

To be able to generalise the impact of the *Clean VOP* policy on a cargo handler's operations and the optimal strategy to employ when faced with this policy, more airport piers should be modelled. The A-pier is a new pier which is situated close to the KLM Cargo premises, and has fifteen cargo buffer lanes built underneath it. Piers which were not designed with *Clean VOP* operations in mind, in many cases do not have similar centralised buffering facilities. This means that the conclusions drawn for the implementation of the *Clean VOP* at Schiphol's A-pier are not necessarily generalisable to other piers at Schiphol or other airports. A model of the entire airport would be able to handle large disruptions and gate changes more easily, and could estimate the impact of changing an existing pier into a pier where the *Clean VOP* is enforced. Furthermore, modelling other airports would indicate how the handling strategies described in this research can be employed by other cargo handling agents to meet the *Clean VOP* requirements while maintaining their on-time performance.

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