KLM
Catering Services Schiphol

# Revolutionizing airline catering trolley transport by using a Unit Load Device

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TU Delft

# Revolutionizing airline catering trolley transport by using a Unit Load Device

by

J.K. Wempe

## Master Thesis

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# Preface

Dear reader,

This thesis is the final hurdle I need to take before completing my Master of Science in Mechanical Engineering at the University of Technology Delft. This thesis was quite the journey and started with the master track Multi-Machine Engineering. During the second year, I started with a literature study on how materials that move through warehouses are unitised, secured and transported in warehouse environments. This turned out to be practical since one of the main challenges KLM Catering Services experiences is the design and implementation of a unit load plate in their future catering facility. The unitising is intended to make the current process more ergonomic and economic.

After the initial proposal the outline of the thesis was set, and after the approval of my supervisors, Wouter van Den Bos and Egbert Rietveld, the journey began. In this work, you may find information about the airline catering process, the different methods of transporting trolleys and design considerations for each step along this process. Although I did not specialise in design engineering, I have learned a lot from the experience of working for a big cooperation. Next to this my data structuring and presentation skills greatly developed during this master and I am proud to present you to my work.

I would like to start by thanking Egbert and Wouter for their daily supervision and assistance. Egbert is an employee who has more than 30 years of experience at KCS. His knowledge on all subjects of the airline catering services is unmatched and the discussions I had with Egbert were fun and greatly helped me writing this thesis. Another great help at KCS was Diederik de Bruin. His model of the future KCS plant provided me with synthetic data to base my research on. Wouters input was aimed more towards the data-presentation and design side of the final design. Additionally, I would like to thank Jovanova. She provided great feedback during the meetings on how to structure the report and how to deal with specific issues.

Finally, I want to thank my parents, family, friends and my colleagues at KCS for their everlasting support, motivation, and guidance. This journey would not have been the same without you.

I wish you a pleasant reading,

*J.K. Wempe*
*Delft, December 2023*

# Summary


With the increasing automation of transportation logistics, the transport of airline catering trolleys is severely lacking. In today's world most of the trolley transport is preformed manually. This is both costly and physically straining. This master thesis is focused on finding a solution to automate the transport logistics of trolleys through an airline catering facility. This is achieved by proposing the implementation of a Unit Load Device (ULD). This ULD should be able to carry and secure multiple airline catering trolleys simultaneously while being transported by material handling equipment such as Automated Guided Vehicles, highloaders or conveyors. The main research question of this work reads as follows.

***How can the implementation of a Unit Load Device affect the logistic chain of an airline catering facility?***

To answer this question, the logistics chain of an airline catering facility needs to be explored. Additionally, the ULD needs to be designed and optimized and the potential economic benefits should be investigated. The sub-questions formulated to answer the main question are as follows:

- What are the existing logistical process steps and trolley movement patterns within KCS?
- What are the current methods for transporting rolling goods and what constitutes the state of the art in the industry?
- What are the specific process requirements for designing an efficient Unit Load Device (ULD) capable of accommodating diverse trolley types and sizes?
- How would the implementation of the designed ULD impact the current operations of the airline catering facility?
- What Key Performance Indicators (KPIs) can be established to measure the success of the ULD implementation and its influence on the logistic chain?

First, the state of the art of the processes within an airline catering facility are described. This includes: flying, transport by means of highloader, emptying, washing, production and flight end assembly. All processes require different operations to the trolley. This is of great importance when optimizing a ULD that transports the trolleys past and sometimes during the different processes. After this the different current methods are described based on a literature review and an exploration throughout the facility of KLM Catering Services (KCS). Although almost all trolley transport is done manually, there are some forms of automation like monorail systems and conveyor systems.

These methods however cover a small fraction of the transportation and lack in certain areas such as flexibility. Following this, an exploration of various ULD types and securing methods is provided.

After the ULD types and securing methods are formulated, the requirements of the ULD are formulated. It is evident that there are significant differences in requirements between a ULD that is designed for securing trolleys during washing and a ULD that is designed to secure trolleys during highloader transport. Thereafter the different methods for securing loads are discussed and tested. An effective solution turned out to slightly tilt the ULD while closing off the declined side as this increased the friction and made sure the trolleys remained flush. For the highloader it was determined that a half size trolley divider was necessary. From this three initial prototypes were constructed. Out of which 1 all purpose ULD and 1 internal ULD remained. The internal ULD initially looked interesting as the piece cost of this ULD was over three times cheaper. From this the question emerged what are the economic implications of using no, one or multiple ULDs within an airline catering facility.

Upon retrofitting the existing facility design into a facility design that incorporates both one and two ULDs, it became evident that using two ULDs introduces the need off additional transport requirements for empty ULDs and would furthermore complicate the overall logistics. Economic evaluations demonstrated that opting for multiple ULDs only yielded small economic benefits compared to using a single ULD. When comparing any facility that uses ULDs with a manual facility, the annual cost reduction proved to be substantial.

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# NOMENCLATURE

## Abbreviations

| | |
|---|---|
| AGV | Automated Guided Vehicle |
| AMR | Automatic Mobile Robot |
| ATLAS | Alitalia, TAP, Lufthansa, Air France, and Sabena. Most widely used airline equipment size and standard |
| Capex | capital expenditures |
| CTR | Container TRolley |
| FEA | Flight End Assembly |
| FSE | Full Size Equivalent |
| GFRP | Glass Fibre Reinforced Polymer |
| ICA | InterContinentAl |
| KCS | KLM Catering Services |
| KPI | Key Performance Indicator |
| KSSU | KLM, Swissair, SAS and UTA. second used airline equipment size and standard |
| M-Class | Economy Class |
| Opex | Operational expenditures |
| T11 | Trolley 1/1, a whole trolley |
| T12 | Trolley 1/2, half a trolley |
| ULD | Unit Load Device |

# 1

# INTRODUCTION

## 1.1. MOTIVATION

KLM Catering Services is in the process of designing a new catering facility. One of the primary reasons for the new facility is the observation that almost all trolley movement at the current facility is done manually. Each day 6000 trolleys are transported an average of 150 meter by hand equating to roughly 900km of manual transport daily. This transport is unwanted due to it being heavy duty work that causes work-related injuries for the employees who on average are 53 years old. Besides from it being ergonomically unsound to move trolleys manually it also takes up a lot of manpower. It is estimated that in the current facility 122 FTE are used for transporting and securing trolleys throughout the facility [1].

While conducting this research, it has become evident that instances of airline catering trolleys being transported via automated methods, such as monorails, (Automated Guided Vehicles) AGVs or conveyors are rare. Indicating that not only KCS uses predominantly manual movement throughout the facility, also other airline catering facilities around the globe phase this logistical struggle. Figure 1.1 is an example of how trolleys are handled manually, in this instance at American Airlines.

Figure 1.1: An employee from American Airlines pushing 4 trolleys and a door open simultaneously [2].

1

This report seeks to address this automation challenge by designing a Unit Load Device (ULD) capable of being transported via AGV, highloader and conveyors, while simultaneously securely carrying multiple catering trolleys. The objective is to develop this ULD to align with the required logistical processes.

## 1.2. RESEARCH PROBLEM

This research encompasses several distinct challenges within the context of designing an efficient and automated transport solution for airline catering trolleys. The challenges defined by this work can be categorized into the following areas:

- **Versatile Process:** The airline catering process involves a multitude of operations, creating many different trolley streams that need to be facilitated with efficient logistics. These different streams consist of different process requirements for which the designed transport solution must be properly adapted.
- **Variability in trolley size and dimensions:** There is a significant diversity between trolley sizes and dimensions used within the airline catering industry. The designed transport solution must be able to accommodate this wide range in trolley sizes.
- **Industry's Limited Attention:** Despite the need for automated trolley transport solutions, the industry as a whole has paid limited attention to automatizing trolley transport.

The following subsections will provide a exploration of each of these challenges, offering insights into their implications and the proposed strategies to address them.

### 1.2.1. VERSATILE PROCESS

Airline catering services consist of multiple processes. For KCS and similar facilities this includes a series of essential steps as is also described by [3]. This process is graphically represented in Figure 1.2, and reads as follows.

- 1. Flying, trolleys are being used for service and waste.
- 2 Transit using a highloader from the airplane to the facility.
- 3. Sorting of trolleys and emptying of contents.
- 4. Trolley washing.
- 5. Production: Adding flight specific content to the trolleys.
- 6. Flight-End-Assembly (FEA): Sorting based on highloader level.
- 7. Transit between facility and airplane via high loader.

Importantly, due to the diversity in the trolleys content, there are numerous emptying, washing, and production stations and, consequently, there are many different trolley streams. It is essential to recognize that each step in the process demands specific methods of trolley handling. This diversity in process steps necessitates a corresponding diversity in transport requirements. For example, the trolley washer requires a ULD that is washable, while the highloader requires trolleys to be securely fixed during the accelerations experienced during maneuvering and emergency breaking.

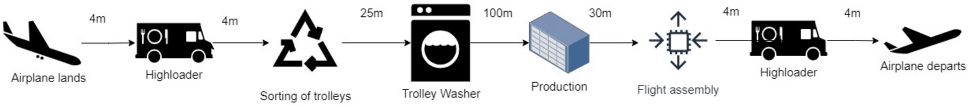



Figure 1.2: Graphical representation of the trolley process through the factory of KCS. Included are the average distances between its process step.

### 1.2.2. VARIABILITY IN TROLLEY DIMENSIONS AND SIZE

Airline catering facilities rely on a range of trolley types and equipment to support their operations. The diversity in trolleys at KCS is due to the following reasons:

- **Trolley types:** There are multiple trolley standards used worldwide. KCS wishes to make their process applicable to the two largest trolley standards namely ATLAS and KSSU. These two trolley standards both have a full size trolley (T1/1 or T11) and a half size trolley (T1/2 or T12). Leading to four distinct trolleys with variations in length, width and sometimes even the number of swivel wheels.
- **Container TRolleys (CTR):** In addition to the trolleys that board the airplane, containers or boxes play a vital role in the catering process. These boxes are transported using CTRs. The CTR is important to take into account since it does not have any brakes and since it is the longest trolley.
- **Trolley Configurations:** The airline catering process requires both open and closed trolleys. Open configurations are typical for washing or production, while trolleys are closed when moving in a highloader. This leads to trolleys varying in width.

Table 1.1 gives a list of all dimensions of all different trolley types which are handled at KCS. Figure 1.3 provides a picture of the exterior of all trolley types. Figure 1.4 provides insights in the different wheelbases of the trolleys.

This diversity in equipment size, wheelbase and the use of both open and closed trolleys presents a significant challenge. Fixating trolleys via their brakes is not a feasible option, primarily due to the absence of brakes on CTRs and the possibility of human error when engaging trolley brakes. Moreover, the substantial differences in dimensions among trolleys further complicate the design process, as there is always room for the smallest trolley to move freely. These complexities greatly hinder the development of a standardized transport solution.

### 1.2.3. LACKING ATTENTION

Despite the need for more efficient methods of transporting airline catering trolleys, there has been limited attention given to the development of automated solutions or

Table 1.1: Dimensions and number of swivel wheels for all different trolley types.

| Trolley type open/closed doors | Length [mm] | Width [mm] | Height [mm] | Swivel wheels [#] |
|---|---|---|---|---|
| KSSU T11 Closed | 843 +-1 | 300 | 1036.8 +- 1.7 | 4 |
| KSSU T11 Open | 800 +-1 | 335.4 | 1036.8 +- 1.7 | 4 |
| KSSU T12 Closed | 424.5 +-1 | 300 | 1036.8 +- 1.7 | 2 |
| KSSU T12 Open | 400 +-1 | 317.7 | 1036.8 +- 1.7 | 2 |
| ATLAS T11 Closed | 810 +-1 | 302 | 1030 +-2 | 4 |
| ATLAS T11 Open | 768 +-1 | 337 | 1030 +-2 | 4 |
| ATLAS T12 Closed | 404 +-1 | 302 | 1030+-2 | 2 or 4 |
| ATLAS T12 Open | 362 +-1 | 329.4 | 1030+-2 | 2 or 4 |
| CTR | 875 +-1 | 330 | 1026.1 | 4 |


Figure 1.3: The different trolley types used at KCS. The middle picture shows a CTR carrying boxes.

methods for transporting multiple trolleys simultaneously. Extensive internet research on the largest airline catering companies [4], and more global searches on material handling systems for airline catering trolley revealed only a handful of material handling methods employed:

- **Monorail Systems:** Many in-flight catering services including Emirates, LSG Sky chefs, Lufthansa and KCS employ a monorail system that transports multiple trolleys along different tray inserting stations [5–7]. Examples of a monorail system are depicted in Figure 1.5.

- **Manual Pallet Truck:** Logitrans has devised a manual-driven pallet truck for Finnair catering capable of carrying up to nine T12 trolleys simultaneously [8].

- **In-floor conveyor belts:** many facilities have adopted low-speed moving floor conveyors primarily to transport trolleys to automatic trolley cleaners [9].

- **Side actuated conveyors:** KCS utilizes side actuated conveyors capable of transporting trolleys on a straight track one by one.

The limited number of existing methods combined with the lack of flexibility provided by all methods underscores the industries need for a more innovative and efficient solution. The scarcity in automated solutions highlights the significance of the research and development efforts being undertaken.

Figure 1.4: Six different wheelbases of different trolleys.

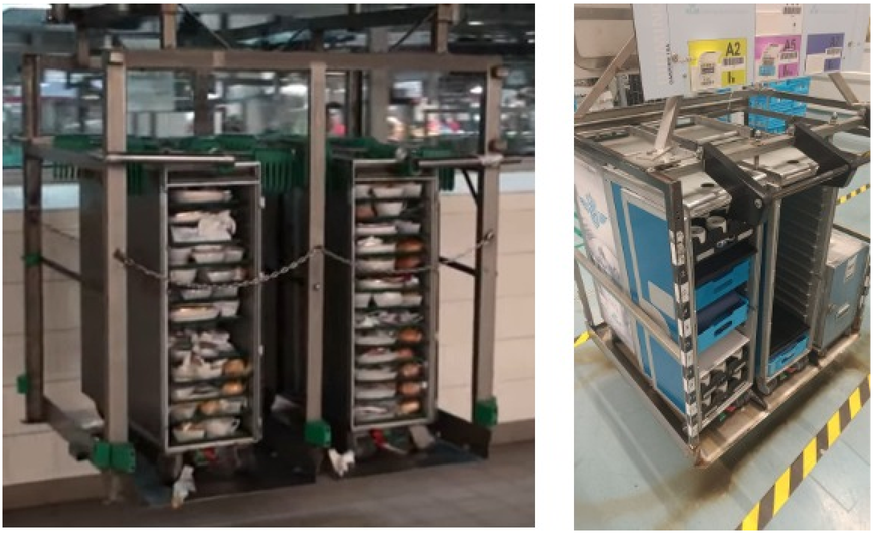


Figure 1.5: The monorail system used by emirates [10] on the left and KCS on the right.

## 1.3. RESEARCH OBJECTIVE

As mentioned before, little to no research has been done on flexible transportation off multiple trolleys at the same time. It is paramount to achieve this as transporting trolleys is heavy, not ergonomic and costly. The objective of this research is to find a solution that allows for multiple varying trolleys to be transported at the same time by AGVs, highloaders and conveyors.

## 1.4. RESEARCH QUESTIONS

The main research question developed for this thesis reads as follows:

***How can the implementation of an Unit Load Device affect the logistic chain of an airline catering facility?***

To answer this question, the logistics chain of an airline catering facility needs to be explored. Additionally, the ULD needs to be designed and optimized and the potential economic benefits should be investigated. The sub-questions formulated to answer the main question are as follows:

- What are the existing logistical process steps and trolley movement patterns within KCS?
- What are the current methods for transporting rolling goods and what constitutes the state of the art in the industry?
- What are the specific process requirements for designing an efficient Unit Load Device (ULD) capable of accommodating diverse trolley types and sizes?
- How would the implementation of the designed ULD impact the current operations of the airline catering facility?
- What Key Performance Indicators (KPIs) can be established to measure the success of the ULD implementation and its influence on the logistic chain?

## 1.5. RESEARCH SCOPE

Before proposing a design, a thorough literature review has been carried out regarding different methods of load securing and different methods of material handling equipment [11]. The scope of this thesis is limited to trolley transport among an airline catering facility. This research will not focus on standardizing trolleys or adjusting current trolley designs although it might give recommendations on that topic. The logistical streams of other products than trolleys and ULDs are considered outside of the scope. The required contents off a specific flight is also considered outside of the scope.

## 1.6. OUTLINE

This introduction has described the different problems KCS faces by transporting trolleys manually. It also briefly touched on challenges that KCS faces for automating a flexible transport system. Chapter 2 will delve deeper into the state of the art of the current logistical process, the way trolleys could potentially be secured, and what ULDs are feasible for this challenge. Chapter 3 will cover the design and testing of the ULD. It will first summarize the different possible process and design requirements of the ULD. It will then formulate different possible designs based on the requirements and the literature. These designs will be tested and evaluated for suitability in a highloader and on a AGV. Chapter 4 will focus on how the ULD could be implemented in the current facility and how this will change the current operations. An economic analysis will be used to measure the success of the ULD like. Chapter 5 will give a conclusion and recommendations. This is visualised in Figure 1.6.

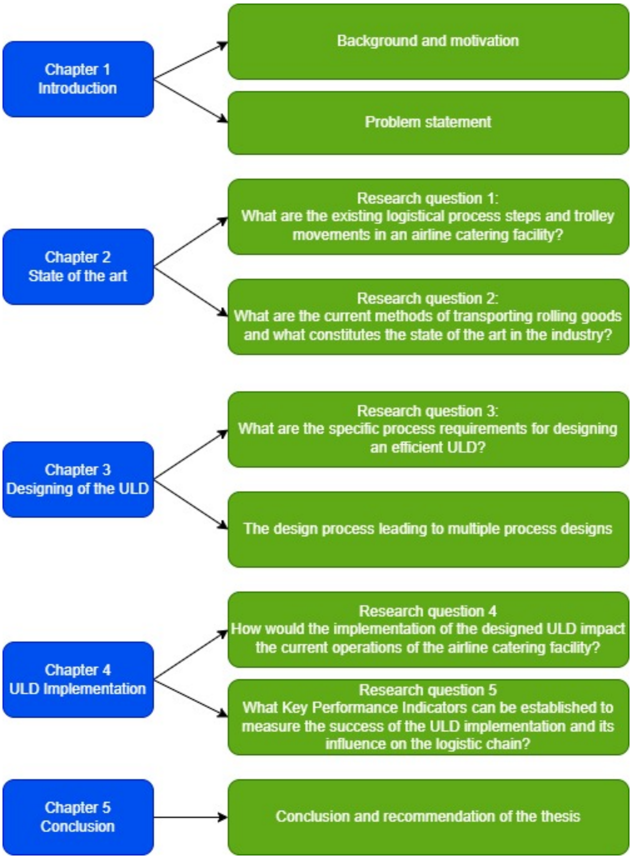



Figure 1.6: The outline that this thesis will follow.

# 2

# State-of-the-art

This chapter will address the first two research questions: 'What are the current logistic steps and trolley movements within an airline catering facility?' and 'What are the current methods of transporting rolling goods and what constitutes the state of the art in the industry?' In doing so, this chapter will provide an exploration of the existing practices and technological advancements related to the transportation and securing of trolleys within an airline catering facility. This chapter will further describe the different ULD types and what ULD type could potentially be used by an airline catering facility.

## 2.1. State-of-the-art of the catering process

The process of airline catering trolley is described by dividing the process into smaller sub processes and focus on what happens to the trolley during these processes. The identified sub processes are:

- Flying, trolleys are being used for service and waste.
- Transit using a highloader from the airplane to the facility.
- Sorting of trolleys and emptying of contents.
- Trolley washing.
- Production: Adding flight specific content to the trolleys.
- Flight-End-Assembly (FEA): Sorting based on highloader level.
- Transit between facility and airplane via highloader.

Figure 2.1 shows a graphical representation and explanation of the process as is. Appendix A describes every step off the process in more detail.
It is important to remember that each process can take place among different locations in the facility this is shown in Figure 2.2. ICA (Intercontinental) and Europa (EUR) are separated since they require vastly different contents. It furthermore depicts what type of trolley movement is used.

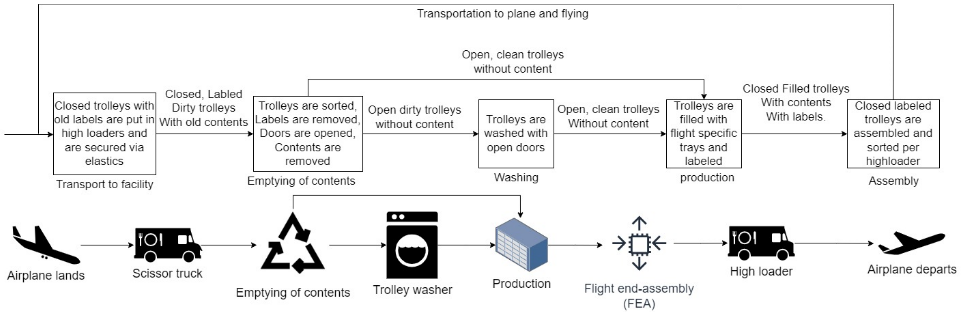



Figure 2.1: The process of a trolley through KCS including explanation.

## 2.2. STATE OF THE ART TROLLEY MOVEMENT

After detailing the different processes executed in the airline catering process, it is essential to explore the different methods currently employed for trolley movement. The efficient transportation of these trolleys within the facility is a critical aspect of streamlining operations. This section will delve deeper into the diverse methods utilized for trolley movement, highlighting their respective advantages, limitations and applications. Different trolley moving methods have been observed at either KCS or via online research. These include manual transportation, side-gripping conveyors, moving floor conveyors and monorails.

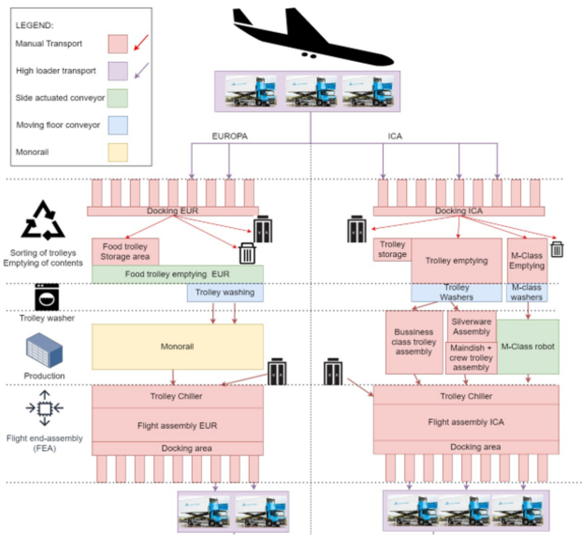



Figure 2.2: A schematic representation of the ground floor of the current facility and the current way trolleys are transported.

### 2.2.1. MANUAL TRANSPORTATION

Manual transportation stands as the prevailing method for moving airline catering trolleys. Its advantages lie in its simplicity, versatility, flexibility and the ease of visual sorting by employees. Trolleys can be handled individually, as is common for flight crew during flights, or multiple trolleys can be managed simultaneously. At KCS, it is a frequent sight to observe employees walking with multiple trolleys, sometimes handling up to six T12 trolleys simultaneously as is visualised by Figure 2.3. This practice primarily aims to reduce the overall distance covered during their shifts. However, due to the relatively small base-to-height ratio of these trolleys (1:3.5) the trolleys are top-heavy. It is therefore essential for all T12 trolleys to be supported during manual transportation. Although this prevents trolleys from tipping over during minor bumps or irregularities in the ground. It results nonetheless in ergonomic challenges, as most employees tend to bend over the trolleys and lean on them while walking. Consequently, manual transportation exhibits drawbacks, including limited scalability and physically demanding working conditions.

Figure 2.3: An employee at KCS walking with 6 T12 trolleys at once [12].

### 2.2.2. SIDE-GRIPPING CONVEYORS

Side gripping conveyors achieve movement by engaging the sides of the trolleys using brushes, bristles, or other elastic materials to push the loads. This action propels the trolleys over a dedicated track. It is important to note that both sides of the trolley need to be actuated for transportation, resulting in single-line movement only. Consequently, there is no option for lane splitting or sorting after the trolley enters the conveyor.

Due to the absence of lane splitting and sortation, this conveyor type is used when large quantities of trolleys undergo an identical process. KCS uses these conveyors in two different locations: at the trolley return of Europa, as visualised in Figure 2.4. And at the ICA economy class meals (M-class). At the European return, the side-gripping conveyor is used to elevate all trolleys to an appropriate height before propelling them past employees who empty the trolleys. This elevation is to ensure ergonomic conditions.

At the M-Class line, brushes are employed to propel the trolleys through an automatic filling machine responsible for inserting all food trays into the trolleys.

Figure 2.4: A side-gripping conveyor is used to transport all Europa food trolleys past emptying workstations.

### 2.2.3. MOVING FLOOR CONVEYORS

Flat belt conveyors use an actuated belt on which the trolleys stand to drive the trolleys. Since trolleys have a high center of gravity the trolleys are unstable. It is for that reason that moving floor conveyors use low speeds and accelerations while confining the free movement in the lateral direction. At KCS and other facilities these conveyors are only seen in dedicated automated trolley-washers for example Meiko [9]. Since trolley washers use low speeds and by having unobstructed access to the trolleys these type of conveyors are suited for handling trolleys.

### 2.2.4. MONORAILS

Monorail systems are a type of conveyor system that employs a track along which elevated carts are driven. In the case of airline catering facilities this system is used at many different facilities. All facilities that use monorails employ carts that can carry multiple open trolleys at the same time, as is visualised by Figure 1.5. The trolleys are loaded on the carts at designated docking stations. Carts are lifted off the ground putting the trolleys at an elevated height. Thereafter the trolleys are guided along different workstations at an appropriate height for the insertion of trays and container boxes on the trolleys.

### 2.2.5. CONCLUSION TROLLEY HANDLING

Several methods of handling airline catering trolleys have been discussed in this chapter. Each method of transportation has its own use cases and drawbacks. It is clear that at KCS and at other facilities manual transportation is still used the most for its simplicity and endless flexibility. All current transportation methods have distinct advantages and drawbacks. They are summarized in Table 2.1.

Table 2.1: The different trolley transportation methods, their advantages, disadvantages.

| Mode of transport | Advantages | Disadvantages |
|---|---|---|
| Manual Transportation | - Flexible.<br>- Facilitates easy sorting. | - Scaling requires scaling labor cost.<br>- Physical strain.<br>- Trolleys might tip over. |
| Brush Track Conveyors | - Consistent high speed.<br>- Easy loading. | - Initial installation and maintenance costs.<br>- Spatial requirements.<br>- Unable to split lanes. |
| Moving Floor Conveyors | - Automated movement.<br>- No obstruction to trolley.<br>- Easy loading. | - Initial installation cost.<br>- No flexibility.<br>- Low speed and acceleration. |
| Monorail Systems | - Space-efficient.<br>- High-capacity transportation. | - Initial investment.<br>- No routing flexibility.<br>- Built in wast of employees time.<br>- Time spend handling trolleys. |

## 2.3. BACKGROUND ON ULDS AND LOAD SECURING

In this section, the different types of ULDs and potential load securing methods for transporting multiple trolleys will be explored. ULDs are practically used to unitize multiple individual loads and thereby reduce the required amount of transport and handling movements [13]. Kay [14] adds that the use of unit loads enables the use of standardized material handling equipment. This section will cover Various ULD types, their suitability and examine different methods to secure loads.

### 2.3.1. ULD TYPES

In a literature assignment by Wempe [11] on ULDs in warehouse environments multiple different types of warehouse ULDs are discussed based on research from [14] and [15]. These ULDs include:

- **Pallets** provide a portable, horizontal, rigid platform that allows goods to be assembled, stored, handled and transported as a single unit load [16]. Ackerman [15] added that the pallet should allow for forks to be used to pick up the unit load.

- **Slipsheets** are small lightweight sheets allowing for efficient use of space and weight [17]. Difficulties arise with handling since this requires specialised push-pull forklifts. They are primarily used for long distance transport in trucks and containers.

- **Boxes and totes** Lightweight small containers to unitise smaller loads and make their exterior uniform ensuring uniform handling requirements [18].

- **Racks** are a ULD recently in part to picker systems to reduce walking distance of employees. An advantage off using racks is that they add height which allows for multiple products to be placed atop of each other [19].

- **Load plates** just like pallets provide a portable, horizontal, rigid platform that allows goods to be assembled, stored, handled and transported as a single unit load. However there is no access from underneath for forks. Load plates are typically transported via conveyor or AGV.

Since slipsheets are used for lightweight loads and not easily handled, they are not suitable for transporting trolleys. Boxes, totes and racks are used for smaller loads. The two viable ULD types that remain are: Pallets and load-plates. Both types are represented in Figure 2.5. The pallet is the most used, well known and versatile ULD. The main difference between a pallet and a load plate is its base which makes it accessible to inserts forks of a forklift into the pallet. This makes the pallet a ULD which can be stored at the ground without the need of docking stations [20]. The platform however also makes the pallet heavier, weaker and adds more height compared to a load plate [21]. It is therefore that a load plate is advised.

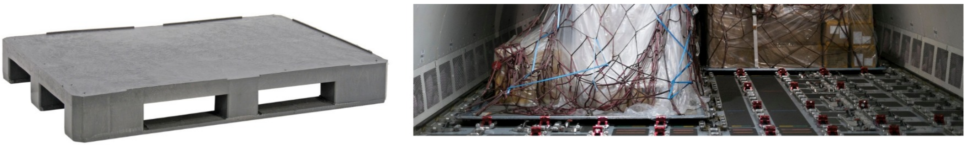


Figure 2.5: A pallet on the left and a load plate on the right.

### 2.3.2. SECURING OF LOADS

This section aims to provide an overview of load securing measures found in the literature. The load restraining measures used for this section are based on methods found in the following literature [22–26]. These include: blocking, locking, lashing, increasing friction, shrink wrapping, strapping, adhesives and formfitting.

- **Blocking** or bracing means that the cargo is stowed flush against fixed structures and fixtures on the load carrier[22]. These fixtures are mostly placed after loading. Examples include dunnage to fill voids but also wedges or steal beams [27].

- **Locking** is the practice of locking multiple loads together or to the material handling equipment. Applications include the interlocking between containers in the shipping industry using twist locks [28], the locking of ULD plates in the aviation industry [29], on a smaller scale the interlocking between different boxes when stacked correctly or the use of clamps to hold a load down.

- **Lashing** is a method used to secure loads by using the tensile strength from devices such as ropes, chains, wires or straps to hold the load in place during transport [30].

- **Increasing friction** will make a rolling object that moves unaided on a horizontal surface eventually come to rest as a result of rolling friction [31]. This rolling friction can be increased in several ways. By using friction maths, or by making the surface rougher.

- **Wrapping** includes the process of using a plastic film to cling on to the materials on top of the ULD. This can be done in two methods namely by stretching the wrap or by shrinking the film after applying heat [32].

- **Strapping** is a method that uses straps or bands to form enclose multiple items. As the elastic is released or the band is tightened this creates a tension force between the enclosed loads [33].

- **Adhesives** such as glues or tapes, can be used to secure items together or to the load carrier. Adhesives provide a bonding force that holds the load in place and prevents shifting or movement. Adhesives are mostly used for securing smaller items and lightweight packages [34].

- **Formfitting** is designing the load and the load carrier in such a way that they fit together tightly, minimising the potential for movement. This can be achieved through customises packaging, inserts, or dividers that create a secure fit for the items. It is basically a form of preemptively blocking the load inside the ULD.

Since KCS handles over 6000 trolleys daily and since each trolley has to be loaded and unloaded of each ULD multiple times throughout the process, a method off securing is required which requires minimal effort and no use off material. The method used should furthermore be fail safe. Therefore securing by means of blocking, lashing, shrink wrapping, strapping and adhesives are not considered for confining the trolley to the ULD. Methods that are viable are: locking, increasing friction and formfitting.

# 3

# Designing of the ULD

The previous chapter has described the challenges faced by KCS in automating trolley transport as well as describing complexities for designing a Unit load device. This chapter will delve deeper into the ULD design for trolley transport by describing the specific process requirements for an Unit Load Device, as well as prototyping and testing the ULDs on both AGV and highloader.

The process of ULD design and testing is essential to ensure that the ULDs are properly secured.

## 3.1. ULD usage for trolleys in the catering process

The introduction has sketched the process trolleys undergo in an airline catering facility. This included flying, transit, sorting, emptying, washing, production and flight end assembly. Each step has its own special demands and process requirements.

### 3.1.1. Requirements

This subsection will explore the requirements by first defining a set of universal requirements. Thereafter it will delve deeper into different process related requirements like highloader transport and washing. If needed the requirements are further explained.

#### Universal requirements

- **Size** Applicable for 3 Full Size Equivalents. This includes 3 CTR, 3 T11 or 6 T12.
- **For all trolleys used at KCS** KSSU ATLAS and internal trolleys should be able to be transported on the ULD.
- **Properly secured** The ULD must ensure that no trolley can fall off during transportation as this could damage the material handling equipment and the content of the trolleys. The ULD should furthermore keep the trolley flush to the ULD for washing and potentially production.

- **Price** The ULD should be designed to be cost effective. KCS has formulated the goal to keep the piece price below €650,-.
- **Handling** ULDs should be designed for easy loading and unloading of trolleys as over 6000 trolleys daily will traverse the facility. Trolleys furthermore should not be able to fall of the ULD during loading.
- **MHE** ULDs must be compatible with transportation via AGV and Conveyor systems.



Some off these requirements are not trivial. Therefore further explanation is provided in the following sections.

### SIZE

Since the ULDs should be transported via AGV and conveyors it is important to have a stable, maneuverable and strong ULD. For this reason it is important that the ULD is as square as possible.

As indicated by Table 3.1 the longest trolley is a CTR with a length off 876mm and the widest trolley is a KSSU T11 with open door configurations at 335.4mm. A trolley position or Full Size Equivalent (FSE) should at least encompass (335.4 X 876mm). In order to make the ULD as square as possible, two primary size options emerge: making the ULD two (FSE) wide, resulting in a (720mm X 876mm) size, or opting for a 3 FSE width, which would yield a (1080mm X 876mm) size. Choosing a trolley size of 3 FSE increases the ULDs transport capacity by 50% compared to a size of 2 FSE. Moreover by choosing 3 FSE this aligns better with standard pallet sizes. This suggests that the ULD size should roughly encompass (1080mm X 876mm). Prioritizing efficient space utilization, strength, maneuverability and compatibility to existing pallet handling systems.

Table 3.1: The different trolley sizes. In bolt are the largest and smallest size.

| Trolley types and if open/closed doors | Length [mm] | Width [mm] | Height [mm] | No swivel wheels [#] |
|---|---|---|---|---|
| KSSU T11 C | 843 +-1 | **300** | **1036.8 +- 1.7** | 4 |
| KSSU T11 O | 800 +-1 | **335.4** | **1036.8 +- 1.7** | 4 |
| KSSU T12 C | 424.5 +-1 | 300 | **1036.8 +- 1.7** | **2** |
| KSSU T12 O | 400 +-1 | 317.7 | **1036.8 +- 1.7** | **2** |
| ATLAS T11 C | 810 +-1 | 302 | 1030 +-2 | 4 |
| ATLAS T11 O | 768 +-1 | 337 | 1030 +-2 | 4 |
| ATLAS T12 C | 404 +-1 | 302 | 1030+-2 | **2 or 4** |
| ATLAS T12 O | **362 +-1** | 329.4 | 1030+-2 | **2 or 4** |
| CTR | **875 +-1** | 330 | **1026.1** | 4 |

### FOR ALL TROLLEYS

Each trolley used at KCS, including KSSU, ATLAS and internal trolleys, must be supported by the ULD design. Notably, a single T12 trolley should be capable of occupying the same position as a CTR, suggesting the potential need for additional support or a divider within the ULD to prevent any unintended movement. Figure 3.1 provides a visual representation of the different possible wheel positions off each trolley type both with open as well as closed configurations. The red bar indicates a potential T12 divider that will be discussed later. This figure is made assuming that trolleys remain within there trolley position. This figure underscores the importance of designing a ULD that is versatile enough to accommodate the diverse trolley types used in the airline catering process.

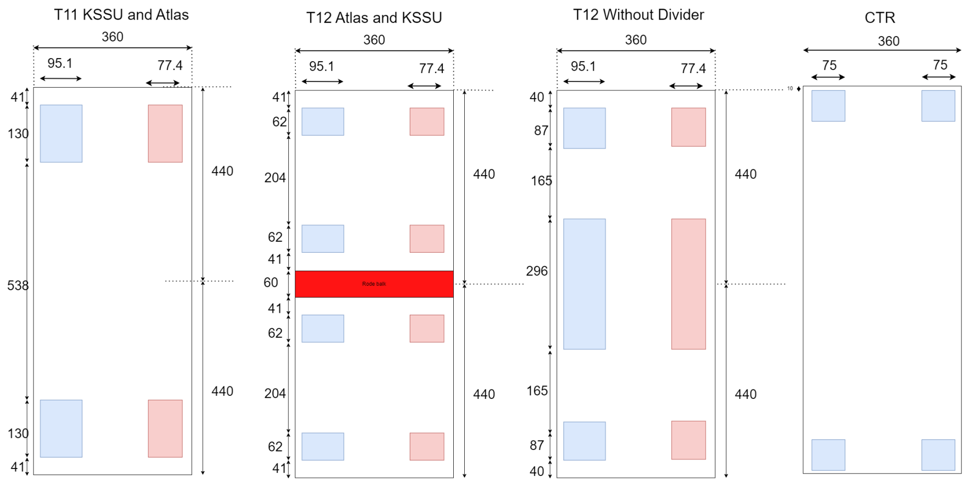



Figure 3.1: All different trolley-wheel positions projected on a trolley position.

### COMPATIBILITY TO MHE

The ULD should be designed that conveyors and AGVs can transport them. This has influence on the required maximum deflection. Since AGVs and conveyors require a mostly flat surface. The maximum load bearing capacity of the ULD is achieved when 3 fully loaded CTRs of 120kg each are placed on the ULD, or when 6 T12 trolleys of 60kg each are placed. The maximum deflection should be kept below 10mm when supported on the sides. This is since the AGV and conveyor require minimal deflection when initially lifting and dropping of the ULD. Additional testing will be preformed on AGVs to make sure the trolleys are secured for the high emergency breaking accelerations.

## 3.1.2. SPECIFIC REQUIREMENTS

As outlined in the introduction, each distinct process within the future facility introduces specific requirements for ULDs used in trolley transport. To provide a comprehensive understanding of these requirements, it is essential to first establish where and how the ULDs are utilized in the facility. A flowchart identifying where ULDs could potentially be used at a future facility of KCS is given in 3.2. Each enclosed box represents where trolleys are transported on a ULD. The important areas are: highloader transport, trolley washing, and internal transport.

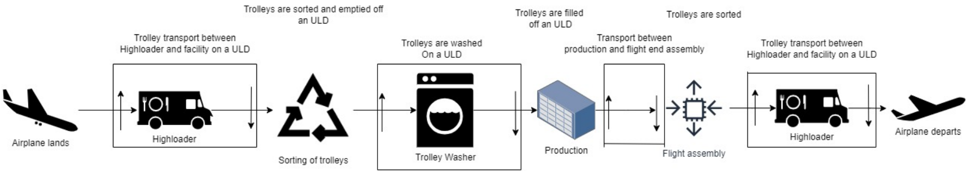



Figure 3.2: Schematic of where an ULD should be loaded and unloaded at KCS. Each box represents where a ULD is used.



### REQUIREMENTS OFF THE ULD BASED ON THE HIGHLOADER

One economical improvements posed by using an ULD at the new facility off KCS would be if the ULD has the capacity to autonomously roll into position and secured while being loaded with trolleys. This feature is shown in Figure 3.3 and promises significant time savings during docking maneuvers, reducing the number of required docks, and eliminating the manual removal, insertion, and securing of trolleys via the elastic ropes by the driver. The new load securing method is compared to the old load securing method in Figure 3.4. The potential ULD required is represented in Figure 3.5

Figure 3.3: A schematic representation how multiple ULDs could be loaded in an highloader.

The expected accelerations are assumed to be the same as a road truck. The European Commission [22] has determined the minimal containment force for road trucks that go on the highway. Their conclusion was that loads should be secured in longitudinal direction for 80 percent of the load, and in lateral direction for 50 percent of the weight of the load. The forces in lateral directions are dealt with via the draw cage. The forces in longitudinal directions should be counteracted by the ULD frame and potentially by FSE dividers.

The draw-cage is able to secure all trolleys at full size trolley length. While the back of the trolley rests against the highloader wall. The metal cage is visible in Figures 3.3 and 3.6. Implementing the metal draw-cage solution necessitates the presence of the T12 divider. This is due to the fact that a single half-size trolley in a FSE is half the length of a CTR, equating to 0.4 meter where the trolley could collide with the cage. To address this gap, a T12 divider would secure the trolley between itself and the wall or between

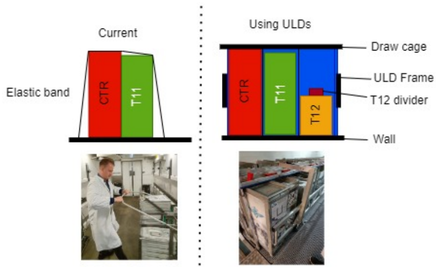



Figure 3.4: Current trolley securing vs trolley securing using ULDs.

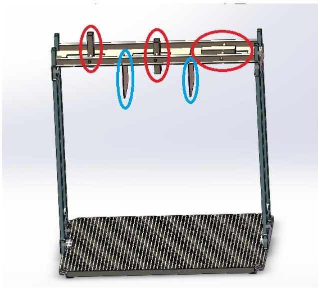


Figure 3.5: A ULD capable to transport trolleys in a highloader. Red T12 divider. Blue Trolley position divider.



itself and the draw cage. The T12 divider is seen in Figures 3.5 and 3.6. This divider is unobstructed and rest atop of the ULD when not in use. However after a half size trolley is loaded one simply turns the T12 divider downwards. The trolley position divider is added and required since only a single trolley on the ULD would leave 0.7m of room for that trolley to accelerate.

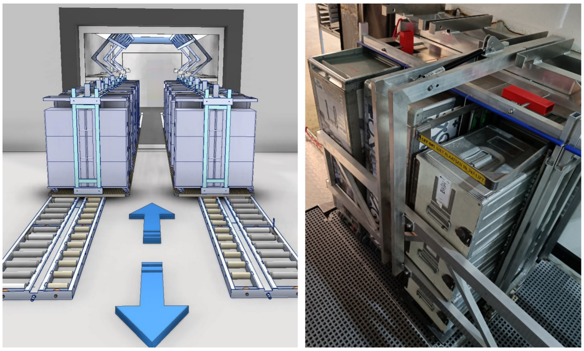


Figure 3.6: A potential containment method as envisioned by KCS. With the draw fence on the left and right side.

Since a highloader has a maximum lifting capacity, and since every ULD adds more weight compared to the current operations, it is important that the ULD is lightweight. In current practices it would mean that the weight off each ULD should not exceed 20kg.

### Requirements for the ULD based on the washing process

The washing ULD section starts with empty, used trolleys with open doors sorted onto the ULD according to their respective trolley types. The section concludes when sorted, empty and clean trolleys are removed from the ULD to be filled during the production process.

Given that the ULD secures the trolleys during trolley washing, it is important that the ULD is chemically resistant, capable of withstanding hot water, capable of withstanding detergents while ensuring efficient drying for the ULD and the trolleys. Since

UV cleaning is a future possibility the ULD should also withstand UV radiation. The maximum water temperature during this process reaches 70 degrees Celsius. For all cleaning processes it is important that the trolleys remain flush in the ULD.

During the washing phase, neither the trolleys nor the ULD are exposed to high accelerations. Subsequently, the ULD must be transported to another section, which will be executed via AGV or conveyor systems. Automated Guided Vehicles (AGVs) are equipped with heavy braking systems that exert braking accelerations of over $1\frac{m}{s^2}$ [35–37]. Moreover, it is worth noting that, since the trolleys remain empty throughout the washing process, the maximum required load on top of the ULD in the washing area is reduced from 420 kg to 80 kg.

#### BETWEEN PRODUCTION AND FLIGHT END ASSEMBLY

Trolleys are removed from the washing ULD in a production cell. Here they are labeled, filled with flight-specific items and their doors are securely closed before they are placed on a new ULD. This ULD is responsible for transporting the trolleys to the Flight End Assembly area.

As the ULD is transported through this phase via AGV or conveyor systems, it must have the capability to secure loads effectively under different acceleration and deceleration conditions, with a maximum deceleration reaching $1\frac{m}{s^2}$. This specification aligns with the deceleration capabilities of AGV manufacturer Lowpad [37].

Considering that this ULD is tasked with transporting fully loaded trolleys, the maximum load capacity in this section is kept at 420 kg.

## 3.2. BRAINSTORM AND MORPHOLOGICAL CHART LOAD SECURING METHODS

In designing an efficient ULD capable of securing airline catering trolleys effectively, a pivotal step is the exploration of innovative and practical load securing methods. This section serves as a brainstorm where different strategies to safely secure trolleys on the ULD are explored. These methods are based on the viable methods identified in section 2.3.2: locking, increasing friction and formfitting.

### 3.2.1. METHODS FOR LOAD SECURING

Different methods of load securing are discussed in section 2.3.2. From this, three practical ways to secure the trolleys on ULDs remained: locking, increasing of friction and formfitting. From section 3.1.2 it became apparent that transport specific solutions in for example the highloader are also possible. Next to these requirements it was required to be able to separate the 3 trolley positions via trolley dividers and a T12 divider was required for highloader applications. Figure 3.7 shows all different methods that came up during the brainstorm.

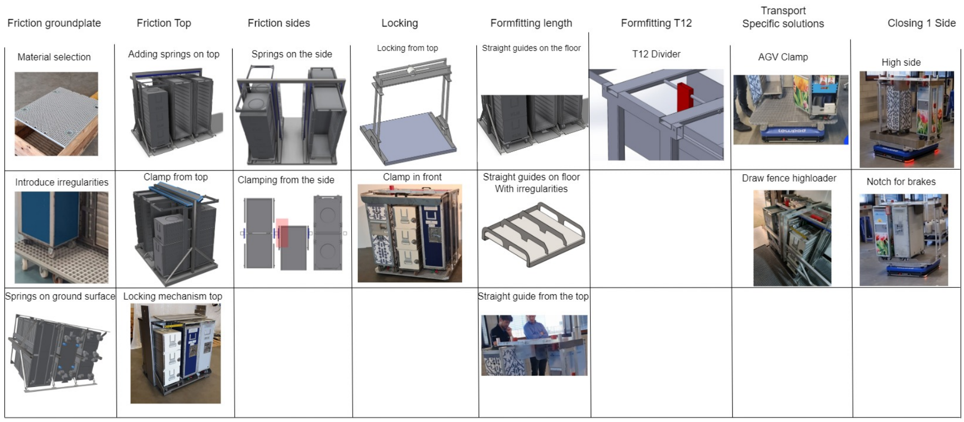



Figure 3.7: The result of a brainstorm session based on the different identified securing methods.

### 3.2.2. AGV CLAMP

The AGV clamp was designed and lowpad build retrofitted the design on a AGV. When a ULD is loaded on the AGV the end of the clamp is pushed down. This ensures that when the ULD is loaded the trolley inlet and outlet is blocked. This is shown in Figure 3.8 and during all AGV tests.

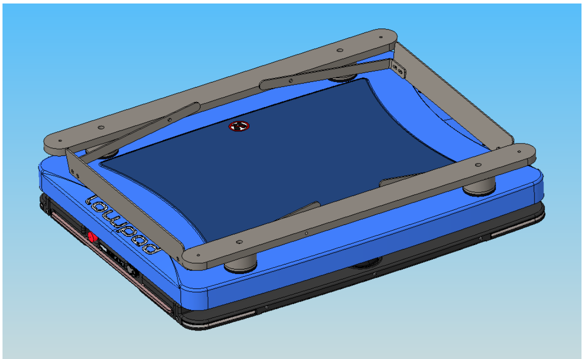


Figure 3.8: The designed AGV clamp. when the ULD is loaded the clamp goes up securing the trolleys.

### 3.2.3. INCLINATION

A last method has been included due to the work of [38]. This study researched the required pushing and pulling forces required to move an airline catering trolley during take of and landing. The study observed that the force required for pushing and pulling the trolley significantly increases when pushing a trolley at an inclination. In some instances, it was registered that the required force almost doubled if the airplane is under an angle of just 8 °. Therefore a slight inclination is also considered viable for this study, however this is only viable if one of the sides is closed off.

There are three reasons identified why the inclination increases the security of the trolleys.

- A normal force along the x component
- Only one position on the ULD with the lowest potential energy
- The energy required to turn the swivel wheels of the trolley



**Normal force X-direction** As can be indicated from the free body diagram of Figure 3.9 there is a normal force in the x-direction pointing towards the closed side. Equation 3.5 shows that the size of this normal force in x-direction scales with weight, the gravitational constant and $tan(\theta)$. The maximum acceleration compensated by an inclination is derived in Formula 3.7. It is of special importance that this variable is not includes mass. Since both filled and empty trolleys are placed on the ULD.

Assuming the gravitational constant is 9.81 $\frac{m}{s^2}$ and the max deceleration of the AGV is 1 $\frac{m}{s^2}$, it follows that an inclination of 5.8 °is enough regardless the initial friction or the swivel wheels turning. These two influences are yet to be determined via ground testing.

$$F_z = m \cdot g \tag{3.1}$$
$$F_{Ny} = F_z \tag{3.2}$$
$$F_N = \frac{F_z}{\cos(\theta)} \tag{3.3}$$
$$F_{Nx} = F_N \cdot \sin(\theta) \tag{3.4}$$
$$F_{Nx} = \frac{F_z}{\cos(\theta)} \cdot \sin(\theta) = F_z \cdot \tan(\theta) \tag{3.5}$$
$$a_x \cdot m = g \cdot m \cdot tan(\theta) \tag{3.6}$$
$$a_x = g * tan(\theta) \tag{3.7}$$

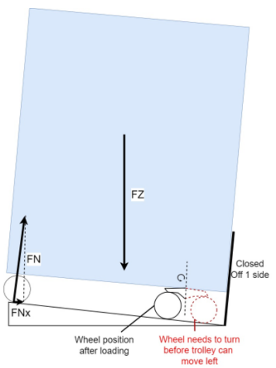



Figure 3.9: A visualisation of the normal force and the turning of wheels.

## 3.3. TESTING AND EVALUATION OF LOAD SECURING METHODS

In this section, the various load securing methods will be examined. By implementing structured testing methodologies and comprehensive evaluation criteria. The aim is to measure the practicality and effectiveness of each method.

### 3.3.1. INITIAL SELECTION

After building several prototypes and testing them, a lot of the proposed solutions of Figure 3.7 were proven inadequate. Primary reasons for this are:

- Varying trolley height rendering all mechanisms that use the top friction or top locking inconsistent.
- Ergonomically unsatisfactory results when increasing the hole size in the ground plate.
- The swivel wheels being able to get stuck if they both turn outwards.
- The fact that a locking mechanism that could be forgotten therefore not being fail safe
- The locking of the clamp atop of the trolleys was unsafe for employees.

After this initial selection the remaining options are visualised in Figure: 3.10

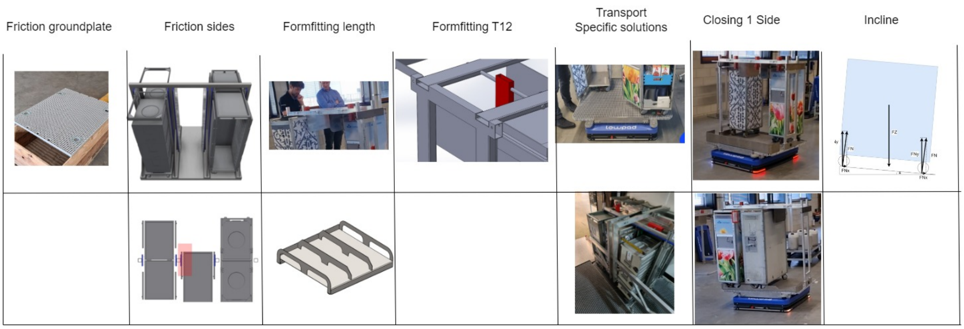



Figure 3.10: The viable ideas after initial selection.

### 3.3.2. GROUND TESTING, FRICTION AND INCLINATION

A final solution will either be based on friction of the ground plate with the possible addition of inclining the ULD, or the solution will be formfitting the trolleys aided by an AGV clamp to secure trolleys on an AGV. It is important to accurately determine the friction factor of a flat surface as well as under varying angles. There are several important hypothesis to test.

- What force is added by swivel wheels turning.

- A trolley under an angle will require significant more force to move the other direction compared to a trolley on a flat surface.
- As the weight of the trolley increases, the friction scales linearly.

In order to measure the required force to get a trolley into motion for different scenarios the following setup was used: 2 trolleys for horizontal pulling, 1 KERN scale with an inaccuracy 50 grams [39], and a way to connect the scale between the two trolleys. An example of the setup is shown in Figure 3.11 and 3.12. The lead trolley is pushed until the following trolley starts to move. the amount of required force is written down after which the test is repeated.

Figure 3.11: Test setup of testing the different levels of inclination

Figure 3.12: Using a second trolley to pull at constant angle.

The turning force of the wheels is expected to add a considerable amount of force to the required pulling force. Therefore each trolley type with each floor type are tested both with the swivel wheels forwards as well as with the wheels turned backwards. The turning of the wheels is registered as locked. The tests on flat surfaces were performed on three different floor types shown in Figure 3.13.

- Bolidt floor: This is a cast floor of epoxy with little to none inconsistencies. Since it has almost no inconsistencies it is expected to have the lowest friction factor of the three floor types.
- Glass Fibre Reinforced Polymer (GFRP) floor: that is perforated with a 19mm grid. It is a rough material and in combination with the perforated grid it is expected to have the highest friction.
- Workplace floor: the most inconsistent floor type with grout and small dents. Expected to have a medium high inconsistent friction.

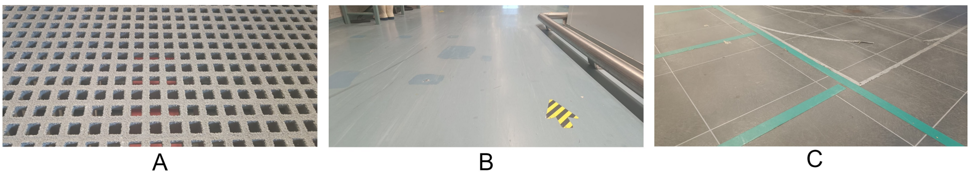



Figure 3.13: The 3 different floortypes A) GFRP with 19mm grid B) Bolidt floor C) Workfloor.

Each test is conducted with 3 different types of trolleys namely: a T11 trolley, a T12 Atlas trolley and a T12 KLC trolley. Each of these trolley types are varied between 13 kg, 26 kg and 39 kg for each floor type. Each test was conducted 20 times. The reason two types of T12 are used is since these trolleys differ in number of swivel wheels. The ATLAS trolley has 2 swivel wheels where a KLC trolley has 4.

After the trolleys have all been tested on flat surfaces it is important to test what inclination is required to account for the acceleration experienced by the AGV. The only floor type that is put under an inclination was the perforated GFRP for this was the only material available to incline. The angle is varried between 0°and 3°with 0.5°increments. Since the test is inaccurate each test is repeated 20 times. This leads to a total of 1440 tests. All results are presented in the next sections and Appendix B.



### 3.3.3. RESULTS TESTING FRICTION AND INCLINATION

In this section all different tests and results will be discussed.

#### WEIGHT

Since the friction force scales with the normal force and the friction coefficient, it is to be expected that by increasing the weight linearly the amount of required force scales linearly. This is also observed in the results shown in appendix B.

#### SWIVEL WHEELS

In order to measure the added force by the turning of the swivel wheels, it is important to look at the test of locked vs non locked wheels. Locked wheels in this study means that the wheels are turned in the opposite direction. Therefore in the locked situation the wheels always have to turn and in the standard situation, the wheels never have to turn.

It is hypothesised that with more swivel wheels, the weight on the swivel wheels will increase. Therefore the amount of force required to turn the swivel wheels will increase. It is therefore expected that the KLC T12 (4 swivel wheels) has a larger difference between locked and normal compared to the ATLAS T12 (2 swivel wheels).

Figure 3.14 shows the box and whisker charts for both the ATLAS T12 trolley as well as the KLC T12 trolley on the different floor types. Table 3.2 shows the average values for both the locked and non locked configurations on all floor types for all trolley types. And shows that the turning of the wheels sometimes doubles the required force. Table 3.3 shows that absolute difference in required force (N) between the wheels turning and not.

Table 3.2: The required average pulling force (N) to get all trolley types of 26kg to move on all different floor types with turned wheels (L) or standard.

| Floor type<br>Locked (L) or normal | WF | WF(L) | Bolidt | Bolidt(L) | GFRP | GFRP(L) |
|---|---|---|---|---|---|---|
| KLC T12 (4) | 9,0 | 16,1 | 4,9 | 12,8 | 13,5 | 24,1 |
| ATLAS T12 (2) | 7,4 | 12,2 | 6,8 | 11,2 | 12,9 | 19,9 |
| T11 | 6,9 | 12,9 | 5,7 | 9,6 | 11,8 | 22,9 |

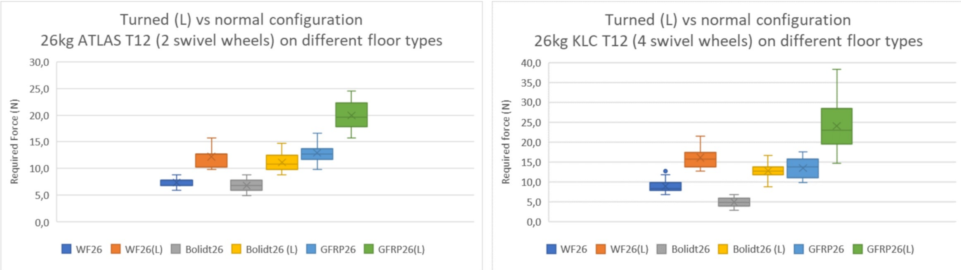





Figure 3.14: The difference between the locked configuration and the standard configuration is significantly higher with more swivel wheels.

Table 3.3: Average added force (N) by requiring the wheels to turn for the different trolleys and the different ground surfaces.

| Ground type and trolley type | WF | Bolidt | GFRP |
|---|---|---|---|
| KLC T12 (4) | 7.1 | 7.9 | 10.6 |
| Atlas T12(2) | 4.8 | 4.4 | 7.0 |
| T11 | 6.0 | 3.9 | 11.1 |

## INCLINATION

The results of inclining of an ATLAS T12 trolley on GFRP for different angles is shown in Figure 3.15. Table 3.4 shows the minimal measured value to move a trolley for each trolley type under varying angles. The required force increases with $tan(\theta)$

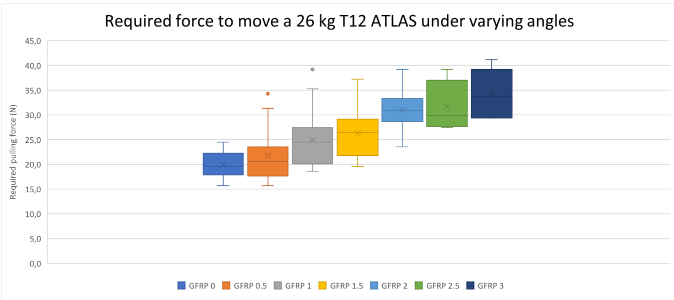



Figure 3.15: by varying the angle a considerable amount of force is added.

Table 3.4: Minimum measured force (N) expressed in acceleration ($\frac{m}{s^2}$) to initiate trolley movement for different angles

| Angle | 0° | 0.5° | 1° | 1.5° | 2° | 2.5° | 3° |
|---|---|---|---|---|---|---|---|
| ATLAS T12 (2) | 0.60 | 0.60 | 0.72 | 0.75 | 0.90 | 1.06 | 1.13 |
| KLC T12 (4) | 0.57 | 0.64 | 0.64 | 0.79 | 0.94 | 1.06 | 1.28 |
| T11 | 0.57 | 0.64 | 0.64 | 0.75 | 0.90 | 1.13 | 1.13 |

As the maximum brake acceleration of an AGV can reach $1\frac{m}{s^2}$ the minimum required inclination to contain a trolley would be 2.5°. The testing has furthermore shown that inclination is the only way to design a friction based design capable of counteracting this braking acceleration.

### 3.3.4. Highloader testing

The prototype highloader, featuring multiple fixed ULDs and a manually actuated draw cage was designed and build for highloader. The only ULD used in the highloader is depicted in Figure 3.5, was successfully constructed and assembled. As is shown in Figure 3.6. During operational tests with the highloader, the effectiveness of trolley securing was observed to be satisfactory if and only if the T12 dividers where applied properly. It was observed that the force exerted by the draw cage should be increased which was accomplished by adding an additional spring to the design.

### 3.3.5. Testing on AGVs

Based on the highloaders requirement to have a T12 divider, and the AGV requirement to either be inclined or have an AGV clamp, three different ULD designs have been selected and prototypes were constructed. The designs are shown in Figure 3.16 and Figure 3.17

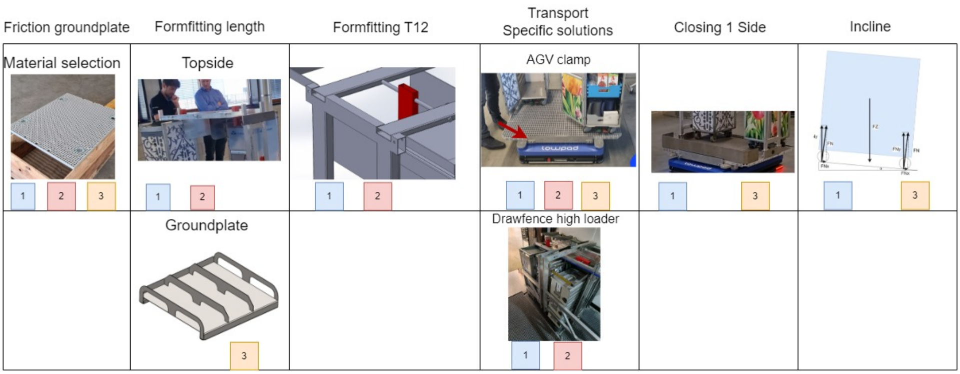



Figure 3.16: The 3 different ULD designs tested at lowpad. 1 T12 divider and inclination, 2 T12 divider no inclination, 3 inclination no T12 divider.

The testing at Lowpad was designed to see if the ULDs could secure the trolleys during multiple emergency brakes and sharp turns. Also maneuvering was tested at Lowpad were the AGV was tasked to make a fast turn on the spot. For this Lowpad had developed a track that would push the trolley securing to the limit. The used track is visualized in Figure 3.18.


Figure 3.17: The 3 different ULD designs tested at Lowpad. 1 and 3 are inclined, 1 and 2 are usable in a highloader.

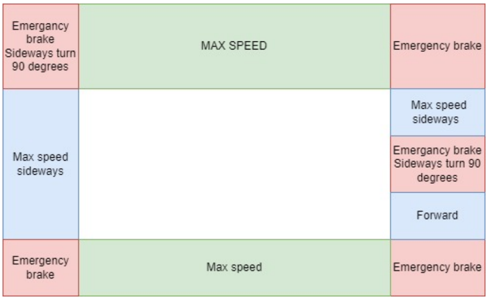



Figure 3.18: The path designed by Lowpad for testing the ULD.

### 3.3.6. TESTING THE NON INCLINED ULD

During testing of the non inclined ULD in combination with the AGV clamp the trolley fell of the ULD almost immediately as visualized in Figure 3.19a. After that test the length of the trolley dividers was increased. Another problem arose, the trolley wheel drove of the ULD as shown in Figure 3.19 b. The wheel hanging over the edge is unacceptable as it will interfere with docking manoeuvres.

After the two failed test the AGV clamp was elongated as indicated by the arrow in Figure 3.20. During this test no trolley fell over, also no trolley wheel escaped the ULD. It was however observed that the trolleys were not able to remain flush with respect to the ULD. This will be troublesome for washing on a ULD and potentially automatic filling applications.

(a) Trolley falling off the ULD with a short divider

(b) Elongating the divider lead to the wheel maneuvering over te edge

Figure 3.19: 1 trolley falling of the ULD. Another trolleys wheel is over the edge.

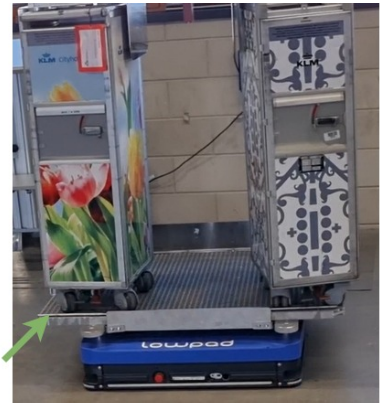


Figure 3.20: The arrow points towards the metal rod used to simulate an elongated AGV clamp. It can be seen that the trolleys do not remain flush to the ULD.

### 3.3.7. TESTING INCLINED ULD WITH T12 DIVIDER.

The cad model of the inclined ULD with top part is represented in Figure 3.21. During testing of the inclined ULD with top part no trolleys fell off the ULD and the trolleys remained flush to the ULD as can be seen in Figure 3.22. The angle was 3°

3

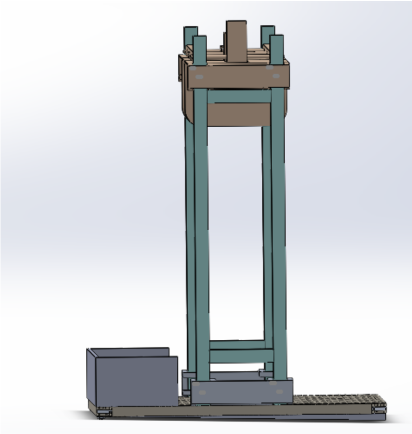


Figure 3.21: The cad model of the tested ULD.


Figure 3.22: During testing no trolleys fell off and the trolleys remained flush to the ULD.

### 3.3.8. TESTING INCLINED ULD WITHOUT T12 DIVIDER

During testing of the inclined ULDs with an angle of 3°, no trolleys fell of the ULD. Furthermore the viability of the trolley dividers on the ULD floor was proven by the metal rods on the ULD. The frame however was required to prevent trolleys from tipping over the side. Both are visualised in Figures 3.23 and 3.24. This test indicated that with a simple added side support, the AGVs could carry trolleys on a ULD that is lower and significantly cheaper compared to the highloader ULD.


Figure 3.23: During testing without the frame, the trolleys tipped over the sides.

Figure 3.24: With the frame, no trolleys fell of the ULD during testing.

## 3.4. CONCLUSION AND RECOMMENDATIONS

This section has demonstrated the successful design of two ULD types. One ULD that is capable of transporting trolleys via AGV and highloader, the other was viable only for internal transport this ULD is however significantly cheaper. Since the securing off trolleys via an inclination is integrated into the ULD and does not rely on the AGV, there is no need for additional solutions when transporting trolleys and ULDs on other material handling system with slower accelerations, such as conveyor systems. Another crucial benefit of the slight inclination is that the trolley remains flush with the ULD and its sides, keeping the option of production on the ULD open as well as enabling washing on the ULD.

For the highloader the T12 divider was an essential solution to secure the single T12 trolley. Ensuring that when not used it does not obstruct trolleys entering and leaving the ULD while when engaged it is able to secure a single T12 between the T12 divider and either the highloader wall or the draw fence.

# 4
# Impact of ULD Design on Future Facility

The previous section left two viable ULD designs. The first ULD was capable of transporting trolleys in a highloader and on an AGV the second ULD was able to transport and secure trolleys only during AGV transport. This section will focus on the economic implication that implementation of the ULD designs would have on the future facility.

In this chapter, the use of no ULD will be compared to the use of 1 universal ULD and a multi ULD facility. While the shift towards multiple ULDs will introduce increased transportation requirements of ULDs and will introduce additional complexities, it holds the promise of designing more cost effective ULDs for the specific sections of the facility. Thereby having the potential to be more cost effective or equipped.

A series of flowcharts and potential layouts will be used to describe the different ULD movements and the overview of the facilities. This is coupled with the simulated data of the transport requirements of the facility. These flowcharts illustrate the differences between the potential facilities, allowing the evaluation of real-world implications of no, single and multiple ULD integration.

This chapters goal is to provide KCS and other airline catering facilities with a comprehensive road map that will enable them to make informed decisions regarding the implementation of ULDs to transport trolleys within their facility. By comparing the different scenarios, the aim is to optimize operational efficiency and reduce costs.

## 4.1. ULD usage future facility

To retrofit the current facility to a ULD it is important to summarize how the trolleys move through a facility with the help of ULDs. Figure 4.1 shows a potential process using ULDs and also indicates where trolleys are added to the ULD and removed from the ULD. Figure 4.1 also explains what happens to the trolleys at each stage of the process.

Each moment that the trolley is added to a ULD is a possibility to switch to a different ULD. This might be interesting as we have seen that an internal ULD is significantly

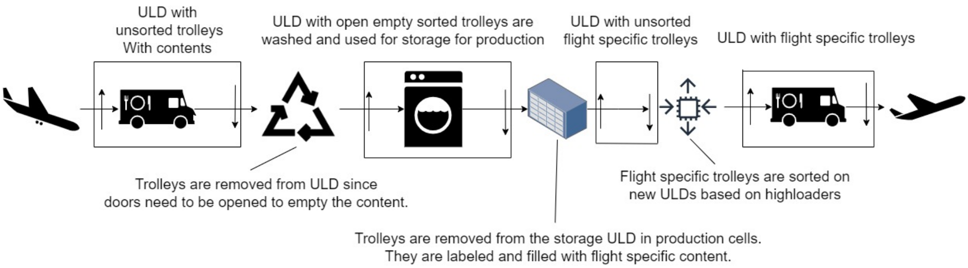



Figure 4.1: Summary of how the ULDs could be used to transport trolleys in the new factory of KCS.



more cost effective compared to the universal ULD. Each of the possible configurations is illustrated in Figure 4.2 namely: 1 universal ULD, 1 highloader ULD combined with a washing and storage ULD and an internal ULD combined with an highloader ULD.

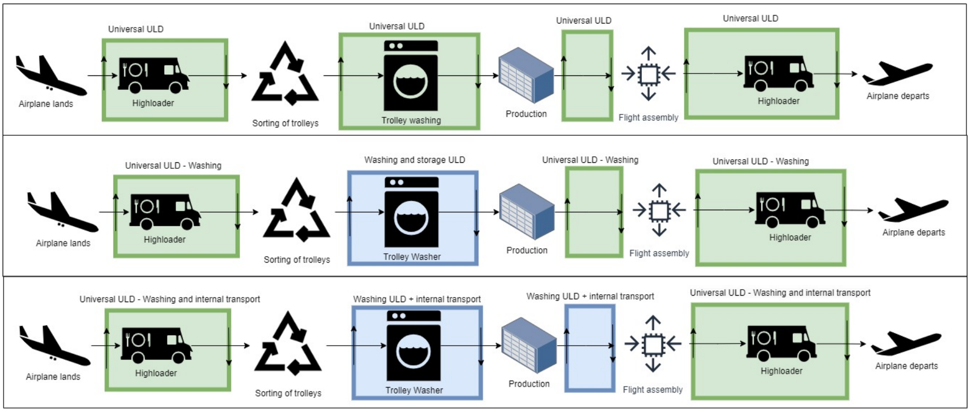



Figure 4.2: The three possible ULD configurations. 1 Universal ULD, 1 washing ULD in combination with an external ULD, 1 Internal ULD in combination with an External ULD.

### 4.1.1. THE FLOW OF ULDS

Since the addition of multiple ULDs will influence the way ULDs move through the facility it is important to have a clear idea on the different flows of ULDs that are expected in the facility of KCS. Therefore both the flowchart of the universal ULD shall be given as well as a possible flowchart for adding an additional ULD.

#### UNIVERSAL ULD

A flowchart depicting the movement of a universal ULD within KCS's facility is presented in Figure 4.3. Since highloaders are used for both loading and unloading trolleys and boxes to the airplane and since the emptying could require 12 entire ULDs it is important to always fill the highloader to maximum capacity before leaving the facility. This will result in empty ULDs being loaded in the highloader. Since always the same amount of

ULDs is used inside a highloader, an additional locking mechanism can be devised to secure the ULDs in the lateral direction.

The arrow connecting ’highloader out distribution’ to ’highloader in’ represents a scenario in which a highloader, after filling an airplane, uses the empty highloader to unload another plane before returning to the facility. Additionally, due to the possibility of ULDs being only partially filled, an extra arrow is included to illustrate the return of these ULDs to the storage after sorting.

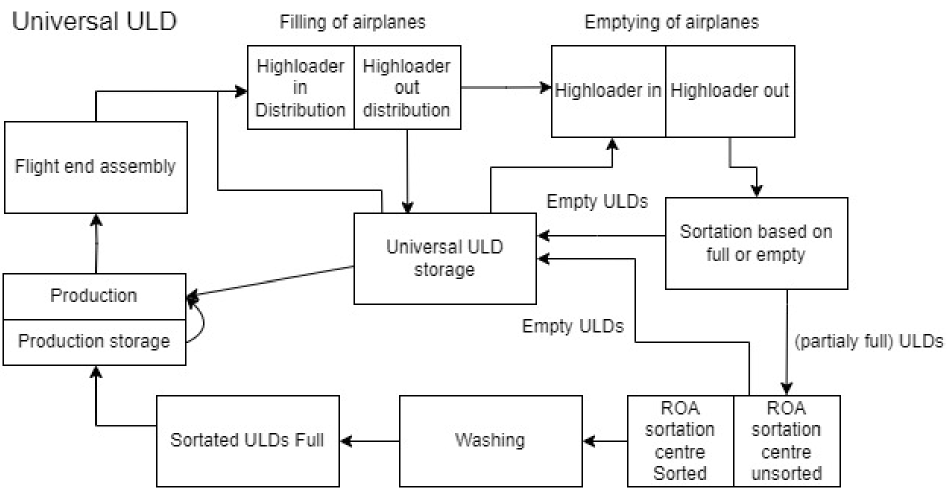



Figure 4.3: The flowchart of how ULDs move through the facility in the case of 1 universal ULD.

This flowchart is also made into a potential facility design envisioned in Appendix C1 and C2.

### Multiple ULD facilities

The washing ULD is the second configuration of Figure 4.2. The flowchart for this configuration is given in 4.4, where the blue dashed line indicates where the washing ULD is used. The red arrows indicate where there will be an increased transport requirement compared to using only 1 ULD.

As is indicated by Figure 4.4, the transportation requirement will increase due to multiple flows increasing in volume and no flows decreasing in volume. Additionally, the figure illustrates the need for an extra storage unit to accommodate the newly added ULD. To ensure that both storage ULDs never run out of ULDs, an additional amount of ULDs must be acquired. This amount is dependant on the variation in demand of ULD types at different time intervals. Consequently, the introduction of a new ULD at KCS will lead to higher transportation requirements and an overall increase in the absolute quantity of ULDs. The potential facility layout is given in Appendix C3.

## 4.1.2. Requirements of the different ULDs

In chapter 3 the different requirements of the different ULDs have been discussed. Since, the adding of an additional ULD type will both increase the transportation requirement

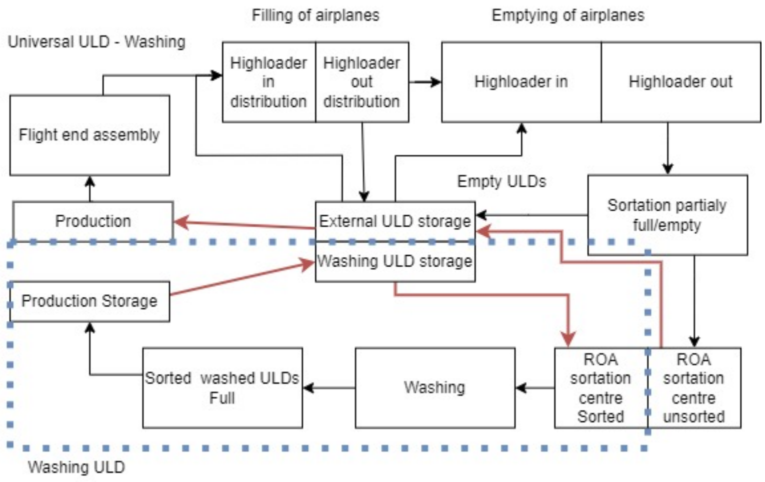



Figure 4.4: The flowchart of how ULDs move through the facility in the case of a washing ULD.

as well as increase the storage requirements, it will only prove viable if there are vast differences between the different requirements making 1 or both ULD designs significantly more cost effective.

### DIFFERENCES IN PROGRAM OF REQUIREMENTS

There are significant differences between the specific requirements of each section in the airline catering facility. The highloader required the ULD to have a T12 divider, to have a strong frame, and to be lightweight. While the washing process primarily requires a ULD that is resistant to the washing process. The requirements apart from the standard program of requirements are given in Table 4.1. An internal ULD is considered to be considerably worse compared to a washing and storage ULD. Since this internal ULD would require the transport off loaded trolleys instead of empty trolleys. Making this internal ULD considerably more expensive compared to a washing ULD. Next to the increased expenses there are at no time many ULDs between production and flight end assembly at the same time therefore the amount of added cost effective ULDs would not be impacted much. Lastly, the inclusion of the automated transport of produced trolley will hamper further optimisation. When at some point the process will improve to not produce flight specific trolleys but flight specific ULDs these ULDs need to be highloader ULDs.

Since a plastic ULD could be considerable amounts cheaper, more lightweight and better equipped to handle the washing process compared to the universal GFRP/ aluminium ULD. It will be interesting to see the economic viability. An example of a plastic ULD that might suffice is given in Figure 4.5.

Table 4.1: A comparison between the program of requirements of 1 ULD compared to multiple ULDs.

| Component | Universal ULD | Washing ULD |
|---|---|---|
| Max load | 420kg | 100kg |
| Washable | Resistant to chemicals, water UV radiation and nonporous | Resistant to chemicals, water, UV radiation and nonporous |
| Operating temp | -5 to 70 degrees Celsius | 15 to 70 degrees Celsius |
| T12 divider | Required | Not required |
| Overhanging | Required | Not required |
| Does not break At max accelerations | Lateral accelerations of 5 $\frac{m}{s^2}$ | Latteral acceleration = 1 $\frac{m}{s^2}$ |
| Max weight | Max 20kg. | Not required |



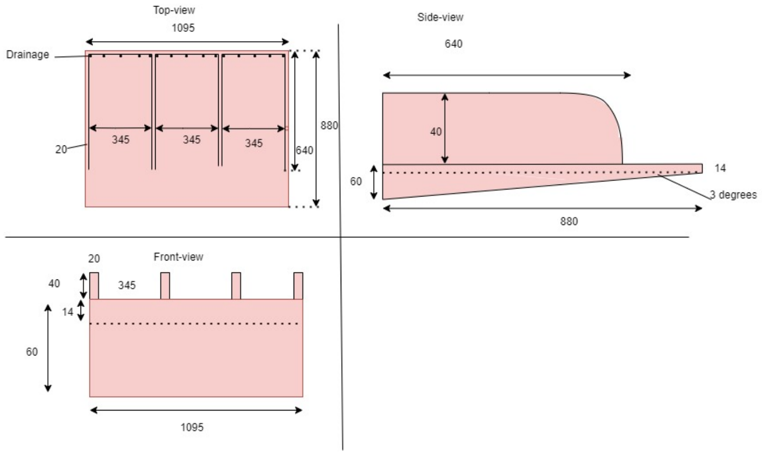



Figure 4.5: The different views of a potential washing and storage ULD.

### 4.1.3. AMOUNT OF ULDS

KCS conducted an extensive simulation based on actual flight data, spanning a week using information from 2019. This year is chosen since this was the last year before corona. The outcome of this simulation is illustrated in the dashboard shown in Figure 4.6.

After conducting basic calculations within Excel, it was possible to estimate the number of ULDs at various stages in the process, including the highloader, flight end assembly, washer, production, trolley storage, and the emptying stage. These calculations provided valuable insights into the ULD requirements at each point in time. The results are presented in Table 4.2.

The analysis reveals that the maximum demand for Universal ULDs at any given time is 3413. When comparing this to the maximum requirements off washing and distribution ULDs, the total required ULDs would amount to 3524. This allocation includes 1038 ULDs for washing and storage and 2486 for distribution ULDs. This means that in absolute terms 111 extra ULDs are required when opting for the dual ULD facility.


Figure 4.6: The dashboard provided by KCS.



Table 4.2: Amount of ULDs required at different hours in the facility.

| Time | Required # Washing ULDs | Required # distibution ULD | Required # Universal ULDs |
|---|---:|---:|---:|
| 1-7-2019 10:00 | 673 | 2459 | 3098 |
| 1-7-2019 12:00 | 796 | 2304 | 3066 |
| 2-7-2019 00:00 | 1028 | 1418 | 2412 |
| 2-7-2019 07:00 | 709 | 2305 | 2980 |
| 2-7-2019 09:00 | 549 | 2468 | 2983 |
| 2-7-2019 12:00 | 978 | 2469 | 3413 |
| 3-7-2019 00:00 | 1038 | 1414 | 2418 |
| 3-7-2019 07:00 | 716 | 2382 | 3064 |
| 3-7-2019 10:00 | 789 | 2289 | 3044 |
| 3-7-2019 12:00 | 869 | 2175 | 3010 |
| 4-7-2019 07:00 | 676 | 2459 | 3101 |
| 4-7-2019 09:00 | 565 | 2486 | 3017 |
| 5-7-2019 09:00 | 670 | 2390 | 3026 |
| 5-7-2019 12:00 | 946 | 2404 | 3316 |
| 6-7-2019 12:00 | 902 | 2239 | 3107 |
| 7-7-2019 07:00 | 655 | 2463 | 3084 |
| 7-7-2019 09:09 | 672 | 1636 | 2274 |
| **Maximum** | **1038** | **2486** | **3413** |

## 4.2. COST COMPARISON

To indicate the impact of using ULDs and manual transportation of airline catering trolleys, an evaluation of financial implications is made.

### 4.2.1. MANUFACTURING COSTS AND UPKEEP

Manufacturing costs and upkeep are critical considerations in the cost function. Discussions with two companies, BFF Trading and Rota Moulding, provided estimates for manufacturing costs of the ULDs. The washing and storage ULD is priced at €175 each with a setup cost of €15.000. The universal ULD has a piece price of €650 per unit and a setup cost of €45.000. This cost disparity sets the stage for our analysis, with the 2-ULD system offering initial savings of over €400.000.

Upkeep is challenging to quantify. It is estimated that the washing ULD is expected to have a life expectancy of 5 years, while a frequently washed universal ULD has a life expectancy of 5 years, and a ULD less frequently washed has a wear time of 7 years. Figure 4.7 visually represents the initial investment and wear and tear costs of only the ULDs.

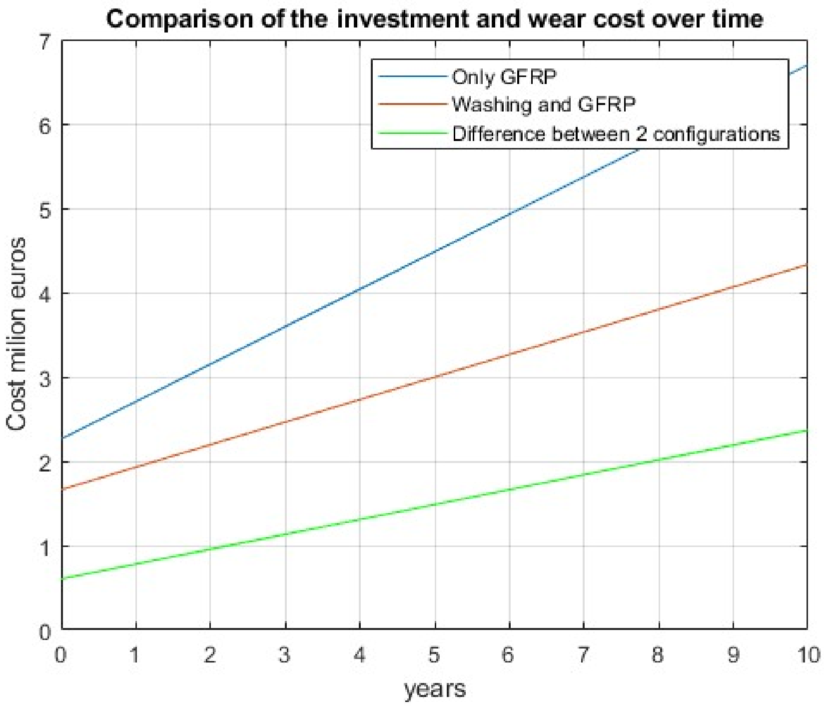



Figure 4.7: Visualisation of the initial investment and wear costs of the different ULDs.

### 4.2.2. Transport cost implications

The introduction of multiple ULDs increases empty ULD movements impacting cost. Analyzing the extra 60,000 ULD movements per week, the simulation suggests the need for 12 additional Automated Guided Vehicles (AGVs). For the price Lowpad was contacted. An estimated cost of €50,000 per AGV. With a wear time of 10 years.

Comparison to Manual Labor: Currently requiring 122 Full-Time Equivalents (FTEs), manual transportation may be reduced to 42 with automation, saving 80 FTEs. An FTE is expected to cost €62.400 at KCS

### 4.2.3. COST COMPARISON 3 CONFIGURATIONS

The values for the entire cost comparison are presented in Table 4.3, and their graphical representation over time is depicted in Figure 4.8. This analysis underscores that both systems using ULDs significantly reduce opex compared to manual transportation, making any type of ULD facility the preferable choice for KCS.

Figure 4.8 underscores the business case for the washing and universal ULD system, resulting in total savings of €585,000 over five years compared to employing only a universal ULD. Despite this apparent cost advantage, it is crucial to recognize that introducing a second ULD system might bring about increased system complexity without significantly altering the overall cost dynamics. Therefore, if the sole motivation is cost reduction, the adoption of a dual ULD system is not recommended.



Table 4.3: Economic comparison between the 3 facilities.

| | 1 ULD Facility | 2 ULD facility | Manual |
|---|---|---|---|
| # AGVs required | 100 | 112 | NA |
| Initial cost of an AGV | €50.000 | €50.000 | NA |
| Setup Cost AGVs | €2.000.000 | €2.000.000 | NA |
| Wear time AGVs (year) | 10 | 10 | NA |
| Cost of universal ULD | €650 | €650 | NA |
| # Universal ULDs | 3413 | 2486 | NA |
| Wear time universal ULD (year) | 5 | 7 | NA |
| Setup cost Universal ULD | €45.000 | €45.000 | NA |
| Cost of washing ULD | NA | €175 | NA |
| # Washing ULDs | NA | 1038 | NA |
| Wear time washing ULD (year) | NA | 5 | NA |
| Setup cost washing ULD | NA | €15.000 | NA |
| FTE required | 42 | 42 | 122 |
| Cost FTE per year | €62.400 | €62.400 | €62.400 |
| Total initial investment cost | €9.263.000 | €9.458.000 | 0 |
| Cost per year | €3.565.000 | €3.446.000 | €7.613.000 |

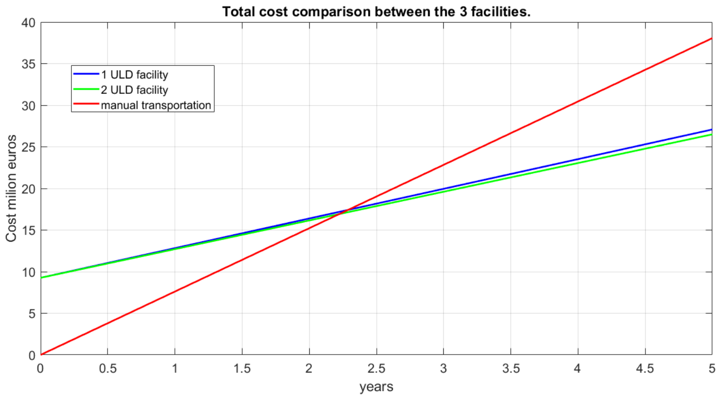



Figure 4.8: Total cost of the 3 different facilities with values from Table 4.3.

# 5
# Conclusions and Recommendations

This thesis, has described the design and implementation of a ULD in an airline catering facility. After evaluating the costs of using a ULD and the current transportation methods it showed that using a ULD has the ability to revolutionize airline catering transport through significant cost reductions and ergonomic improvements. This thesis has done so by answering the question: "How can the implementation of an Unit Load Device affect the logistic chain of an airline catering facility?" . This chapter will provide the concluding remarks of each chapter followed by the recommendations.

## 5.1. Chapter 1

The introduction lays the foundation by providing background and motivation. It was demonstrated that the current method of transporting airline catering trolleys relies heavily on manual labor, incurring significant costs and physical strain. This highlighted the necessity of automate flexible trolley transport. The proposed solution took the form of a Unit Load Device (ULD), designed to efficiently transport and secure multiple airline catering trolleys via various means such as AGVs, conveyors, or highloaders. This chapter adresses several challenges, namely: 1. The process is versatile, each with its own set of requirements; 2. The trolleys are not uniform; and 3. The industry has not paid much attention to the subject of automation.

## 5.2. Chapter 2

This Chapter addresses the first sub-question: What are the current logistic steps and trolley movements within an airline catering facility? This investigation involved observations at KCS and a literature review. It was confirmed that catering trolleys undergo various crucial sub-processes in the facility, including flying, transportation with highloaders, emptying of contents, washing, production, and flight end assembly. Each of these processes requires distinct handling of the trolley, playing a pivotal role in the airline catering sector.

The second sub-question: What are the current methods for transporting and securing rolling goods, and what constitutes the state of the art of the industry? Was answered through a literature review and observations at KCS. The chapter highlights that most trolley transport is manual, offering flexibility and easy sorting based on external earmarks. Monorail systems are observed during production or filling of trolleys, while moving floor conveyors are used during washing due to the slow speed required. Brush track conveyors are suitable for large quantities off trolleys with identical start and end points.

The chapter also delves into the state of the art of Unit Load Devices (ULDs), identifying pallets and ULD load plates as viable options. ULD plates are slightly preferable, being stronger, lighter, cheaper, and adding less height compared to pallets. However, pallets may be preferred if there is a need for temporary storage without a docking position, as a forklift does not require a specific docking position.



## 5.3. CHAPTER 3

This chapter addresses the third sub-question namely: What are the specific process requirements for designing an efficient ULD? It outlines the diverse requirements for designing a new ULD. It initially addresses the overlapping requirements present in each section of the facility. Subsequently, a proposed ULD design for the upcoming facility is presented. This design reveals that trolleys need to be removed and added multiple times from a ULD, leading to distinct requirements for various sections of the facility, including highloader, washing and storage, and internal transportation with filled trolleys.

The chapter explores various load securing methods, resulting in a wide array of techniques. Two crucial discoveries are the effectiveness of a specific method off tilting the ULD slightly, increasing the friction and ensuring that the trolleys remained flush in the ULD, and the T12 divider, which proved crucial for the highloader as without the T12 divider a single T12 would gain to much momentum.

Three ULD designs were subjected to real-time testing with a Lowpad AGV. The results for the inclined ULD were impressive, demonstrating the trolleys resistance to multiple emergency brakes, maintaining a flush position with the ULD. Conversely, the non inclined ULD proved less viable. Even with a significant increase in the ULD clamps length, the trolleys failed to remain flush compared to the ULD. It is therefore advised to tilt the internal ULDs by 3°.

## 5.4. CHAPTER 4

This chapter addresses the fourth sub-question: How would the implementation of the designed ULD impact the current operations of the airline catering facility? The process was revisited to identify the different ULD facilities, resulting in three possibilities: Only one universal ULD, Two ULDs: Washing/ storage ULD and a Universal ULD-washing and lastly Two ULDs: One for the highloader and one for all internal transport in the facility. The latter was deemed unsuited for a multitude of reasons, as this would not add many cost effective ULDs and would require the cost effective ULD to also handle filled trolleys. Lastly it would potentially hamper further process innovation when flight specific ULDs would be produced instead of flight specific trolleys. A flowchart off both ULD facilities and a possible design for a washing ULD was provided.

The chapter proceeds to answer the last sub-question: What Key Performance Indicators (KPIs) can be established to measure the success of the ULD implementation and what is its influence on the logistics chain? Due to the challenges in measuring ergonomic improvements, the focus shifted primarily to Capital Expenditure (CAPEX) and Operating Expenditure (OPEX). After consulting companies such as rotamoulding, BFF trading, Lowpad, and an internal simulation of KCS predicting the transport requirements a rough estimates for the cost functions was obtained. The calculations, revealed that whichever ULD configuration was chosen, it would be significantly more cost-effective than manual transport. Next to the economic viability the choice for ULDs will also significantly improve the ergonomics since the heavy elastic bands of the highloader and almost all walking with trolleys are removed.

Between the two ULD configurations, it was determined that the use of a washing ULD and a universal ULD would be the most economically viable option. This configuration has the potential to save over half a million euros in the first five years. Despite this apparent cost advantage, it's crucial to recognize that introducing a second ULD to the facility might bring about increased system complexity without significantly altering the overall cost dynamics. Therefore, if the sole motivation is cost reduction, the adoption of a dual ULD system is not recommended.



## 5.5. RECOMMENDATIONS

The automatic loading and unloading of the ULD into the highloader is paramount. Further investigation in the feasibility of the automatic loading and unloading is required.

There are different assumptions based on wear in the cost function. It will be advisable to test the assumptions, especially those of the wear of the ULD when being washed and when the ULD is not washed. Although a conservative assumption was used it should be verified. Moreover the cost function is not yet completed and excludes the retrofitting of the highloaders. This is since KCS is acquiring new highloaders.

Moreover, since the CTR is an internal trolley. It might prove worthwhile to standardise the CTR in length, width and height to other trolleys used at KCS. Since the CTR is the longest this will improve the securing of trolleys.

Since the inclination is used to secure the trolley and thereby increase the required force to get the trolley to move out of the ULD, it might be worthwhile to envision a docking station that is slightly inclined in the other direction. This way employees do not need additional force.

# A

# Airline catering process steps

## A.1. Flying

During flight, food, drinks and non-food items are served from different trolleys divided over the different galleys among the airplane. Besides to food and non-food trolleys, each flight is also equipped with multiple waste trolleys containing waste bags. The contents of the trolleys for each flight differ based on multiple factors. These include: The type of airplane, the destination of the airplane, the amount of passengers on the plane, allergies and the length of the flight. Apart from this differences, KCS among other airlines has expressed the wish to give each customer the choice for a diverse subset of meals[40]. Giving each passenger the option to have a special meal like an Indonesian rice table. During flight a lot of food and beverages are served and eaten. Waste is thrown in the waste bags so at the end of a flight two different sources appear. Waste trolleys and dirty trolleys that need to be washed with contents. Figure A.1 shows the amount of trolleys and the diversity of trolleys from a single ICA flight.


Figure A.1: The contents of an entire ICA flight.

## A.2. FROM AIRPLANE TO FACILITY

After the flight, the next process step involves transporting the trolleys back from the aircraft to the catering facility. The trolleys are loaded onto highloaders, to ensure safe and secure transportation back to the facility while being subjected to the high loaders acceleration and cornering. Trolleys at KCS are typically secured using heavy-duty elastic bands and in some cases steel dividers. Important to note is that these elastic bands are oftentimes described by employees as heavy.

Importantly, at this stage, the doors of the trolleys are closed. Upon arrival at the catering facility, the truck is docked to the catering facility and the trolleys are carefully unloaded manually at the appropriate location, either at the Intercontinental (ICA) or Europa (EUR) side. This is the first separation of trolleys before subsequent processing within the facility. It is important to note that emptying and filling of trolleys in a highloader takes up a significant amount of time. Since reducing this turn around time will lead to less required docks and highloaders, it is important that this is optimised necessary in the new facility of KCS.

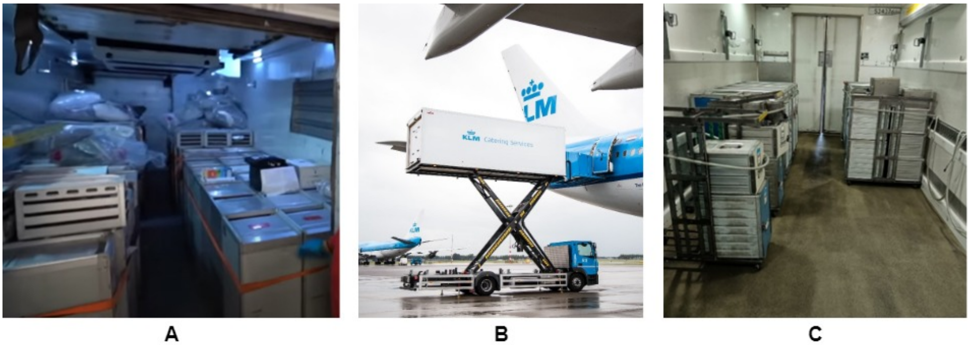



Figure A.2: A) a highloader of emirates using tension straps [41] B) a highloader docked to an airplane at KCS C) a highloader being filled at KCS.

### A.2.1. EMPTYING OF CONTENTS

Once safely transported back to the catering facility, the trolleys must be emptied. The emptying process is a critical link in the catering logistics chain. It ensures that trolleys are ready for thorough cleaning and restocking. These trolleys contain a diverse array of items as described in subsection 2.2.1. It is noteworthy that trolleys are essentially compact carriers, with a single trolley accommodating up to as many as 52 food trays. Although it is mostly a mix between several drawers and around 16 trays. In order to reduce the transportation of carrier items it is therefore important to use the trolley as a carrier as long as possible. To facilitate this, the current facility of KCS has implemented a strategy where individual trolleys are transported to their respective departments within the facility, such as NFNB EUR, ICA- Economy class and even subsequent sorting like alcoholic non-food and non-alcoholic non-food. The sorting in the current facility is done based on external earmarks like colour coded stickers or by trolley size. It is important to note that some of the departments such as Non-food and beverages (NFNB) are located not on the ground but on the first floor. This requires trolleys to be moved using elevators. Therefore additional transportation is required for the trolleys need to be loaded and unloaded to and from the elevator.

After the trolleys are sorted and sent to the correct department, the labels and possibly seals from the previous flight are removed, which indicate the old origin and destination of the trolley. After this label is removed, the trolley doors are opened, granting access to the contents. The contents are either thrown out, washed or regenerated. Figure A.3 shows the emptying of trolleys on the Europa side.

Figure A.3: The Europa side where trolleys return. A clear visual division is made between T11 in the back and CTRs in the front. The T11 waste is removed and the waste is conveyed to the different recycling shutes.

## A.3. WASHING

The KCS facility must adhere to meticulous standards to maintain high levels of hygiene and cleanliness of the catering product. Since the airline catering trolleys are used as a carrier for food items, it is important that the trolley is cleaned properly. The trolley emptying phase provides the washing phase with dirty, empty, opened trolleys. These trolleys are washed with specialized trolley washing equipment and detergent. The trolleys are placed sideways with open doors on a slow moving conveyor with a perforated floor. This is in order to be able to drain all water. The trolley washers are designed to efficiently eliminate any residual food particles, stains, and potential contaminants. This process leaves the trolleys clean and sanitized and offers an open clean trolley to the production phase.

To achieve the high cleanliness standards, the washing procedure incorporates the use of specialized cleansing agents and high-temperature water. In the future the process might include the use off UV-radiation. This is another way for disinfection that uses considerable less amounts off energy. For UV-radiation to be used the trolleys should be presented perfectly in line with the tube.

During washing, trolleys are methodically conveyed with a conveyor that moves at approximately 1 m/min through the cleaning system via a moving floor conveyor [9]. It is essential to address a notable challenge that exists within the current trolley washer since a few times per day stability issues are observed during the washing process causing trolleys to tip over. Resolving this challenge is essential to ensure the overall efficiency and effectiveness of the washing phase at the KCS facility. Clean trolleys with open doors come out of the washing stage.

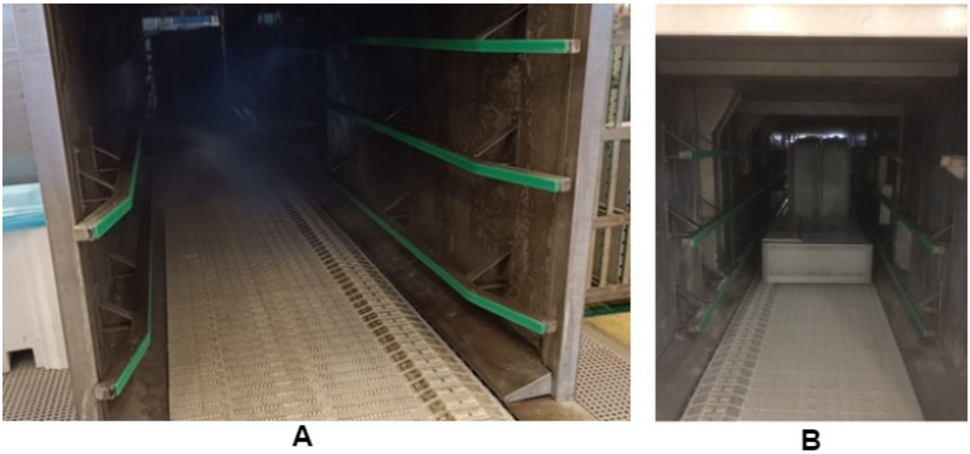



Figure A.4: A) a running washing machine B) a trolley fell over during washing.

## A.4. PRODUCTION

With clean trolleys with open doors at hand, the subsequent phase at the KCS facility involves the production or the filling of the trolleys for upcoming flights. The contents of these trolleys may vary widely, encompassing an array of meals, snacks, beverages, and other amenities, all tailored to the specific requirements of each flight. Therefore first the trolley is allocated, precision is paramount in this process, as it ensures that each trolley is stocked precisely with the correct items and quantities, thus preparing them to meet the diverse needs of passengers.

At KCS attention is not solely on what goes into the trolleys, but also on the ergonomics of the production process. Given that some trays and items that need to be inserted weigh up to twenty kilograms, the trolleys must be at an appropriate height to facilitate the insertion of contents. This ergonomic consideration is integral to safeguarding the health and well-being of the personnel involved in the loading process.

Additionally, it is notable that the M-Class line, which is responsible for all the food trolleys for economy class ICA is fully automated. Here the trolleys at KCS undergo an unique filling process involving a filling robot. This robot assists in efficiently and precisely loading items into the trolleys. These trolleys are carefully moved through the filling robot via side actuated conveyors, ensuring that they are expertly stocked for their respective flights.

A B

Figure A.5: An employee filling multiple trolleys at unergonomic heights.

A

## A.5. FLIGHT ASSEMBLY

Upon the completion of flight-specific trolleys with closed doors, the trolleys proceeds to the Flight End-Assembly area. In this area, the trolleys are grouped based on flight, docking door and even galley level. This is visualized in Figure A.6 This sorting is crucial because trolleys from various production departments make up a flight, and these departments deliver the trolleys at different times.

There is a significant distinction between European and Intercontinental flights in terms of high loader requirements. European flights are serviced by two high loaders for each flight, while Intercontinental flights use three to four full high loaders. Since European flights use a fraction of the high loader capacity, one truck can accommodate up to four half-European flights. This often involves pairing a high loader with another since two high loaders are needed to service one plane for a quick turnaround. This highlights the importance of precise grouping and organization.

Once the trolleys are assembled, grouped and allocated to a docking door, they are manually loaded onto high loaders. Due to the significant forces during transit to the airplane, securing the trolleys with care is paramount, as any shifts can result in complications for in-flight personnel.

This level of security is especially crucial because the trolleys are configured with items specific to each flight. Any last-minute adjustments or disruptions could potentially result in flight delays, which is undesirable for the airline's commitment to passenger satisfaction. Currently, at KCS, robust, heavy-duty elastic bands are employed to secure the trolleys. T12 trolleys are secured in pairs, while T11/CTR trolleys are secured individually. Stretching the elastic bands requires quite some effort and is heavy work. It would be beneficial when the elastic bands could be replaced with something as adequate but lighter and less work.

Once loaded, the high loader proceeds to the aircraft door, where the driver unloads the trolleys at designated galleys. This concludes the assembly and loading phase, ensuring efficient in-flight service delivery.

Figure A.6: KCS Flight End Assembly Europa: Chillers on the right, high loader docking doors on the left, and flight indicators atop trolleys.

# B

# EXCELL GRAPHS

The remainder of the graphs that underscore the conclusions made in 3.3.3 are presented here. Each box is made by means of 20 tests.

B

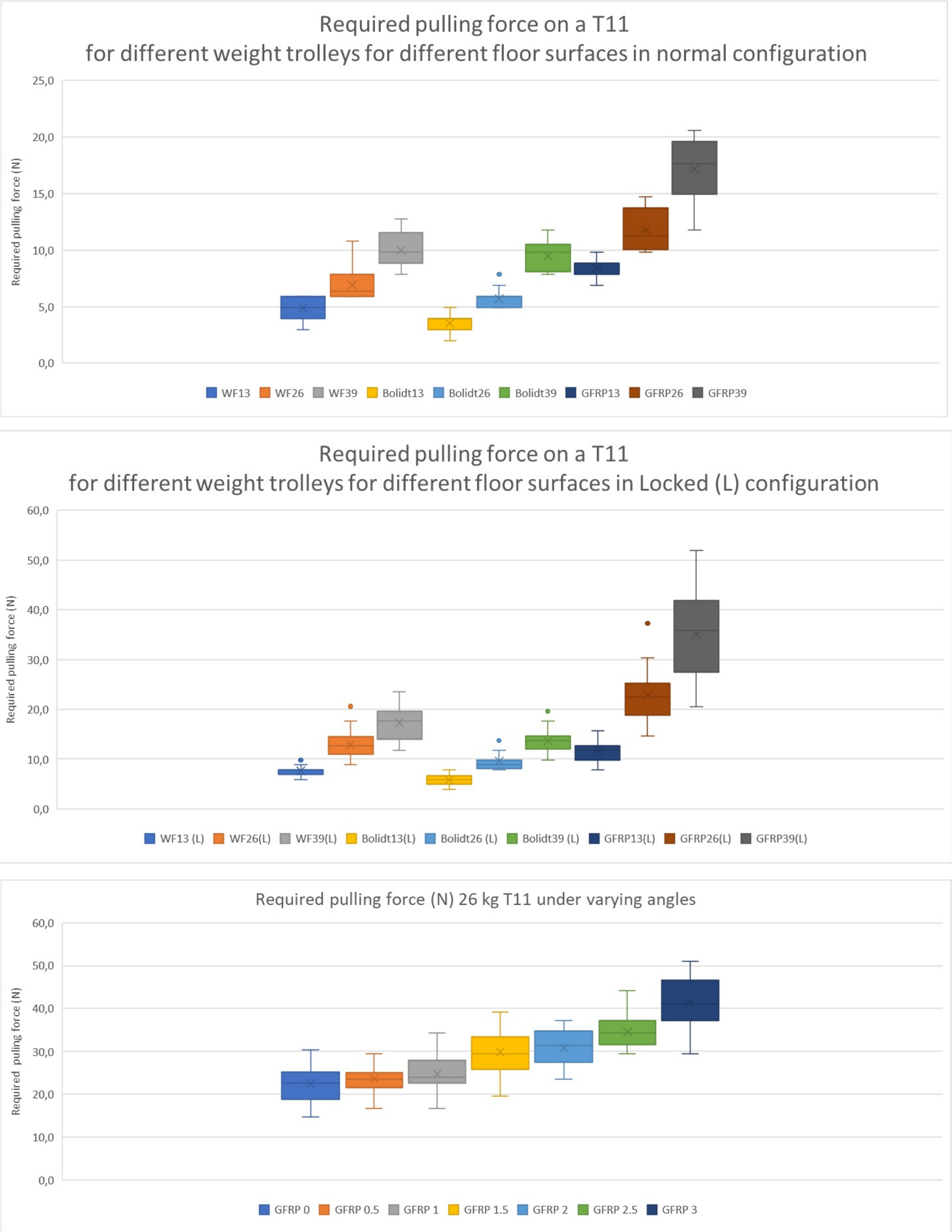
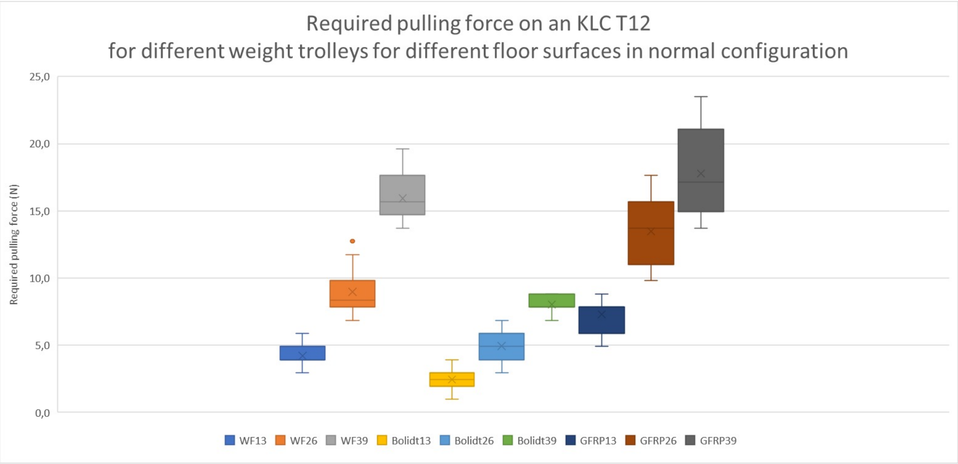
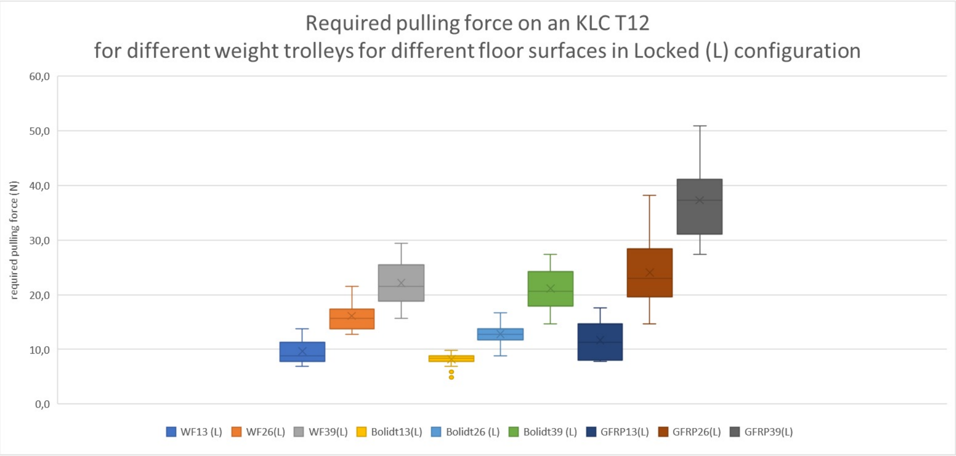



Figure B.1: The remainder of the T11 Graphs



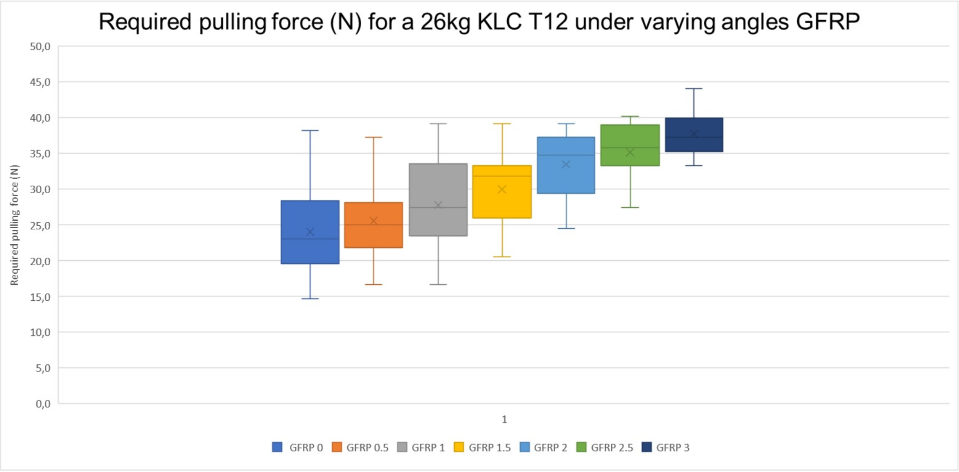
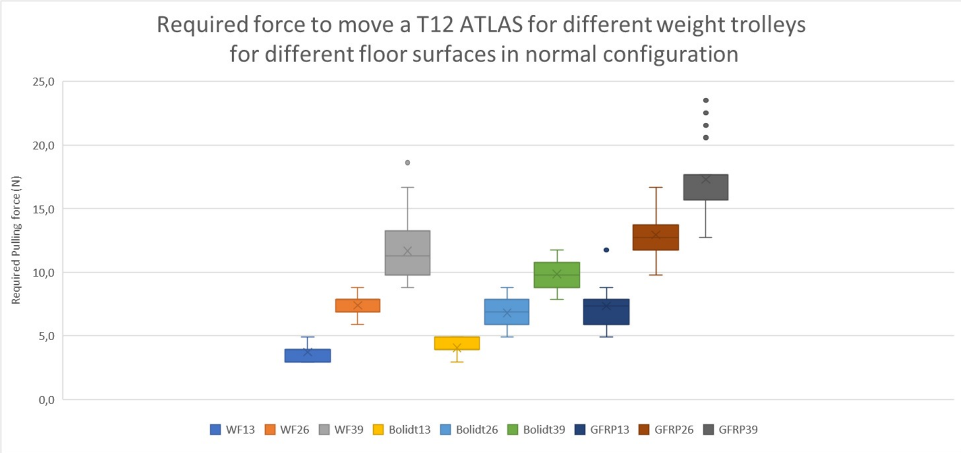
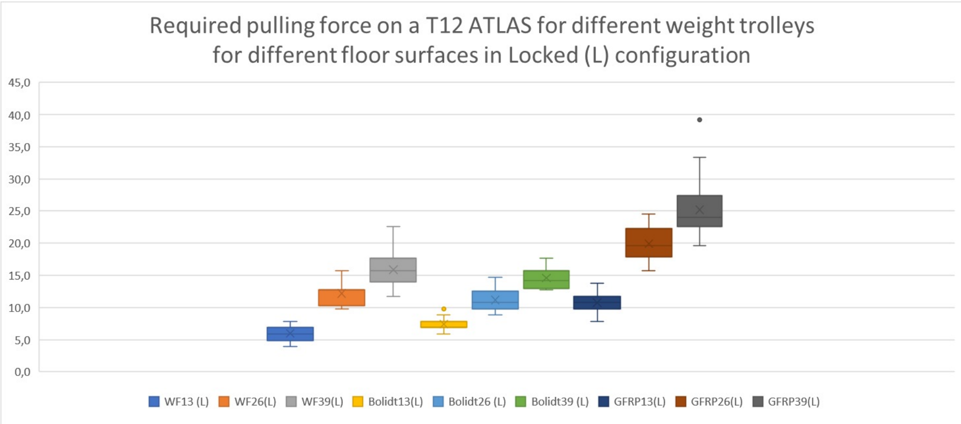




Figure B.2: The remainder of the KLC T12 Graphs

B



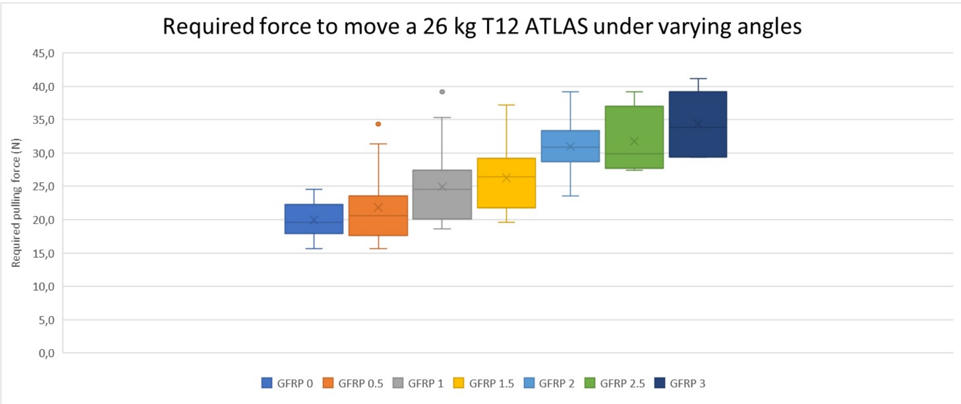




Figure B.3: The remainder of the ATLAS T12 Graphs

# C

# FACILITY LAYOUTS

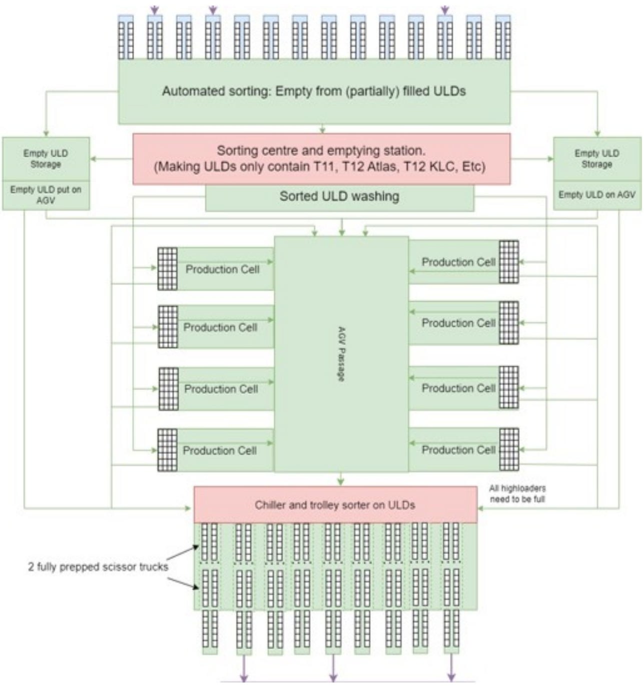



Figure C.1: Potential layout of a facility using ULDs.

C

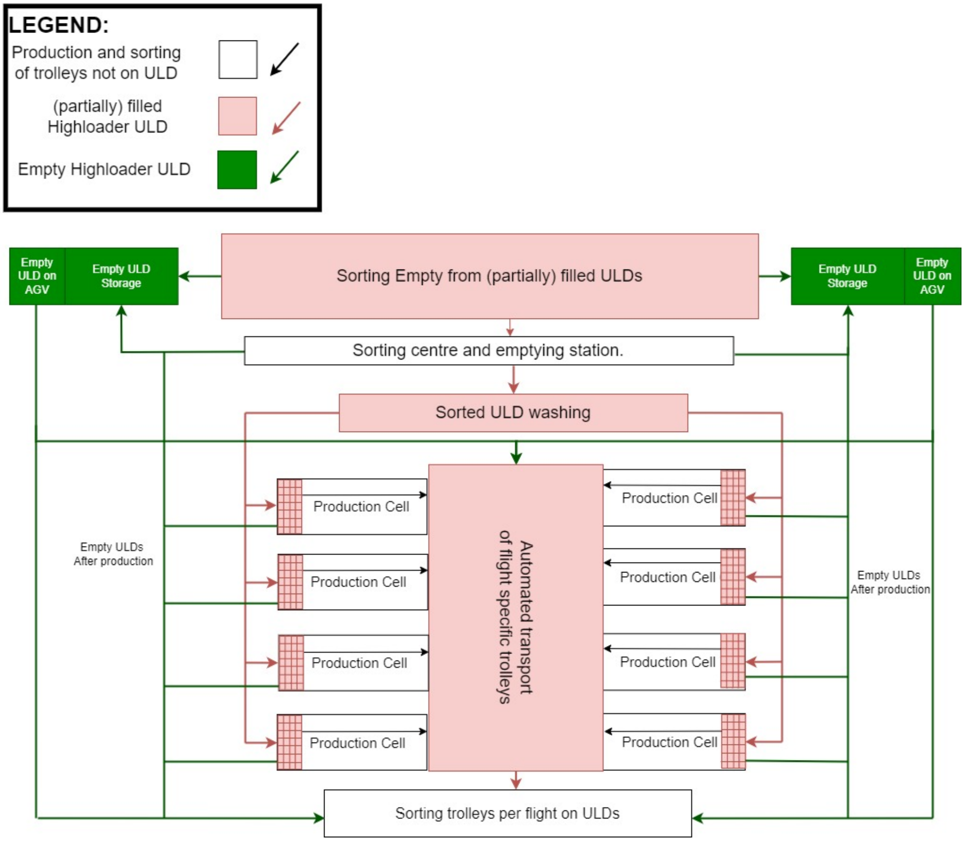



Figure C.2: Schematics of a single ULD facility.

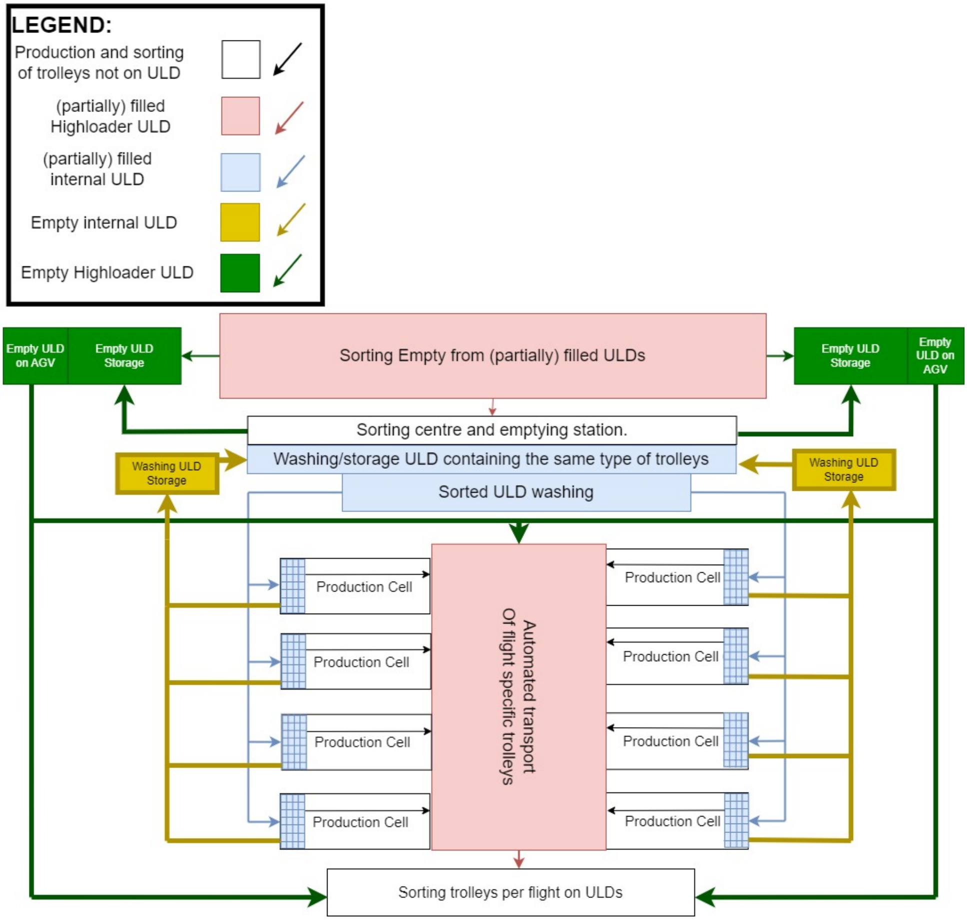



Figure C.3: Schematics of a dual facility. Larger arrows indicate an increased requirement for using multiple ULDs.

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# Revolutionizing airline catering trolley transport by using a Unit Load Device

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**Abstract**

The increasing automation in various industries has underscored a notable gap in the airline catering sector, where predominant manual transport of airline catering trolleys within facilities results in substantial costs and physical strain. This paper addresses these challenges by proposing an automated solution for the transport logistics of airline catering trolleys within catering facilities. The suggested solution involves implementing a Unit Load Device (ULD) designed to securely carry multiple airline catering trolleys simultaneously. This ULD is engineered for compatibility with various transport systems, including Automated Guided Vehicles, highloaders and conveyors. The paper outlines the design process for a ULD within an airline catering facility. To formulate a comprehensive design, several design problems are identified, and potential solutions are presented. Subsequently, multiple viable load plate prototypes are constructed and tested on an Automated Guided Vehicle and highloader, resulting in the identification of a single viable all-purpose ULD for the entire process. Additionally, an in-house ULD emerges as a cost-effective alternative to the all-purpose ULD. In this context, this paper introduces a comparative analysis of three possible future airline catering facilities: utilizing 1 ULD, using 2 ULDs, and employing no ULDs (or maintaining the current status quo). The comparison reveals minimal cost differences between facilities employing 1 or 2 ULDs, both facilities however show significantly more cost efficient compared to using no ULDs.

*Keywords:* ULD design, Airline Catering Facility, Dual ULD configuration, Inclined ULD design

## 1 Introduction

### *1.1 Motivation*

KLM Catering Services (KCS) is relocating to a new facility. This led to an evaluation of the current process which identified various problems with the current way of transporting and securing trolleys. In an internal presentation by KCS of 2022 it is estimated that in the current facility 122 FTE is allocated to trolley transport and securing off trolleys within a highloader. Both manual transport as well as securing of trolleys in the highloader is heavy work and for ergonomic purposes it is best avoided for the employees, who at KCS on average are 53 years old. Both challenges of primarily manual transport and manual securing of airline catering trolleys extends beyond the confines of KCS and is pervasive across various facilities. This observation is supported by recent promotional materials from different catering facilities, including those of prominent airlines caterers like American Airlines [1] and UK's largest inflight caterer - DNATA [2].

### *1.2 Background*

#### *1.2.1 Current trolley transport*

As discussed, the predominant mode of transportation of the current facility is manual transport. Next to manual transport there are three different ways to transport airline catering trolleys: via conveyor, via side- actuated conveyor or via monorail. Each type of transport has its own advantages and disadvantages. Each type of trolley transport is shown in Figure 1.

- **Manual** transportation as discussed is expensive, heavy and not ergonomic. Manual transportation however does contain advantages such as easy sorting based on vision, no initial investment cost and a large amount of flexibility.
- **Moving floor conveyors** are slow-moving conveyors primarily utilized in automatic trolley washers. The advantages of this conveyor for washing purposes include easy access to the entire trolley for thorough cleaning. The slow-moving transport is necessary due to the top-heavy nature of the trolleys, reducing the risk of tipping. However as depicted in Figure 1 the trolleys sometimes still tip over.

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**Authors' Biographies**

**J.K. Wempe** is currently a master student at the TU Delft University of Technology at the department of Transport Engineering and Logistics. **Ir. W.van den Bos** Is a professor with the Transport Engineering and Logistics Section of the Maritime and Transport Technology Department. **E. Rietveld** is a manager innovations and development of KLM Catering Services. **Competing intrests** This research was conducted as part of an academic MSC thesis of Wempe. The manuscript was written in close collaboration and approved by all authors. The datasets used and/or analysed during the current study are available from the authors on reasonable request.

- **Side actuated conveyors** propel the side of the trolleys to move the trolley forward. Advantages include a considerable higher speed compared to the moving floor conveyor. These types of conveyors are however when propelled less accessible to insert trays.
- **Monorail systems** are conveyor systems that utilize a track to transport elevated carts carrying and securing trolleys. These systems offer advantages such as space-efficient transportation and high capacity. However, they come with limitations, including limited overtaking capabilities and the loading/unloading of trolleys directly on the monorail line, without a separate plate. Many in-flight catering services, including Emirates, LSG Sky Chefs, Lufthansa, and KCS employ monorail systems for efficient trolley handling as indicated by [3], [4] and [5].

Figure 1: All methods of airline catering trolley transport used inside airline catering facilities, left to right: manual, moving floor conveyor, monorail, side actuated conveyor

Recognizing the limitations of the current transportation methods, characterized by various challenges and downsides, this paper aims to propose an innovative solution. To address the need for faster and more flexible transportation, a Unit Load Device (ULD) designed to be transportable by both Automated Guided Vehicles (AGV) and Conveyor systems. This ULD should not only enhance speed and flexibility but should also be capable of safely carrying and transporting multiple airline catering trolleys simultaneously.

#### *1.2.2 ULDs*

A unit load device groups multiple units so that they can be handled as a single unit and maintain their integrity. According to [6] and [7] the use of ULDs has multiple advantages compared to not using a ULD.

- The use of a ULD allows for more items to be handled simultaneously, thereby reducing the amount of trips.
- The use off a ULD will allow the usage off more standardised transport equipment.

Potential downsides to ULD design and mitigation strategies to minimise these downsides are also discussed by both [6] and [7]:

- Time spent forming and breaking of the ULD load. In order to minimize this time, it is important that units are easily placed on the Unit Load Device.
- Initial investment cost and load restraining cost. In order to minimize the initial investment cost it is important to design a cost effective unit load device.
- Empty Unit Load Devices and pallets may need to return empty creating an additional transport requirement of empty ULDs.

### ***1.3 Approach***

To develop a Unit Load Device (ULD) capable of transporting multiple airline catering trolleys simultaneously, the used approach involves problem formulation, brainstorming diverse solutions, and prototyping. The testing phase on both Automated Guided Vehicles (AGVs) and highloaders leads to the identification of two ULD designs. The first is a versatile ULD suitable for securing trolleys in both the highloaders and the facility, while the second, a more cost-effective option, is designed exclusively for facility use. Subsequently, the existing process is retrofitted to accommodate ULDs, and an economic comparison is conducted among the three potential facilities: one without ULDs, one using a universal ULD, and another using an in-house ULD and an ULD for use inside the highloader.

### 1.4 Structure

This paper is structured as follows. In Section 2 the different design problems that were encountered during the designing of the ULD are discussed and solutions are described. In Section 3 the different prototypes constructed will be tested on an AGV and 1 ULD design is tested in a highloader. Then, in section 4, a possible design for a future facility is presented based on the requirements of the current facility. From this an economic comparison is made between the different facilities. At last, in Section 5 a conclusion is formulated, and recommendations for further research are given.

## 2 Design problems and solutions

This section aims to address the intricate challenges encountered in the design process of a ULD that accommodates and secures multiple airline catering trolleys in various configurations. This task necessitates a comprehensive examination of factors such as size considerations, experienced accelerations, and strategies for mitigating unwanted movements in different directions. Through a detailed analysis of the design problem and different proposed solutions, the paper unveils different possible ULDs for an airline catering facility.

### 2.1 Size considerations

In designing a Unit Load Device (ULD) capable of transporting and securing airline catering trolleys, attention is given to the diverse range of trolleys used at KCS. Next to this all ULDs should be easily transportable and maneuverable.

#### 2.1.1 Trolley Types and Dimensions

Figure 2 visually represents three different trolleys used at KCS. A full size trolley (T11), the unique CTR trolley (used for transporting catering boxes), and a half-size trolley (T12).

Table 1 provides a detailed overview of the dimensions of each trolley type, considering both open and closed door configurations. Notably, the table reveals that a single trolley position encompasses at least (875mm X 335mm). To optimize stability and maneuverability, a square ULD is deemed favorable.

The decision-making process for the ULD dimensions revolves around accommodating either two trolley positions (875mm X 670mm) or three trolley positions (875mm X 1005mm). Opting for three trolley positions results in a 50% increased transport and storage capacity compared to the two-trolley configuration. Consequently, the ULD size is determined to be roughly (875mm X 1005mm), aligning with the goal of maximizing transport efficiency and storage capacity. Moreover since (875mm X 1005mm) is comparable to standard pallet sizes standardised handling equipment is more widely available.


Figure 2: A Full size trolley (T11), a Container Trolley (CTR) and a half size trolley (T12).

### 2.2 Expected accelerations on the trolley

In the design considerations for load-securing measures, the anticipated accelerations of two distinct forms of material handling equipment are paramount: Automated Guided Vehicles and highloaders. Conveyors are expected to have significantly lower accelerations compared to AGV transport, AGVs and highloaders therefore present unique challenges. AGV transport stands out as the internal transport with the highest acceleration requirements. AGVs are capable of emergency braking with accelerations reaching up to $1\frac{m}{s^2}$ in both directions [8]. As such, any

Table 1: The different trolley sizes. In bolt are the largest and smallest sizes.

| Trolley types and if open/closed doors | Length [mm] | Width [mm] | Height [mm] | No. swivel wheels [#] |
|---|---|---|---|---|
| KSSU T11 C | 843 +-1 | **300** | **1036.8 +- 1.7** | 4 |
| KSSU T11 O | 800 +-1 | **335.4** | **1036.8 +- 1.7** | 4 |
| KSSU T12 C | 424.5 +-1 | 300 | **1036.8 +- 1.7** | **2** |
| KSSU T12 O | 400 +-1 | 317.7 | **1036.8 +- 1.7** | **2** |
| ATLAS T11 C | 810 +-1 | 302 | 1030 +-2 | 4 |
| ATLAS T11 O | 768 +-1 | 337 | 1030 +-2 | 4 |
| ATLAS T12 C | 404 +-1 | 302 | 1030+-2 | **2 or 4** |
| ATLAS T12 O | **362 +-1** | 329.4 | 1030+-2 | **2 or 4** |
| CTR | **875 +-1** | 330 | **1026.1** | 4 |

load-securing design must withstand and accommodate these substantial accelerations while ensuring the stability and safety of the transported trolleys.

Highloaders are responsible for transporting trolleys between the facility and the airplane. They have considerable higher acceleration requirements, as braking in highloaders can reach accelerations up to $7\frac{m}{s^2}$, while maneuvering can subject the trolleys to an accelerations of $5\frac{m}{s^2}$ [9]. During truck movement an additional support system for securing can be employed as described in the following sections.

### *2.3 Highloader Securing*

The current method of securing trolleys in the highloader involves the labor-intensive use of elastic bands, securing trolleys in pairs. To streamline and improve this process, the paper proposes the adoption of an automatic draw cage to secure all trolleys in 1 movement as a more efficient alternative. This transition is depicted in Figure 3, illustrating the current elastic band method alongside the proposed draw cage approach.

A noteworthy feature of the ULD depicted in Figure 3 is the integration of the T12 divider, serving as a non-obstructive barrier at rest. Once lowered by rotating the divider, the divider provides space for a half size trolley between itself and the highloader wall or between the divider and the draw cage. The T12 divider is crucial, particularly when considering that a lone T12 in a trolley position leaves 470mm of space. With a maneuvering acceleration of $5\frac{m}{s^2}$ and no obstructions, a single half size trolley could potentially reach speeds of $2.1\frac{m}{s}$, an undesirable outcome.

The absence of dividers between trolley positions would presents another undesirable scenario. A single trolley on an ULD would leave approximately 700mm of space. With a braking acceleration of the highloader at $7\frac{m}{s^2}$, this configuration could result in full-size trolleys reaching speeds of up to $3.1\frac{m}{s}$ within the highloader. Figure 4 depicts a ULD designed for secure trolley transportation in a highloader, featuring the T12 divider and trolley position dividers marked in red and blue, respectively.

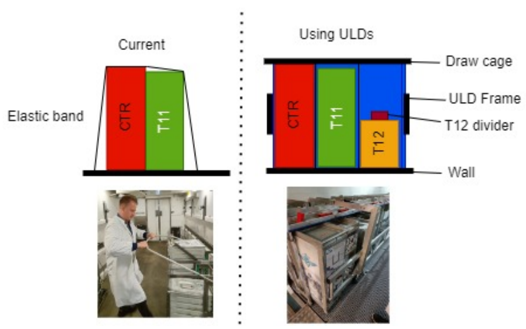


Figure 3: Current trolley securing vs trolley securing using ULDs.

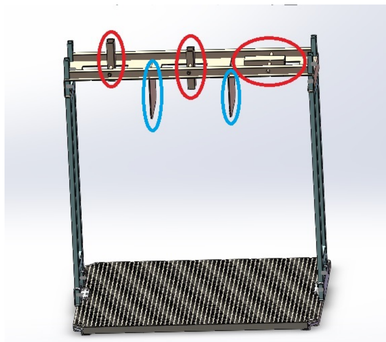

Figure 4: A ULD capable to transport trolleys in a highloader. Red T12 divider. Blue Trolley position divider.

### *2.4 Restricting movement during AGV transport*

During AGV transport, the accelerations are significantly lower compared to those experienced in the highloader. However, a distinct challenge arises as the trolley inlets remain unobstructed by either the highloader wall or a draw cage. This situation increases the risk of trolleys driving off the open inlets and outlets. To address this issue, two potential solutions have been considered:

- **Clamp mechanism on AGV** Implementing a clamp mechanism on the AGV that securely fits around the ULD on both open sides. This clamp would act as a barrier, preventing trolleys from unintentionally moving off the inlets or outlets during transport.
- **Increasing friction via inclination** Blocking off one open side of the ULD using a barrier and increasing friction to the final open side by inclining away from the open side is another solution. This results in a normal force component away from the open side. Furthermore the swivel wheels of the trolleys must turn before they are able to go upwards. Both effects are represented in 5

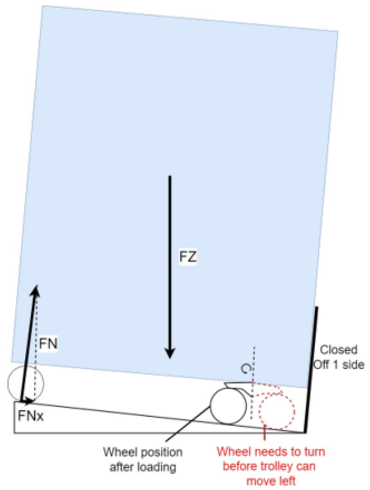


Figure 5: Working principle of the inclined ULD.

#### *2.4.1 Ground Testing for Required AGV Transport Angle*

Given the maximum acceleration of $1\frac{m}{s^2}$ on a trolley during AGV transport, ground testing was conducted to determine the necessary inclination to prevent undesired movement. Figures 6 and 7 illustrate the experimental setup. A ground surface was inclined, and two trolleys were connected by means of a scale. The force required to initiate trolley movement was measured in 20 repetitions for each angle. The minimal measured values are tabulated in 2. The data indicates that an inclination angle of 2.5°theoretically suffices to secure all trolleys in the event of an emergency brake on an AGV. Considering a safety factor, a rounded angle of 3°is deemed suitable.

Figure 6: Test setup of testing the different levels of inclination

Figure 7: Using a second trolley to pull at constant angle.

Table 2: Minimum measured force expressed in acceleration ($\frac{m}{s^2}$) to initiate trolley movement for different angles

| Angle | 0° | 0.5° | 1° | 1.5° | 2° | 2.5° | 3° |
|---|---|---|---|---|---|---|---|
| ATLAS T12 (2) | 0.60 | 0.60 | 0.72 | 0.75 | 0.90 | 1.06 | 1.13 |
| KLC T12 (4) | 0.57 | 0.64 | 0.64 | 0.79 | 0.94 | 1.06 | 1.28 |
| T11 | 0.57 | 0.64 | 0.64 | 0.75 | 0.90 | 1.13 | 1.13 |

## 3 Testing viable ULD designs.

As indicated two different material handling situations are deemed important: Highloader transport and AGV transport. For both cases prototypes are made.

### *3.1 Highloader testing*

The prototype highloader, featuring multiple ULDs designed for highloader use (depicted in Figure 4), was successfully constructed and assembled, as shown in Figure 8. During operational tests with the highloader, the effectiveness of trolley securing was observed to be satisfactory when utilising the T12 dividers propperly. Furthermore it was observed that the force exerted by the draw cage should be increased.

This successful implementation marks a milestone in validating the practical functionality of the highloader ULD design. The prototype's capability to securely transport and contain multiple trolleys underscores its potential for enhancing efficiency and safety in catering facility operations. Additional enhancements and considerations for the highloader involve the automation of both the loading and unloading process, as depicted in Figure 9. This advancement would significantly enhance highloader efficiency by automating not only the securing of cargo but also the transportation between the highloader and the facility.

Figure 8: The prototype highloader.

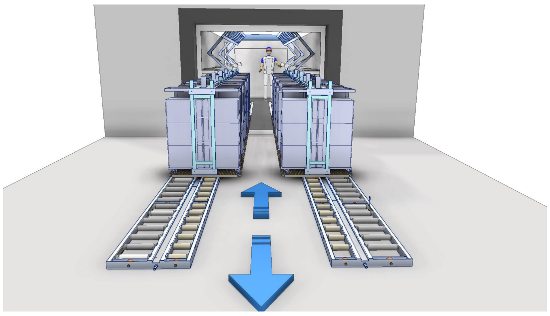

Figure 9: Potential logistical improvement when the ULD loading and unloading is automated via conveyors.

### *3.2 AGV testing*

Due to time constraints in the testing phase at the AGV manufacturer Lowpad, a selection of three distinct ULD designs was made for evaluation on an AGV.

- **ULD with T12 divider and AGV Clamp:** Utilizing the ULD designed for the highloader, as depicted in Figure 4, complemented by an AGV clamp for closing the AGV.
- **Inclined ULD with T12 divider:** The highloader ULD, modified to include a 3°inclination with one side blocked off. This design aims to prevent trolleys from driving off unobstructed inlets and outlets during AGV transport as visualised in Figure 12
- **Inclined ULD without T12 divider:** A simplified ULD without the top part, featuring a slight inclination and trolley dividers in the ground surface is represented in Figure 14. While economically advantageous compared to a ULD with the T12 divider, this design is only suitable for internal transport, as it is not strong enough and cannot accommodate single T12 trolleys in a highloader.

These three designs were selected to encompass a range of features and considerations.

All ULDs are prototyped and tested at Lowpad with varying trolley configurations and a difficult parkour that contained multiple emergency brakes and sharp turns. The following sections will describe the results.

#### *3.2.1 ULD with T12 divider and AGV clamp*

This test employed the ULD illustrated in Figure 4 with AGV clamps extending 0.6 meters on both sides. The initial test results, depicted in Figure 10, clearly indicate that the AGV clamp's length was insufficient to prevent trolleys from staying on the ULD. Subsequent modifications were made, as illustrated in Figure 11, where the length of the trolley dividers and the AGV clamp was extended to cover the entire length of the ULD.

During this modified test, all trolleys remained on the ULD. However, a noteworthy observation is that the trolleys exhibited steep angles in relation to the ULD. This could pose challenges during processes such as trolley washing, where it is essential for the trolleys to maintain a flush position to the washing machine.

Figure 10: A trolley falling of the ULD during testing.

Figure 11: No trolleys fell after increasing the AGV clamp and the Trolley dividers length.

*3.2.2 Inclined ULD with T12 divider*

The inclined ULD with top part is represented in Figure 12. During testing of the inclined ULD with top part no trolleys fell off the ULD and the trolleys remained flush to the ULD as can be seen in Figure 13.

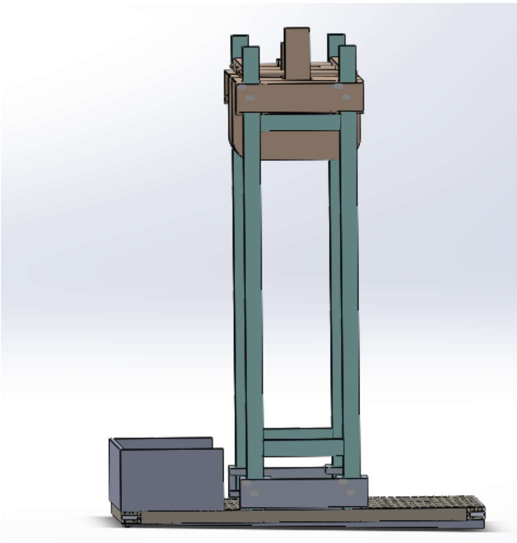

Figure 12: The cad model of the tested ULD.


Figure 13: During testing no trolleys fell off and the trolleys remained flush to the ULD.

*3.2.3 Inclined ULD without the T12 divider*

In consideration of cost-effectiveness, the feasibility of an internal ULD was tested by removing the entire frame and adding the trolley divider to the ground surface. This prototype is illustrated in Figure 14. When testing commenced, the trolleys remained flush and did not drive off the trolley inlet. However during emergency breaks it became apparent that without the frame/sidewall the trolleys were prone to tipping over the sides. When the frame was retained, as visualised in Figure 15, no trolleys fell during testing. A simple, cheap, barrier could potentially also suffice.

This prototype demonstrated that while eliminating the top part may reduce costs, maintaining the sides is crucial for preventing trolley instability. Further assessments and adjustments may be required to optimize this design for internal use that balances cost considerations with the necessity for secure trolley containment.

Figure 14: During testing without the sides the trolleys tipped over the sides.

Figure 15: With the added sides, no trolleys fell of during testing and the trolleys remained flush.

### *3.3 Conclusion: Testing of ULDs*

The testing phase dedicated to evaluating (ULD) designs has provided crucial insights into their performance across distinct transport scenarios.

The testing of ULDs in the highloader environment has highlighted the essential need for a T12 divider and trolley divider.

The testing of various ULD designs for Automated Guided Vehicle (AGV) transport has emphasized the adaptability and versatility of inclined ULDs. Both the inclined ULD design with the T12 divider as well as the inclined ULD without the T12 divider were suitable for internal transport. The inclined ULD with T12 divider was both suitable for the highloader as well as for internal transport.

The key advantage of the inclined ULD design is ensuring that trolleys remain in a flush position during transport. This inclination aligns the trolleys with a fixed barrier. As this is now the only position with the least amount of potential energy this is the natural position.

Moreover, as the inclination is integrated into the ULD rather than the AGV this streamlines its application across diverse material handling methods. This integrated approach eliminates the need for separate solutions for conveyor transport as this has lower accelerations compared to the AGV.

Both the inclined ULD types offer effective solutions. The successful implementation of the inclination concept enhances the ULDs overall performance, prioritizing stability, safety, and flexibility across varying transport scenarios.

## 4 ULD Implementation

The previous section lead to two viable ULD types: one exclusively for internal transport and another designed for both internal and highloader transport. This chapter delves into the implementation details of both ULD types and conducts an economic comparison among three scenarios: a facility with no ULD, a facility with the universal ULD type, and a facility with both ULD types.

### *4.1 Current Facility Overview*

Before introducing ULDs into the facility's operations, it is crucial to understand the existing processes that catering trolleys undergo. As described by [10] the current airline catering facility operations are categorized into several key steps: transport between the facility and the airplane, emptying of trolleys, washing of trolleys, filling of trolleys and sorting of trolleys on highloader level. Figure 16 provides a visual representation of the current facility layout and the manner in which trolley transport takes place within the facility.

In the current facility at KCS, highloaders transport trolleys between airline and facility. Here the trolleys are sorted and transported to their respective emptying station. Here the labels from the previous flight are removed and the trolleys are emptied. Subsequently, the empty open trolleys undergo a washing process. After washing, the

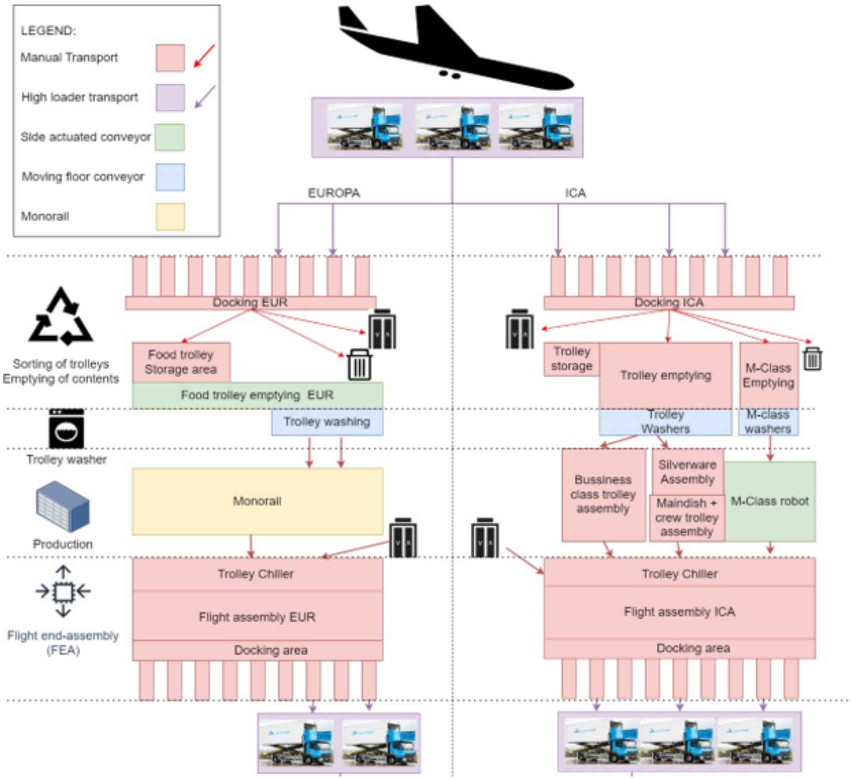


Figure 16: Schematic overview of the current facility of KCS including transport.

trolleys are filled at different production areas, labeled for a specific flight and galley, and sent to a chilled sorting point. At this sorting point, trolleys from various production facilities are organized on the airplanes galley level before being loaded into a specific highloader for transport to the airplane.

This understanding of the existing facility processes serves as a foundation for designing an effective ULD implementation strategy. It allows for the identification of key points for ULD integration and optimization of the overall catering trolley handling system

### *4.2 Potential ULD facility*

For the design of a facility incorporating ULDs, it is important to identify the positions where trolleys are added and removed from the ULD. Assuming an automated highloader transport system, as depicted in Figure 9, one can anticipate the arrival of three different ULDs: filled ULDs, partially filled ULDs, and empty ULDs. These ULDs need to be sorted into categories of empty and (partially) filled.

The process involves empty ULDs being buffered, while (partially) filled ULDs arrive with trolleys with closed doors on ULDs. Here the trolleys are removed from the ULDs, doors are opened, and their contents removed and conveyed to a separate area. Subsequently, the emptied trolleys are sorted onto ULDs based on pre-existing external earmarks to undergo the washing process.

After washing, the clean open trolleys are directed into production buffers specific to different production facilities. In these production facilities, the clean, open trolleys are removed from the ULDs, labeled, filled with flight-specific products, and placed on an automated transport solution equipped with a ULD. This transport solution transports the filled trolleys on ULDs to the flight end assembly area. In an ideal process, all ULDs are already filled based on flight requirements. However, in the case of imperfections in the process or late orders, there may be the need to rearrange trolleys between ULDs in a flight end assembly area.

Since the emptying of planes requires the highloaders to be completely filled with ULDs also empty ULDs are loaded in the highloaders.

Where the highloader is being filled preferably not just 1 but multiple highloader loads can be buffered to ensure quick turnaround times of the highloaders. This comprehensive process ensures a streamlined flow, utilizing ULDs to enable automatic trolley transport at various stages of catering trolley handling. The layout of a possible process is visualized in Figure 17.

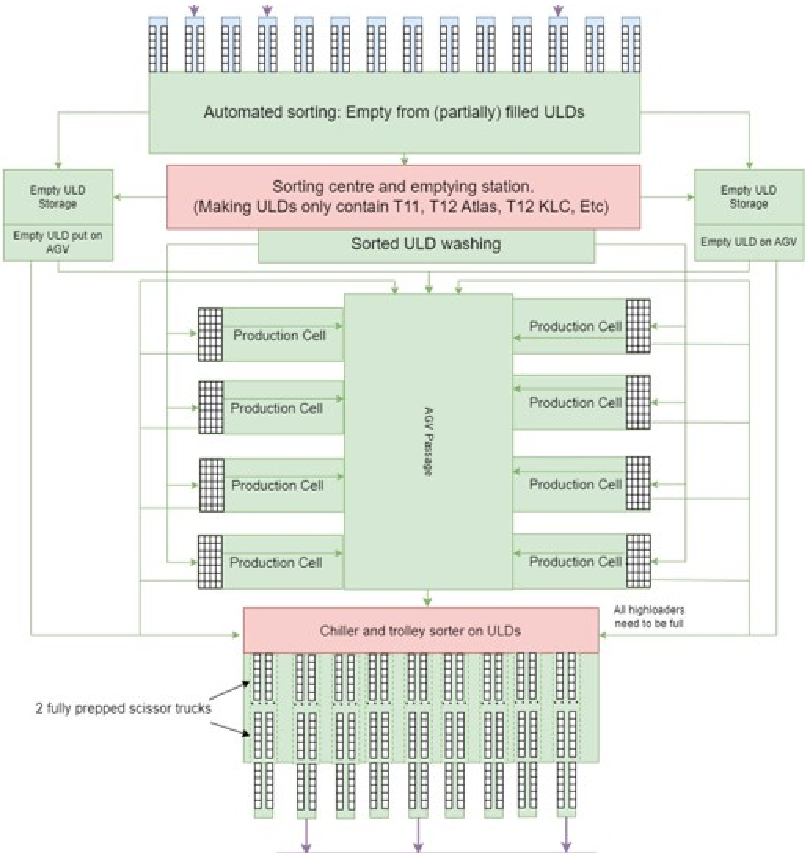


Figure 17: Schematic overview of a potential future facility of KCS including transport.

*4.2.1 2 ULD facility.*

When integrating an additional internal ULD into the facility, certain modifications and additions become necessary. Notably, an extra buffer is required to to accommodate the new type of empty ULDs. In the context of an airline catering facility, this translates to the need for a transport requirement to transport empty washing ULDs back into the buffer instead of sending the empty all-purpose ULD to flight end assembly or to the automated transport hall. Figures 18 and 19 visually represent the schematic layouts of a facility with a single ULD and a facility with dual ULDs respectively. In these schematics, larger arrows denote an increased requirement for using multiple types of ULD over a single one.

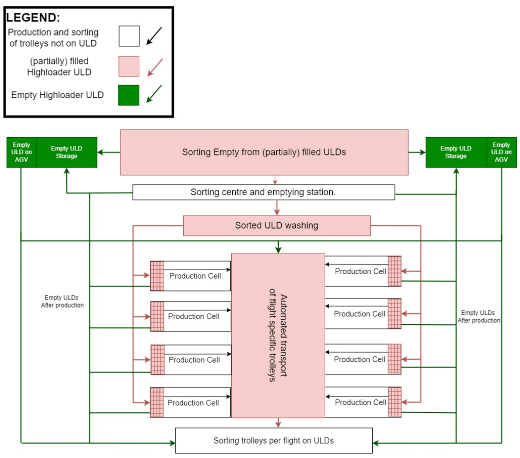


Figure 18: Schematics of a single ULD facility.

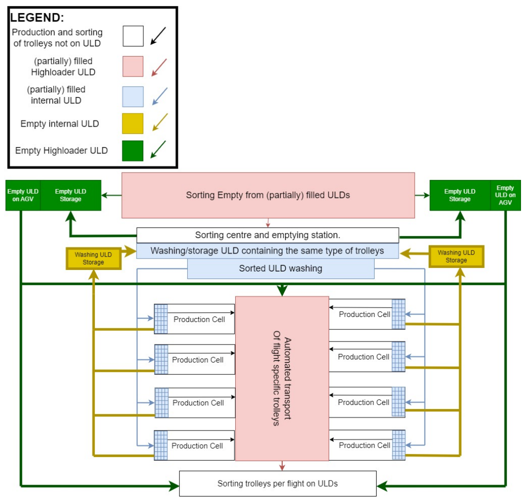


Figure 19: Schematics of a dual ULD facility. Larger arrows indicate an increased requirement for using multiple ULDs instead of 1.

As evident from Figures 18 and 19, the introduction of an additional internal ULD amplifies the demand and the transportation requirement for empty ULDs. The need to manage the flow and logistics of multiple ULDs adds complexity to the facility's operations, necessitating careful planning and efficient handling of empty ULDs in the overall material handling process. This increase in complexity should be a critical consideration in the decision-making process when determining the most suitable configuration for the facility.

### *4.3 Economic comparison*

While the KCS facility is still in development, and the transport requirement and Material Handling Equipment are constantly changing, this section provides a rough initial economic cost comparison among manual operations, a single ULD facility, and a dual ULD facility.

The required number of ULDs is determined through internal simulations. Pricing information, including piece price and mold price, is obtained from a potential manufacturer. The write-off time for the universal ULD without internal ULD is slightly less compared to the Universal ULD with internal ULD. For the fact that the universal ULD is not specialised in washing.

For transport costs, the reduction in Full-Time Equivalent (FTE) positions is based on an internal presentation at KCS, stating that 122 FTEs are currently dedicated to moving and securing trolleys. The number of Automated Guided Vehicles (AGVs) is determined by transport requirements. The additional transport requirement for adding an extra ULD is covered by 12 additional AGVs. Costs are summarized in Table 3. An important cost that is yet to be determined is the retrofitting of the truck.

The table illustrates that, despite a substantial extra initial setup cost for facilities requiring ULDs, significant cost reductions can be achieved, with a return on investment within 2.5 years. Notably, the cost difference between a dual ULD facility and a single ULD facility is negligible. Given that a dual ULD facility significantly increases complexity, it is not recommended to adopt a dual ULD system if the sole purpose is cost reduction.

Table 3: Economic comparison between the 3 facilities.

| | 1 ULD Facility | 2 ULD facility | Manual |
|---|---|---|---|
| # AGVs required | 100 | 112 | NA |
| Initial cost of an AGV | €50.000 | €50.000 | NA |
| Setup Cost AGVs | €2.000.000 | €2.000.000 | NA |
| Wear time AGVs (year) | 10 | 10 | NA |
| Cost of universal ULD | €650 | €650 | NA |
| # Universal ULDs | 3413 | 2486 | NA |
| Wear time universal ULD (year) | 5 | 7 | NA |
| Setup cost Universal ULD | €45.000 | €45.000 | NA |
| Cost of washing ULD | NA | €175 | NA |
| # Washing ULDs | NA | 1038 | NA |
| Wear time washing ULD (year) | NA | 5 | NA |
| Setup cost washing ULD | NA | €15.000 | NA |
| FTE required | 42 | 42 | 122 |
| Cost FTE per year | €62.400 | €62.400 | €62.400 |
| Total initial investment cost | €9.263.000 | €9.458.000 | 0 |
| Cost per year | €3.565.000 | €3.446.000 | €7.613.000 |

## 5 Conclusion

This study focused on the implementation of Unit Load Devices (ULDs) at KCS to optimize trolley transport processes and decrease operational costs. The inclined ULD design, featuring a T12 divider, effectively secured trolleys during AGV and highloader transport, ensuring safe and seamless internal and external trolley transport. The ULD implementation showcased considerable cost savings amounting to 4 million euros annually. While a single ULD facility demonstrated similar economic impacts compared to a dual ULD facility. Since the dual ULD facility has increased complexity and almost equal cost it is recommended to opt for a single ULD system if the only consideration is costs.

Future research could explore the design of an inclined drop-off point to counteract ULD inclination, leveling the ULD and facilitating smoother trolley removal. Additionally, investigating automated transport for ULDs to and from trucks is advisable. Further prototyping and testing on the handling of the ULD would contribute valuable insights for refinement and optimization.

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